Some Milestones in History of Science

About 10,000 bce, **wolves** were probably domesticated.
By 9000 bce, sheep were probably domesticated in the Middle East.
About 7000 bce, there was probably an **hallucinagenic mushroom**, or 'soma,' cult in the Tassili-n-Ajjer Plateau in the Sahara (McKenna 1992:98-137).
By 7000 bce, **wheat** was domesticated in Mesopotamia. The intoxicating effect of leaven on cereal dough and of warm places on sweet fruits and honey was noticed before men could write.
By 6500 bce, **goats** were domesticated. "These herd animals only gradually revealed their full utility--sheep developing their woolly fleece over time during the Neolithic, and goats and cows awaiting the spread of lactose tolerance among adult humans and the invention of more digestible dairy products like yogurt and cheese" (O'Connell 2002:19).
Between 6250 and 5400 bce at Çatal Hüyük, Turkey, **maces**, weapons used exclusively against human beings, were being assembled. Also, found were baked clay sling balls, likely a shepherd's weapon of choice (O'Connell 2002:25).
About 5500 bce, there was a "sudden proliferation of **walled communities**" (O'Connell 2002:27).
About 4800 bce, there is evidence of astronomical **calendar stones** on the Nabta plateau, near the Sudanese border in Egypt. A parade of six megaliths mark the position where *Sirius*, the bright 'Morning Star,' would have risen at the spring solstice. Nearby are other aligned megaliths and a stone circle, perhaps from somewhat later.
About 4000 bce, **horses** were being ridden on the Eurasian steppe by the people of the Sredni Stog culture (Anthony *et al.* 1991:94-95).
About 4000 bce, light wooden **plows** were used in Mesopotamia.
Between 4000 and 3500 bce, **copper smelting** in minute quantities was introduced in Mesopotamia.
By 3500 bce, **irrigation** was developed in Mesopotamia.
Between 3300 bce and 2850 bce, **numerals** appeared in Sumerian, Proto-Elamite, and Egyptian hieroglyphics, and, somewhat later, the earliest known forms of pictographic writing.
By 3200 bce, **wheeled vehicles** were used in Uruk.
From about 3200 bce, there exist Egyptian **sailboat** drawings, showing a mast with a single broad square sail hung from it.
By 3000 bce, **cotton** was being grown in India.
About 3000 bce, **draft oxen** were pulling plows and **potters** were using wheels in Mesopotamia.
About 2700 bce, **cuneiform** signs and numerals appeared on Sumerian tablets, with a slanted double wedge between number symbols to indicate the absence of a number, or zero, in a specific place. .
About 2500 bce, the Stele of Vultures shows the Sumerian infantry in a **phalanx**: "all wearing helmets, advancing shoulder to shoulder behind a barrier of locked rectangular shields reinforced with bronze disks, and presenting a hedgehog of spears protruding from several rows back" (O'Connell 2002:32).
About the middle of the third millenium, **bronze** enabled the dagger form to be stretched into swords.
About 2400 bce, the short, **composite bow** was developed by mounted archers. Unstrung it curved forward and could pierce armor at 100 yards.
About 2300 bce, **Proto-Indian writing** appeared in the Indus Valley.
Before 2000 bce, the Egyptians considered the souring of **wine** comparable to the souring of milk.
In the first half of the second millenium bce, Assyro-Babylonian **cuneiform** decimal notation gradually supplanted the Sumerian sexagesimal system for representing numbers below 60. For representing higher numbers the sexagesimal place-value principle with base 60 was invented (Ifrah 1981:371-372).
In the seventeenth century bce, an Egyptian papyrus listed many diagnoses of head and neck injuries and their treatment and is the "first known document in which the **brain**'s role in controlling limbs or organs at a considerable distance is established" (Changeux 1983:4; Breasted 1930).
In the seventeenth century bce, the first use was made of **phonetic signs**, derived from Eqyptian hieroglyphics, in the Serabit el Khadim inscriptions, in the Sinai peninsula.
In the second millenium bce, in the *Rig-Veda* it was maintained the **Earth** was a globe and in the

Yajur-Veda that the Earth circled the Sun.
By 1500 bce, **Babylonian mathematicians** understood "the determination of the diagonal on the square from its side," that is to say, the 'Pythagorean theorem' (Neugebauer 1957:36).
In the fourteenth century bce, the first known **alphabetic writing**, in thirty cuneiform signs, appeared on Ugaritic tablets.
In the late twelfth century bce, modern **alphabetic writing** was prefigured in the Phoenician alphabet.
Between 1200 and 1000 bce, iron **smelting** was introduced on an industrial scale in Armenia.
About 1000 bce, **mule breeders** noticed that "a mare crossed with a donkey yields a mule, whereas a stallion crossed with a donkey produces a hinny, which has shorter ears, a thicker mane and tail, and stronger legs than the mule. This made [modern] researchers aware that there could be parent-specific effects in off-spring" (Pennisi 2001:1065).
About 850 bce, impaling **rams** jutted from the prows of Greek galleys. These galleys were propelled by ten oarsmen on each side. By the middle of the seventh century, Phoenician galleys, or triremes, employed crews of 200 and three levels of oarsmen (O'Connell 2002:99-104).
About 800 bce, **vowels** were by the Greeks to consonants of Phoenician origin.About 800 bce, vowels were by the Greeks to consonants of Phoenician origin.
From 747 bce, a continuous record of solar and lunar **eclipses** was kept in Mesopotamia.
In the early seventh century bce, **gold coins** were introduced in Lydia, western Anatolia, as a standard of exchange.
About 600 bce, **Thales** of Miletus, arguing from the fact that wherever there is life, there is moisture, speculated that the basic stuff of nature is water, according to **Aristotle**.
About 560 bce, **Anaximander**, a monist of Miletus like **Thales**, said that the primal substance, the substratum of the opposites, the originative stuff, is the *apeiron*, which seems to have meant, at that time, the spatially indefinite or unbounded (Kirk *et al.* 1983:110).
About 530 bce, **Pythagoras** discovered the dependence of musical intervals on the arithmetical ratios of the lengths of string at the same tension, 2:1 giving an octave, 3:2 the fifth, and 4:3 the fourth. He is also credited with a general formula for finding two square numbers the sum of which is also a square, namely (if *m* is any odd number), $m^2+\{{}^1/_2(m^2-1)\}^2=\{{}^1/_2(m^2+1)\}^2$. "The Pythagoreans and **Plato** [as well as the Renaissance Neo-Platonists] noted that the conclusions they reached deductively agreed to a remarkable extent with the results of observation and inductive inference. Unable to account otherwise for this agreement, they were led to regard mathematics as the study of ultimate, eternal reality, immanent in nature and the universe, rather than as a branch of logic or a tool of science and technology" (Boyer 1949:1). Consequently, when the Pythagoreans developed the theory of geometric magnitudes, by which they were able to compare two surfaces' ratio, they were led, for lack of a system which could handle irrational numbers, to the 'incommensurability problem': Applying the side of a square to the diagonal, no common rational measure is discoverable.
About 510 bce, **Almaeon** of Crotona, a member of the Pythagorean medical circle, located the seat of perception in the brain, or *enkephalos*, and maintained that there were passages connecting the senses to the brain, a position he was said to have arrived at by dissections of the optic nerve.
About 500 bce, **Heraclitus** of Ephesus maintained that permanence was an illusion and the only possible real state was the process of becoming. He also said that to the *logos*, all things are one, all opposites are joined. *Logos*, a word which **Anaximander** also used, seems to be a principle manifesting itself in the process or cohering of things, and to occupy a place in Greek ideology similar to *dharma* for Hindus or 'Wisdom' for Jews (Park 1990:10).
About 500 bce, **Xenophanes** examined fossils and speculated on the evolution of the earth.
About 480 bce, **Parmenides** of Elea founded the Eleatic School where he taught that 'all is one,' not an aggregation of units as **Pythagoras** had said, and that to arrive at a true statement, logical argument is necessary. Truth "is identical with the thought that recognizes it" (Lloyd 1963:327). Change or movement and non-being, he held, are impossibilities since everything is 'full' and 'nothing' is a contradiction which, as such, cannot exist. "Parmenides is said to have been the first to assert that the Earth is spherical in shape...; there was, however, an alternative tradition stating that it was Pythagoras" (Heath 1913:64).
Corollary to **Parmenides**' rejection of the existence of 'nothing' is the Greek number system which, like the later Roman system, refused to use the Babylonian positional number system with its marker for 'nothing.' Making no clear distinction between nature and geometry, "mathematics, instead of being a science of possible relations, was to [the Greeks] the study of situations thought to subsist in

nature" (Boyer 1949:25). Moreover, "almost everything in [Greek] philosophy became subordinated to the problem of change.... All temporal changes observed by the senses were mere permutations and combinations of 'eternal principles,' [and] the historical sequence of events (which formed part of the 'flux') lost all fundamental significance" (Toulmin and Goodfield 1965:40).

About 470 bce, **Zeno** of Elea propounded forty paradoxes probably to point out inconsistencies in Pythagorean positions. One of the most famous is this: The fleeing and slower runner can never be overtaken by the faster, pursuer because the faster must first reach the point where the slower is at a that time, but by then the slower will be some distance ahead. Other paradoxes made the same or apposite points, but, in fact, mathematical analysis shows that infinite aggregates and the nature of the continuum are not self-contradictory but only counter to intuition.

About 450 bce, **Empedocles** of Agrigento explained changes in quality or quantity of a thing as movement by the basic particles of which the thing consisted, Fire, Earth, Air, and Water. These elements mix and separate "under the guidance of two opposing principles, Love, which draws them together, and Strife, which drives them apart" (Park 1990:25).

About 450 bce, **Anaxagoras** of Athens taught that the moon shines with the light of the sun and so was able to explain the eclipses.

About 440 bce, **Leucippus of Miletus** said that the world consisted in the void and atoms, which are imperceptible individual particles that differ only in size, shape, and position. That these particles were imperceptible meant they met **Parmenides**' objection to the Pythagorean's geometric points and, since they alone were unchanging, change could be explained as mere sense impressions. "It is scarcely an exaggeration to say that even in 1900 the only new idea to Leucippus's theory was that each chemical element was identified with a separate atomic species" (Park 1990:41).

About 440 bce, **Protagoras** of Abdera held that man is the measure of all things by which he meant that we only know what we perceive, not the thing perceived (*Dictionary of Philosophy* 1984:273).

About 440 bce, **Oenopides** of Chios probably created the first three of what became **Euclid**'s 'postulates' or assumptions. What is postulated guarantees the existence of straight lines, circles, and points of intersection. That they needed to be postulated is because they require 'movement,' the possibility of which was challenged by the Eleatics (Szabó 1978:276-279).

About 430 bce, **Hippocrates** of Chios squared the lune, a major step toward squaring the circle, probably using the theorem that circles are to one another as the squares of their diameters.

Prior to about 425 bce, **Herodotus** wrote the first scientific history; that is, he began by asking questions, rather than just telling what he thinks he knows. Moreover, these questions were "about things done by men at a determinate time in the past, [and the history itself] exists in order to tell man what man is by telling him what man has done" (Collingwood 1946:18).

About 420 bce, **Democritus** of Abdera developed **Leucippus**'s atomic theory: Atoms vibrate when hitched together in solid bodies and exist in a space which is infinite in extent and in which each star is a sun and has its own world. He also produced two major concepts in the history of ideas concerning the brain--that thought was situated there and, anticipating the nervous system, that psychic atoms constituted the material basis of its communication with the rest of the body and the world outside. **Socrates**, and hence the Platonic school, followed Democritus in locating thought in the brain.

About 400 bce, **Hippocrates of Cos**, also locating thought, pleasure, and pain in the brain, maintained that diseases have natural causes, and observed that head injuries led to impairments on the opposite side of the body. The 'Hippocratic method' of treatment of the sick was to keep the patient in bed and let nature take its course.

About 400 bce, an arrow-shooting **catapult** was developed at Syracuse. Its main significance is that it "embodied the deliberate exploration of physical and mechanical principles to improve armaments" (O'Connell 2002:86)

After about 380 bce, **Plato** said, in the *Timaeus*, that "as being is to becoming, so is truth to belief" (Plato 1929:29c). In other words, we can only believe, not know, on the basis of experience. Like, **Parmenides**, he held being and truth, indeed the world, to be timeless and unchanging, an ideal of which man can only hold the idea. This permitted him a certain amount of flexibility: He was willing to accept objections to his view of the universe, for example, if the new hypothesis would provide a rational explanation or 'save the appearance' presented by the planets. In the *Timaeus*, he also held that the 'world soul' was constructed according to mathematical principles, and, therefore, these principles are already fixed in the individual. (Forms or ideas that have existence independent of any particular mind came to be called archtypes.) He scattered reflections on mathematical issues throughout his dialogues; e.g., in the *Meno*, he illustrates the difference between a class and its members by reference to the difference between defining 'figure' and enumerating specific figures. References to ratios and proportions are everywhere. The five regular polygons he ascribed to the four elements plus the "decoration" of the universe (Plato 1929:55c), probably the animals of the zodiac.

By the fourth century bce, Babylonian astronomers had learned enough about the moon's motion that they could predict the occurence of lunar **eclipses**.

About 370 bce, **Eudoxus** of Cnidus invented a model of twenty-seven concentric spheres by which he was able to calculate the sun's annual motions through the zodiac, the moon's motion including its wobble, and the planets' retrograde motion. He used what came much later to be called the 'exhaustion method' for area determination. This method involved inscribing polygons within circles, reducing the difference *ad absurdum*, and was wholly geometric since there was at that time no knowledge of an arithmatical continuum, at least among the Greeks.

By about 335 bce, **Aristotle** had said that universals are abstractions from particulars and that we "have knowledge of a scientific fact when we can prove that it could not be otherwise." But "since observation never shows whether this is the case," he established "reason rather observation at the center of scientific effort" (Park 1990:32). A deductive argument is "a 'demonstration' when the premises from which the reasoning starts are true and primary.... Things are 'true' and 'primary' which are believed on the strength not of anything else but themselves" (Aristotle 1928:100a-100b). Aristotle defined the syllogism as a formal argument in which the conclusion necessarily follows from the premises, and said that the four most common statements of this sort are 'all *Subject* is *Predicate*,' 'no *S* is *P*,' 'some *S* is *P*,' and 'some *S* is not *P.'* He also discerned four sorts of 'cause.' The 'formal cause' is the design of a thing. The 'material cause' is that of which it is made. The 'efficient cause' is the maker. And the 'final cause' is the purpose of the thing. Aristotle also insisted on the operational character of mathematics and rejected any metaphysical character of number.

At the same time, **Aristotle** often states both his observations and his reasons with rather too much conviction: "The shape of the heaven is of necessity spherical; for that is the shape most appropriate to its substance and also by nature primary" (Aristotle 1930:286b). "A heavenly essence could not, according to [his] physics, manifest any but its own 'natural' movement, and its only natural movement [so his reason informed him] was a uniform rotation around the center of the universe" (Duhem 1908:15). His name for the heavenly essence, the quintessence, is *αιθηρ*, of which the Latin cognate is '*aether*' (Although Aristotle is perhaps the earliest theorist of *αιθηρ*, he was not the first to use the word, e.g., **Heraclitus** used it to mean heavenly fire.) In fact, "in dealing with [any] concrete, physical problem, it is...always necessary to take into account the world order, to consider the realm of being to which a given body belongs by its nature.... It is only in 'its' place that a being comes to its accomplishment and becomes truly itself" (Koyré 1968:6,24n1). He also put forth the view that each species has an essence and that divergence from this type was not possible beyond a certain limit. These remained the dominant views until the acceptance of those of Johannes **Kepler**, in the first case, and Charles Robert **Darwin** and Alfred Russell **Wallace**, in the second. If the properties of a thing are its 'form,' then, according to Aristotle, perception is the process whereby the form, and not just the representation of it, enters the soul. This account of perception "was taken as the exact, literal truthby almost every educated person down to the sixteenth century" (Park 1990:44). Also. Aristotle "considered the changes undergone by inanimate things to be analogous to those seen in the biological world. Thus grape juice is the infantile form of wine, fermentation is the process of maturation; the further change to vinegar is the death of the wine" (Fruton 1972:24). Since all matter is formed from the mixture of the four elements, he taught the elements are not permanent and could be transmuted one into another, inspiring all who practice alchemy. After weighing the evidence, Aristotle decided that the organ of thought and sensation was the heart. But he was also the first to perceive the antithesis between epigenesis, "fresh development," and preformation, the "simple unfolding of pre-existing structures." The subsequent history of this controversy is "almost synonomous with the history of embryology" (Needham 1934:40)

About 330 bce, **Heraclides** of Pontus said that the earth turns daily on its axis "while the heavenly things were at rest..., considered the cosmos to be infinite..., [and] with the Pythagoreans, considered each planet to be a world with an earth-like body and with an atmosphere" (Dreyer 1906:123-125). He also suggested that Mercury and Venus have the sun at the center of their spheres.

In 323 bce, **Theophrastus**, suceeded **Aristotle** as head of the Peripatetic school of philosophy of which he was the co-founder. In *Historia Plantarum* and *De Causis Plantarum*, he classified and described the "external parts of plants from root to fruit..., set forth the 'homology' of the perianth members [or floral envelope] of flowers..., to some extent distinguished between monocotyledons and dicotyledons, [and] described the fertilization of the date palm" (Crombie 1952:367).

About 310 bce, **Autolycus** of Pitane defined uniform motion as being when "a point is said to be moved with equal movement when it traverses equal and similar quantities in equal times" (Clagett 1959:164).

About 300 bce, Eukleides, better known as **Euclid**, published his *Elements*, a reorganized compilation of geometrical proofs including new proofs and a much earlier essay on the foundations of arithmetic. *Elements* concludes with the construction of **Plato**'s five regular solids. Euclidean space has no natural edge, and is thus infinite. In his *Optica*, he noted that light travels in straight lines and described the law of reflection.

About 300 bce, **Epicurus** attempted to deal with the contradiction between atoms falling through the void in parallel paths at the same speed and the appearance of novel combinations, or matter, by supposing very slight, chance deviations, or 'clinamen,' in an atom's path. He saw this as analogous to the question of human freedom in a determined nature; i.e., there is no room for ethical considerations Indeed, "Epicureans saw the development of the world as a random, one-way process" (Toulmin and Goodfield 1965:50).

About 280 bce, **Herophilus** of Alexandria studied anatomy and compared humans and animals, distinguished between sensory and motor nerves,and between the cerebellum and the brain, noted that the cortex was folded into convolutions, and named the 'duodenum.'

About 260 bce, **Aristarchus** of Samos, in *On the Sizes and Distances of the Sun and Moon*, used trigonometry to estimate the size of the Moon and its distance by the Earth's shadow during a lunar eclipse. **Archimedes** and others said that he maintained that the Moon revolved around the Earth and the Earth around the Sun which remained stationary like the stars.

About 260 bce, **Archimedes** of Syracuse contributed numerous advances to science including the principle that a body immersed in fluid is buoyed up by a force equal to the weight of the displaced fluid and the calculation of the value of π. "His method was to select definite and limited problems. He then formulated hypotheses which he either regarded, in the Euclidean manner, as self-evident axioms or could verify by simple experiments. The consequences of these he then deduced and experimentally verified" (Crombie 1952:278).

About 250 bce, **Erasistratus** of Alexandria dissected the brain and distinguished between the cerebrum and the cerebellum.

About 250 bce, '**zero**' appeared in the Babylonian place-value system.

About 240 bce, **Eratosthenes** of Cyrene calculated the diameter of the earth by measuring noontime shadows at sites 800 km. apart. Assuming the earth is a sphere, the measured angle between the sites is seven degrees and the circumference is about 50 times 800 km., or about 40,000 km.

Before the end of the third century bce, **astrolabes** were in use for taking the angular distance between any two objects, usually the elevation in the sky of planets.

In the early second century bce, **Diocles**, in *On Burning Mirrors*, proved the focal property of a parabola and showed how the Sun's rays can be made to reflect a point by rotating a parabolic mirror (Toomer 1978).

About 210 bce, **Apollonius** of Perga, in *Conics*, introduced the terms 'parabola' and 'hyperbola,' curves formed when a plane intersects a conic section, and 'ellipse,' a closed curve formed when a plane intersects a cone.

About 170 bce, **parchment**, superior to papyrus because it can be printed on both sides and folded, was invented in Pergamon.

About 134 bce, **Hipparchus** of Rhodes measured the year with great accuracy and built the first comprehensive star chart with 850 stars and a luminosity, or brightness, scale. He is credited with the discovery of the precision of the equinoxes, and seems to have been very impressed that either of two geometrically constructed hypotheses could 'save the appearance' of the path that a planet follows: One shows the planets moving in eccentric circles and the other moving in epicycles carried by concentric circles (Duhem 1908:8).

In the first half of the first century bce, Titus **Lucretius** Carus, writing in Latin, set forth the teachings of the Epicurean school in *De rerum natura.* There he held that "the soul is itself material and so closely associated with the body that whatever affects one affects the other. Consciousness ends with death. There is no immortality of the soul. The universe came into being through the working of natural laws in the combining of atoms" (*Columbia Desk Encyclopedia* 1975:1626). This view is supported by the force of the wind which is the result of the impact of innumerable atoms.

In 45 bce, **Sosigenes** of Alexandria designed a calendar of 365.25 days which was introduced by Julius Caesar.

Late in the first century bce, **Strabo** published his *Geographia*, based on his observations and those of his Greek predecessors.

Late in the first century bce, Marcus **Vitruvius** Pollio, in *De architectura*, wrote of the properties of building materials in terms of atoms. This book remained the standard architectural treatise into the Renaissance.

About the 25th year of the common era, Pomponius **Mela**, in *De situ orbis*, published a map of the known world and formalized the notion of climatic latitudes.

In the first century, Pedanius **Dioscorides** published recommendations as to the medicinal use of specific plant extracts.

About 100, **Hero** of Alexandria explained that the four elements consist of atoms. He also observed that heated air expanded. In *Catoptrica*, he demonstrated geometrically that the "path taken by a ray of light reflected from a plane mirror is shorter than any other reflected path that might be drawn between the source and the point of observation" (*History of Optics* 2001:1).

About 100[?], **Plutarch**, in *On the Face That Can Be Seen in the Lunar Disk*, compared the Moon to the Earth, upheld the idea of the plurality of worlds, and tried to overturn **Aristotle**'s theory of 'natural places' (Duhem 1985:479).

Between 127 and 141, Claudius Ptolemaeus, better known as **Ptolemy**, put together a thirteen volume compendeum of opinion and data concerning the stars, including the Mesopotamian eclipse record. In this book, the *Almagest*, Ptolemy rejected the Peripatetic physics of the heavens, using circles rather than spheres. He did so in order to simplify his calculations, judging the circles to be only models devised for the purpose of calculation and recognizing that the actual movements were unknowable. The *Almagest* also contains errors which were not corrected until the sixteenth and seventeenth centuries: e.g., saying that the earth is the center of the universe, the planets have circular, if eccentric, orbits, and the earth does not move--because the centrifugal force would cause anything even temporarily disconnected to lag behind. On the other hand, the tables of the planet's positions were of such accuracy that Nicholas **Copernicus** computed most of his numbers from them.

About 170, Claudius **Galen** used pulse taking as a diagnostic, performed numerous animal dissections, and wrote treatises on anatomy aid. The Galenic doctrine assumed that health depends on a balance of affinities or antagonisms associated with various bodily fluids or 'humors:' blood and fire (hot and dry), yellow bile and air (hot and wet), black bile and earth (cold and dry), and phlegm and water (cold and wet). "The object of good medical practice...was to restore the balance of the humors by such treatment as bleeding or purgation with plant extracts" (Fruton 1972:27). Galen eskewed 'action at a distance' through the agency of gods or spirits, in his formulas he employed many odd ingredients, such as crocodile bllod and mouse dung. But, if he can, he relates the efficacy to some mechanism: for example, for a root worn around the neck, inhalation of the particles of the root. He distinguished three ventricles and proposed that nerves are ducts conveying fluid *pneuma* secreted by the brain and spinal cord to the periphery of the body, which was the basis of the idea, widespread until the eighteenth century, that nervous tissue had a glandular function He broke *pneuma*, which means spirit or soul in Greek, down into various faculties, motor, sensory including the five senses, and rational. He divided the rational *pneuma* into several functions, imagination, reason, and memory. He also wrote of 'seeds of disease,' presumably what are now called germs.

About 250, **Diophantus** pioneered in solving certain indeterminate algebraic equations, i.e., an equation in which the variables can take on integer values and has an infinite but denumerable set of solutions: e.g., $x + 2y = 3$.

In perhaps the middle of the third century, **Calcidius** translated the first 53 chapters of **Plato**'s *Timaeus* into Latin. He translated 'analysis' and 'synthesis' as *resolutio* and *compositio*, and maintained in his commentary that combining these was the proper method of philosophical research.

In the late third century, **Porphyry** wrote an introduction to **Aristotle**'s logic, the *Eisagoge*, which was much read in the course of the Middle Ages. It emphasized the distinction between facts held to be universally true because they existed 'prior to experience,' the Platonic opinion, or 'posterior to experience,' the Aristotelian opinion. This difference grew into the distinction between 'realists,' who hold that universals are the ultimate reality, and 'nominalists,' who hold that universals are derived from real experience. In our time, this distinction lives in the controversy concerning the 'humanity' of a fetus (Park 1990:100).

About 385, Aurelius Augustinus, later known as **Augustine**, a Christian saint, writing in Latin, found the Platonist notion of eternal ideas a certain basis for knowledge which he promulgated in his books *Confessiones* and *Civitas Dei.*

["The fourth and fifth centuries saw the intellectual triumph of [Roman] Christianity in Europe.... In 389 Christian monks sacked the great Greek library in Alexandria.... Since Greek was the language of a literature whose most famous works expressed a pagan culture [and] by 425 Saint Jerome's [official Latin or] Vulgate Bible was being copied and distributed..., Western scholars no longer needed Hebrew or Greek" (Park 1990:78-79).]

About 450 or later, **Proclus**, the final head of **Plato**'s Academy, said that astronomers "do not arrive at conclusions by starting from hypotheses, as is done in the the other sciences; rather, taking conclusions [the appearance of the heavens] as their point of departure, they strive to construct hypotheses from which effects conformable to the original conclusions follow with necessity" (Proclus, quoted by Duhem 1908:20). The astronomer is only interested in saving the appearance of the phenomena, and whether this conforms to reality is left to the other sciences to decide.

In 458, the *Lokavibhaga*, a Jain work in Sanscrit on cosmology, demonstrated a clear understanding of place-values and the concept of **zero**.

In 517, John **Philoponus** determined that falling objects do so with the same acceleration, or 'impetus,' specifically opposing **Aristotle**'s notion that the air through which a projectile moved was its motive force.

After about 520, Ancius Manlius Severinus **Boethius** wrote *De consolatione philosophiae* in Latin, probably the most widely read book in Europe in the Middle Ages, and translated **Aristotle**'s logical books. "Until the rediscovery of Aristotle in the twelfth century his translations were the basic texts for all students of logic" (Park 1990:79). He also wrote a commentary on **Porphyry**'s logic. Aside from Boethius and **Augustine**, students in the monasteries read Pliny's first century *Historia Naturalis*, Cassiodorus's sixth century encyclopedia, Isadore of Seville's sixth century *Etymolagiarum*, and **Discorides**' *De Materia Medica*.

About 530, **Simplicius** of Cilicia, in a commentary in Greek on **Aristotle**'s writings on 'gravity', interpreted him to mean that the intensity of the tendency of bodies toward their natural place varied with their distance from that place.

In the first half of the seventh century, **Brahmagupta** regarded zero, the place holder in the base-10 number system as "an infinitissimal quantity which ultimately reduces to nought." For Hindus, "arithmetic and mensuration, rather than geometry and considerations of congruence, were fundamental" (Boyer 1949:62). By this time, Hindus also conceived of negative numbers and did not disregard the the irrational roots of quadratics, as had the Greeks.

In 662, Severus **Sebokt** referred to calculations with Indian numerals by fellow Syrians.

In 673, the Muslim fleet, laying seige to Constantinople, probably used 'Greek fire,' an inflammable mixture of quicklime, naptha, pitch, and sulphur.

About 700, the venerable **Bede** tried to determine an atom of time, arriving at something like "about 1/6 of our second, and therefore on the order of the briefest sounds that we can distinguish in speech" (Park 1990:98). He also made original observations concerning the tides at ports. His writings are virtually a summary of learning of his time. His best known scientific treatises are those on chronology.

In the early eighth century, **stirrups** were introduced in Frankish lands, enabling the development of the armored knight. They were common in China as early as 477, and Muslim cavalry wore them in Persia in 694.

By 770, iron **horseshoes** were common.

In 793, the first **paper**, a Chinese invention, was made in Baghdad.

About 800, **Jabir** ibn Hayyan, later known as Geber, was educated reading translations from Greek and based his chemical system "on two substances: sulphur, which...is hot and dry, and mercury, which is cold and wet. Since each contains all four elements, any other material can be formed by the proper combination of these two, and since we cannot know substance but only form, our search must aim at the most desired product, gold" (Park 1990:115). This is the most perfect, most virtuous product since, as **Aristotle** said, all things, even base metals, struggle upward.

About 820, Muhammed ibn Musa **al-Kwarizmi** wrote essays on Hindu arithmetic and *al jabr*, translated as 'the transposition,' and pronounced 'algebra.' The word 'algorism,' which we have refashioned 'algorithm,' is thought to be derived from his name and denotes the decimal system of notation, which is thought to have passed from India to the West in the translation of his algebra into Latin.

About 850, Moors in Spain prepared pure copper by reacting its salts with iron, a forerunner of electroplating.
About 850, Abu Yusek Yacob ibn Ishak **al-Kindi** commented on **Aristotle** and wrote numerous treatises on optics, perspective, and medicine.
About 900, Abu Bakr al-Razi, better known as **Rhazes**, distinguihed smallpox from measles in the course of writing several medical books in Arabic. Holding against any sort of orthodoxy, particularly **Aristotle**'s physics, he maintained "the conception of an 'absolute' time, regarded by him as a never-ending flow" (Pines 1975:125).
About 976, a manuscript from non-Moslem Spain showed the first examples of the nine Hindu-Arabic numerals in Europe.
About 1000, Ibn Sina, or **Avicenna**, hypothesized two causes of mountains: "Either they are the effects of upheavals of the crust of the earth, such as might occur during a violent earthquake, or they are the effect of water, which, cutting itself a new route, has denuded the valleys, the strata being of different kinds, some soft, some hard.... It would require a long period of time for all such changes to be accomplished, during which the mountains themselves might be somewhat diminished in size" (Toulmin and Goodfield 1965:64). In *Kitah al-Shifa*, he denied the Aristotelian notion that an object thrown through the air is pushed by that air and held that "every motion occurs through a power in the moving object by which it is impelled" (Avicenna, quoted in Pines 1975:141). He also published *Al-Quanun*, or *Canon of Medicine*, where he held that medicines were to be known either by experiment or by reasoning.
About 1000, Ibn al-Haitam, or **al-Hazen**, in *Opticae Thesaurus*, introduced the idea that light rays emanate in straight lines in all directions from every point on a luminous surface. He also discussed spherical and parabolic mirrors and was aware of spherical aberration. In *Epitome of Astronomy*, he took a position against **Ptolemy**, insisting that the hypothetical spheres corresponded "to the true movements of really existing hard or yielding bodies [and] so...were accountable to the laws of physics" (Duhem 1908:28). This led to disageements that persisted through the twelfth century.
Early in the eleventh century, **crossbows** with sights and mechanical triggers were introduced into warfare.
About 1050, Solomon ben Judah Ibn Gabirol, or **Avicebron**, held that every material thing possesed a 'common corporeity' which was continuous through the universe.
In 1054, Chinese astronomers at the Sung national observatory at K'ai-feng observed the explosion of a supernova in the *Crab Nebulae*, visible in daylight for twenty-three days. Since then debris has moved out about three light years.
In 1079, Omar **Khayyam**, computed the length of the year as 365.24219858156 days, which approaches the accuracy of the late 16th century Gregorian Calendar. The length of a year decreases in the sixth decimal within a typical human lifetime and is today 365.242190 days. Khayyam also, in *Treatise on Demonstrations of Problems in Algebra*, produced a complete classification of cubic equations and their geometric solutions.
As early as 1091 or 1092, **Walcher** of Malvern, having observed an eclipse in Italy, determined the difference in longitude of England by discovering the time which it was observed there.
By the twelfth century, alchemists had developed the art of distillation to the stage at which distillates could be captured by cooling in a flask, and wine could be distilled to yield *aqua vitae.*
About 1100, Pierre **Abelard** began teaching Aristotelian dialectic and took a moderate position between the extreme Augustinians and the extreme nominalists; i.e., he held that universals are entities which exist only in thought but which are based in particulars. In consequence, observation of material nature and the importance of the individual increased.
About 1100, the **crossbow** was developed in Europe and outlawed, in 1139, by the second Ecumenical Lateran Council, "as humankind's first formal attempt at arms control" (O'Connell 2002:64). The crossbow could be shot accurately with comparatively little training.
About 1120, Awhad al-Zaman **Abu'l-Barakat** al-Baghdadi, *Kitah al-Mu'tabar*, denied **Aristotle**'s notion that a constant force produces a uniform motion and maintained that the 'violent inclination' by which a stone is thrown declines and is replaced by an accelerating 'natural inclination' as it returns to earth: "The farther the power moves the stone away from its natural region, the more natural inclinations are produced" (Abu'l-Barakat, quoted in Pines 1975:142).
About 1126, **Adelard** of Bath translated **Euclid**'s *Elements* and **al-Kwarizmi**'s arithmetic and astronomical tables from Arabic into Latin.
About 1145, **Robert** of Chester translated **al-Kwarizmi**'s *Algebra*.

After 1145, Abraham ben Meir **Ibn Ezra** explained the Arabic system of numeration and the use of the symbol 0.
After about 1150, Ibn Rushd, better known in Latin Europe as **Averroës**, and also sometimes as the Commentator, wrote commentaries on several of **Aristotle**'s books where he explained that prime matter, matter at its most fundamental level, has no form of its own. Its essence is its potential. He also criticized the artificiality of **Ptolemy**'s orbits: "Astronomers propose the existence of these orbits as if they were principles and then deduce conclusions from them" (Averroës, quoted by Duhem 1908:30).
By 1175, **Gerard** of Cremona had translated from Arabic into Latin most of **Aristotle**'s work as well as **Ptolemy**'s *Almagest*, **Autolycus** of Pitane's *De spera mota*, **Avicenna**'s *Canon*, **al-Kindi**'s treatise on optics, and some of **Rhazes**' medical books.
About 1185, **Burgundio** of Pisa translated from Greek into Latin various treatises by **Galen** and *Aphorisms* by **Hippocrates** of Cos.
About 1190, Moses ben Maimon, better known as **Maimonides**, wrote *The Guide for the Perplexed* in Arabic for Arabic-speaking Jews and included his ideas about astrological systems. For sublunar physics, he accepted the word of **Aristotle** as wholly true: This is man's sphere. But the heavens are the 'deity's,' and therefore man cannot know them, but can only try to describe them "rely[ing] on the arrangement postulating the lesser number of motions" (Maimonides 1963:274), reiterating **Ptolemy** and **Proclus**.
In 1202, Leonardo Pisano, better known by his nickname **Fibonacci**, in *Liber abbaci*, asked the question, "How many pairs of rabbits can be produced from [one] pair in a year if it is supposed that every month each pair begets a new pair which from the second month on becomes productive?" The resulting sequence 1, 2, 3, 5, 8, 13, 21, 34... is formed by adding the prior sum. He was a well-known and prolific mathematical writer and his publications were instrumental in the the introduction of Arabic numerals to Europe (Fibonacci, quoted in the archive of *The MacTutor History of Mathematics* 2000:"Fibonacci"2-3). He also interpreted a negative number as a debit and solved geometric problems using algebra.
In 1206, **al-Jazari** published a book in which he demonstrated some understanding of the use of a crank for producing reciprocal rotary motion. "No secure evidence evidence for it is found in Europe earlier than c. 1405" (White 1962:111). The crank had been understood at least as early as **Archimedes**, but presumably forgotten in the Dark Ages.
[Beginning in the thirteenth century, medical doctors, especially in Italy, wrote *consilium*, or case-histories, describing the symptoms and courses of numerous diseases. In Italy, the study of surgery and, therefore, anatomy was encouraged in the universities, but, in France and England, the universities were closed to surgeons because the Catholic Church forbade clerks to shed blood.]
After about 1215, Robert **Grosseteste** "made the first thorough logical analysis of the inductive and experimental procedures of practical science" (Crombie 1953:35). He called for investigation of effects leading to discovery of causes followed by demonstration of how causes produce effects, i.e., *resolutio* and *compositio*, **Aristotle**'s double movement. But since this only provided a possible cause, at the end of *compositio*, a process of experimental verification and logical falsification is required. Grosseteste considered light to be the basis of all natural causes so he considered optics the basis of all explanation: He not only attempted mathematical explanations of the properties of mirrors and lenses, rainbows and refraction, but also to explain the rectilinear propagation of light as a sucession of waves. "He was the first medieval writer to discuss these subjects systematically" (Crombie 1953:116). He also translated from Greek into Latin part of **Simplicius**' commentary on Aristotle's *De Caelo et Mundo*.
In 1217, Michael **Scot** translated into Latin **Averroës**' commentaries on **Aristotle** as well as some texts of Aristotle's. Probably later, he gave the University of Salerno recipe for anesthesia as equal parts opium, mandragora, and henbane. He also wrote a treatise ascribing to each of the practical sciences a corresponding theoretical science of which it is the manifestation.
About 1230, **Jordanes** de Nemore demonstrated the law of equilibrium of the lever: "Whatever can lift a given weight to a given height can also lift a weight 24 *k* times heavier to a height *k* times smaller. This is the principle which [René] **Descartes** will take as the foundation of all statics and, which due to Jean **Bernoulli**, will become the 'Principle of Virtual Displacements" (Duhem 1905:90).
About 1230, **Vincent** of Beauvais compiled about six thousand folio pages in an encyclopedia, *Speculum majus*, of knowledge gleaned from translations of Greek and Arabic books on philosophy, science, and mathematics.
[Throughout the Middle Ages there were various schools of thought about the Aristotelian system of

the universe. Among the Franciscans at Oxford, there were two schools. Most accepted only some explanations of natural phenomena such as the movement of heavenly bodies. Others, such as Roger **Bacon**, were less offended by pagan metaphysics and had great interest in Aristotelian medicine, physics, and mathematics. At the University of Paris, there were also two schools. Dominicans, such as **Albertus** Magnus and Thomas **Aquinas**, accepted most Aristotelian principles, except for determinism. The other school of thought, represented by **Siger** de Brabant, accepted an entirely deterministic interpretation of the universe. At Montpellier in the south of France and at the Italian universities, Salerno, Padua, and Bologna, theological matters counted for less and **Aristotle** and the Arabs were studied mainly for medical learning (Crombie 1952:41).]
About 1250, Albert of Bollstadt, called **Albertus** Magnus, in *De Vegeabilibus et Plantis*, a commentary on a pseudo-Aristotelian plant book, shows "a sense of morphology and ecology unsurpassed from **Aristotle** and **Theophrastus** to [Andrea] **Cesalpino**" (Crombie 1952:204). Probably following this, Albertus wrote *De Animalibus*, a commentary on three treatises of Aristotle as well as commentaries on **Avicenna**'s *Canon* and some of **Galen**'s works.
About 1250, **Gilbert** the Englishman described the local loss of sensation of the skin, that is, the peripheral nerves of early stage leprosy. This remains one of the best early diagnostic symptoms. "So successful were the methods of [early] diagnosis and segregation that by the early sixteenth century Europe was almost entirely free from leprosy, and similar preventitive measures were taken against other infectious diseases" (Crombie 1952:204).
About 1260, **Albertus** wrote a geology book, *De Mineralibus et Rebus Metallicis*, in which he "worked his authorities into a coherent theory and made a number of observations of his own, [including extending] **Avicenna**'s account of fossils. He was the first to produce arsenic in a free form.
About 1260 [?], **Siger** taught that the universe was predetermined and "that the individual soul had no immortality.... [He] adopted the Averroist notion of 'double truth'--that something could be true in rational philosophy but false in religious belief" (*Columbia Encyclopedia* 1975:2515).
In 1266, Hugh and Theodoric **Borgogoni** advocated putting surgical subjects to sleep with narcotic-soaked sponges. They also recommended that wounds should be "cleaned with wine, the edges brought together with stitches, and left for nature to heal" (Crombie 1952:206).
During the second half of the thirteenth century, **gunpowder** became known in Europe, perhaps introduced from China through the Mongols. "Knowledge of the explosive properties of salpetre, sulphur, and charcoal seems to have been perfected [in China] about 1000 " (Crombie 1952:192). The evolution of the gun in China appears to have been, first, bamboo flame throwers, then metal tubed flame throwers, then arrow throwers, and, after 1280, ball throwers (O'Connell 2002:113)
In 1267 and 1268, **Bacon** published proposals for educational reform, arguing for the study of nature, using observation and exact measurement, and asserting that the only basis for certainty is experience, or verification. In a book on optics, he noted that the maximum altitude of the bow, reached when the sun is on the horizon, is 42 degrees He considered the speed of light to be finite and that it is propagated through a medium in a manner analogous to that of sound. He wrote a Greek grammar and also noted that the power of the new explosive powder "would be increased by enclosing it in an instrument of solid material" (Crombie 1952:192).
Between 1267 and 1273, **Aquinas**, in *Summa Theologica*, pointed out the "difference between a hypothesis which must necessarily be true and one which merely fitted the facts. Physical (or metaphysical) hypotheses were of the first type, mathematical hypotheses of the second" (Crombie 1952:61). This was a 'realist' position.
In 1269, **Petrus** Peregrinus of Maricourt, in *Epistola de Magnete*, reflected on his experience with 'lodestones.'
In 1269, **William** of Moerbeke translated from Greek into Latin **Archimedes**' *On Plane Equilibriums* and *De lis quae Humido Vehuntur*. Earlier, after 1260, he had translated **Hero** of Alexandria's *Catoptrica.*
*After 1274, Ramon **Lull** claimed that, in every branch of knowledge, "there are a small number of simple basic principles or categories that must be assumed without question. By exhausting all possible combinations of the categories we are able to explore all the knowledge that can be understood by our finite minds. To construct tables of possible combinations we call upon the aid of both diagrams and rotating circles" (Gardner 1982:9).*
About 1285, somebody, perhaps **Alessandro** della Spina, invented spectacles for far-sightedness.
After about 1290, John **Duns Scotus** began teaching that "being must be regarded as the ultimate abstraction that can be applied to everything that exists" (Columbia Encyclopedia 1975:809), a nominalist position.

About 1290, **Giles** of Rome put forward an atomic theory, based on **Avicebron**'s theory of matter, which rendered geometric arguments against the existence of natural 'minima' irrelevant: Magnitude was either a mathematical abstraction or realized in a material substance. If the last, there must become a point in its division when it becomes something else.
Before the end of the thirteen century, greater efficiency in iron smelting was achieved by the introduction of mechanisms for producing blasts of air under pressure from a head of water.
At the end of the thirteenth century, the Royal Bethlehem Hospital, later simply **Bedlam**, was built in London specialized for mental patients.
Between 1304 and 1310, **Theodoric** of Freiberg showed that rainbows could be explained through experiments with hexagonal crystals and spherical crystal balls; i.e., "the rays were refracted on entering each raindrop, reflected at the inner surface, and refracted on passing out again" (Crombie 1953:237).
In 1304, **Giotto** di Bondone, reviving the antique Roman style, began painting the frescoes in the Scrovegni Chapel, Padua, in which he achieved a new naturalism in the human figure and a convincing representation of space.
In 1316, **Mondino** of Luzzi published Anatomia. He had already introduced the practice of public dissections for teaching.
In 1323 or earlier, William **Ockham**, in Questiones super quattuor libros sententiarum, introduced the distinction between 'being in motion' and 'being moved,' that is, as it is now called, between dynamic motion and kinematic motion. Motion, he maintained, does not exist separate from a moving body, rather it is "a term standing for a series of statements that the moving body is now here, now here, etc." (Clagett 1959:521).
In 1327, Francesco Petrarca, or **Petrarch**, began to write poems to Laura which ignored courtly conventions and, surpassing the medieval picture of woman as a spiritual symbol, created images of a real woman and real emotions.
In 1328 or earlier, **Ockham**, in Summa Logicae, wrote that universals exist only in men's minds and in language, disputing the Aristotelian principle that such things as the final cause were self-evident or necessary. In other words, facts could only be correlated, not caused. Preferring the notion of 'intuition,' he also denied the efficacy of reason in matters of faith and thus the self-evidence of Christian theological principles, such as the existence of God. He also elevated **Aristotle**'s and **Grosseteste**'s pragmatic economic principle, or lex parsimonae, into the cornerstone of his methodology, known as 'Ockham's razor:' What can be done with fewer assumptions is done in vain with more.
In 1328, Thomas **Bradwardine**, in *Tractatus de Proportionibus*, made clear, in geometric terms, **Ockham**'s distinction between being in motion and being moved, that is, between '*potentias*,' or force, and "the magnitude of the thing moved and of the space traversed" (Bradwardine, quoted in Clagett 1959:208). He also introduced the distinction "between 'qualitative' (instantaneous or intensive) velocity and 'qualitative' velocity (the total velocity of some period of time measured by the distance traversed during that period of time)" (*ibid.*:411). Studies with William **Heytesbury**, in *Regule solvendi sophismata*, Richard **Swineshead**, in *Liber calculationum*, and John **Dumbleton**, in *Summa de logicis et naturalibus*, all at Merton College, Oxford, produced the Mertonian Rule wherein the measure of uniform acceleration is shown to be its medial velocity. Dumbleton's proof used algebraic symbols.
In the second quarter of the fourteenth century, Richard **Suiseth**, also known as the Calculator, pointed out that a finite part cannot be in ratio to an infinite whole.
In 1333 or earlier, **Ockham**, in the *Quodlibeta*, wrote that "all causes properly so-called are immediate causes.... This is the special characteristic of a final cause, that it is able to cause when it does not exist.... This movement towards an end is not real but metaphorical" (Ockham, quoted in Crombie 1953:174).
In 1348, **Gentile** da Foligno used **Galen**'s words 'seeds (*semina*) of disease' in a *consilium* on the bubonic plague.
About 1350, Jean **Buridan** extended **Philoponus**'s idea by specifying the nature of '*impetus*,' that is, the motive power which the agent gives to the moving body which would maintain it at a constant velocity were it not for air resistence and natural gravity. In falling bodies, the impetus, which is analogous to Isaac **Newton**'s '*momentum*,' was gradually increased by the accelerating force of natural gravity. In each case, Buridan is arguing against theories of **Aristotle**'s largely on the basis of exprerience.

About 1350, **Albert** of Saxony was perhaps the first to distinguish between the center of gravity and the geometric center. Drawing from this theory, he concluded that Earth's center of gravity does not coincide with its center of volume: The Sun's heat caused part of the Earth to expand, forming dry land and mountains. He also did logical exercises with infinite sets.
In 1360, **Guy** de Chauliac, in *Chirurgia Magna*, recommended extending fractured limbs with pulleys and weights and recommended replacing lost teeth with bone fastened to the sound teeth with gold wire.
Probably before 1361, Nicole **Oresme**, in his chief work, associated continuous change with a geometric diagram and revived the Greek use of a coordinate system to represent it. Although he to algebra the conception of a fractional power, in his graphs there is no systematic association of an algebraic relationship. In *De Configurationibus Intensionum*, he a geometric proof to the Mertonian Rule, namely, in a given time the space traversed by a body with uniformly 'difform,' or accelerating, velocity is equal to the total time multiplied by the mean velocity. He also disposed of an argument against the earth's rotation by pointing out that is "if a man in the heavens, moved and carried along by their daily motion, could see the earth distinctly..., it would appear to him that the earth is moving in daily rotation" (Oresme 1968:523). It should be noted that Oresme, **Buridan**, and **Albert** of Saxony, who each observed the same rule of procedure, namely, that "*all* the facts of experience...are brought to bear on [their hypotheses]," were at the University of Paris (Duhem 1908:60).
In 1364, Giovanni **di Dondi** built a complex clock which kept track of calendar cycles and computed the date of Easter by using various lengths of chain.
In 1370, the **clocks** of Paris were synchronized.
In 1410, Benedetto **Rinio** published a herbal which contained 450 paintings of plants, botanical notes, citations of authorities used, and the names of the plants in various languages including Greek and Arabic.
About 1420, Filippo **Brunelleschi** drew panals in scientifically-accurate perspective.
About 1431, Nikolaus von **Cusa** established by internal evidence that the document known as the *Donation of Constantine*, for at least six hundred years the foundation of the Pope's political claims, could not have had the antiquity it purported.
About 1437, Johann **Gutenberg** became the first in Europe to print with movable type cast in molds.
In 1440, **Cusa**, in *De docta ignorantia*, said that the Truth can neither be increased nor diminished and that Intellect, or Reason, can never completely comprehend Truth. But "the more deeply we are instructed in this ignorance, the closer we approach the truth" (Cusa 1440:53). This is at the same time NeoPlatonist mysticism and post-Scholastic Humanism. Instead of the opposition between physics and astronomy, he set up an opposition "between the absolute physics of real essences and genuine causes and the relative and developing physics of abstract essences and fictive causes" (Duhem 1908:58). Revivng Platonic arithmology, Cusa "again associated the entities of mathematics with ontological reality and restored the cosmological status which **Pythagoras** had bestowed upon it" (Boyer 1949:90). In other words, he viewed mathematics as independent of the evidence of the senses. This encouraged the conceptual possibility of the infinite and the infinitesimal, which had been inimical to the Aristotelianism of the Middle Ages. Cusa held that "a finite intelligence can approach the truth only asymptomatically[; i.e., the infinite was] the unattainable goal of all knowledge" (*ibid.*:91). He compared man's search for the truth to the squaring of the circle, which, indeed, he attempted by treating the circle as a polygon with an infinite number of sides. This was later named the 'exhaustion method.'
In 1444, **Cusa** denied that the earth could be at the center of the universe since the universe is unbounded and made several astronomical claims including that the Earth moved around the sun, the stars were other suns, and had inhabited worlds. He also performed the first modern, formal biological experiment from which he concluded that plants absorb nourishment from the air.
In 1463, Marsilio **Ficino** finished the first complete translation of **Plato's** dialogues into Latin. His NeoPlatonism emphasized the conception that opposites are reciprocal, e.g., the higher actively strives for the lower, and that matter is not the mere opposite of form, i.e., evil, but the beginning of active form. Earlier, about 1460, Ficino had interrupted this labor to translate a newly discovered manuscript, the *Pimander*, which was purported to contain the 4000 year old wisdom and magic of Hermes Trismegistus. This meant that it was the Egyptian source of Plato's learning as well as being a prefigurement of Christian theology.
Between May of 1449 and August 1450, employing **bombards**, "siege guns put together like beer barrels out of forged iron staves reinforced by hoops [which] fired stone projectiles up to thirty inches

in diameter and weighing in excess of 1500 pounds," the French liberated seventy English-held castles, ending the Hundred Years War. Key to bombards was the discovery, about 1420, that when gunpowder was mixed with water it dried in grains which burned faster and was more powerful. In 1453, Turks used a huge bombard to reduce and capture Constantinople, sending "reverberations across the West so profound that [that year] is often called the end of the Middle Ages" (O'Connell 2002:115-116).
About 1482, Leonardo **da Vinci** began his notebooks in pursuit of evidence that the human body is microcosmic, which, by 1510-1511, included dissections of the human body. These notebooks, which circulated in manuscript copies, also contained his thoughts on the impossibility of perpetual motion, dynamics, statics, numerous machines, and other matters. "His devotion to the Archimedean ideal of measurement is shown by the scientific instruments which he tried to improve or devise, such as the clock, a hydrometer similar to **Cusa**'s to measure moisture in the atmosphere, a hodometer similar to **Hero**'s to measure distance travelled, and an anemometer to measure the force of the wind" (Crombie 1952:280).
In 1483, **Theodore** of Gaza translated **Theophrastus**'s *Historia Plantarum* into Latin.
In 1486, Bartholomeu **Dias** sailed around the Cape of Good Hope, initiating an era of sea faring discoveries.
In 1492, Cristóbal **Colón** vastly underestimated the Earth's radius and his ships failed to reach China.
At the end of the fifteenth century, Nuremberg watchmakers introduced clocks driven by springs rather than weights, making possible the invention of portable **watches**.
Before 1500, "screw-based breech loading and exploding shot, two prime factors in the **artillery** convulsion of the nineteenth century, were known.... The shoulder stock, the wheel lock (the basis for the pistol), and rifling were all in use by 1525" (O'Connell 1989:121).
About 1512, Nikolaus Kopérnik, better known as **Copernicus**, circulated a manuscript, the *Commentariolus*, which hypothesized that the Earth was a planet and planets revolved in circles and epicircles around the Sun, that the Earth rotated daily, and regressions in planetary orbits were explained by the Earth's motions (Park 1990:143). The problem, as he saw it, was to save the appearance of the phenomena with an hypothsis which was compatible with the principle of physics that hypotheses be founded in the truth of nature, and to demonstrate that to reject this hypothesis meant that the appearances were not saved.
[It is the notion that the universe is earth- and, hence, man-centered and, therefore capable of being personalized and animated which distinguishes primitive man from civilized man.]
In the early sixteenth century, Theophrastus Bombastus von Hohenheim, who called himself Philippus Aureolus **Paracelsus**, opposed the four humors of Galenic medicine with "a triad of chemical properties: combustibility (termed 'sulphur'), fluidity and changeability (termed 'mercury'), solidity and permanence (termed 'salt').... The medical doctrine of Paracelsus was a new humoralism, but it emphasized the use of specific medicines for specific diseases" (Fruton 1972:29). He wrote prolifically in German and his *On Diseases of Miners* is the earliest book on occupational diseases.
In 1521, **Berengario** da Carpi, in a commentary on **Mondino**, observed that "the kidney is not a sieve [and] the bladder [has] no opening other than the urinary pores..., gave the first clear accounts of the vermiform appendix, the thymus gland and other structures..., and coined the term *vas deferens*" (Crombie 1952:371).
In 1527, Matteo **Bresan**, supervisor of the Venice Arsenal, oversaw the construction of a full-rigged sailing ship with lidded gunports, called a 'galleon.'
In 1530, Girolamo **Fracastoro** published a long poem, *Syphilidis, sive, De mordo gallico libri tres*, the disease taking its name from the poem. He also identified typhus.
In 1535, Niccoló Fontana, who was called **Tartaglia**, demonstrated a solution for cubic equations, but did not reveal the details. When finally published in 1545, the expression was seen to be "built up from the coefficients by repeated addition, subtraction, multiplication, division, and extraction of roots. Such expressions became known as *radical* expressions" (Stewart 1989:xiv). This formula was "probably the first great achievement in algebra since the Babylonians" (Davis and Hersh 1981:196).
In 1537, Ambrose **Paré** revived the practice of ligature for gunshot wounds, replacing cautery with hot oil. Later, he performed herniotomies and manipulated fetuses so they could be born feet first.
In 1541, Giambattista **Canano** published illustrations of each muscle and its relation with the bones.

In 1543, Andreas **Vesalius** published a large collection of meticulous anatomical drawings, emphasizing especially the systems of organs.
In 1543, **Copernicus** published *De revolutionibus orbium coelestium*. Although he made some astronomical observations, this work is that of a mathematician using **Ptolemy**'s data, who could read Greek and cite **Aristarchus** of Samos. NeoPlatonic and NeoPythagorean influences loom large: "In the center of it all rests the Sun. For who would place this lamp of a very beautiful temple in another or better place than wherefrom it can illuminate everything at the same time? As a matter of fact, not unhappily do some call it the lantern; others, the mind and still others, the pilot of the world. Trismegistus calls it a 'visible god'" (Copernicus 1543:527). In so placing the Sun, Copernicus "overthrew the hierarchy of positions in the ancient and medieval Cosmos, in which the central was not the most honorable, but, on the contrary, the most unworthy. It was, in effect, the *lowest*, and consequently appropriate to the Earth's imperfection. Perfection was located *above* in the celestial vault, above which were 'the heavens,' whilst Hell was deservedly placed beneath the surface of the Earth" (Koyré 1961:114n24).
In 1543, Pierre de la **Ramée** published two books of logic which were anti-Scholastic and anti-Aristotelian and were very influential in Protestant countries in the following century.
In 1545, Charles **Estienne** published illustrations showing the venous, arterial, and nervous systems.
In 1545, Girolamo **Cardano**, in *Ars Magna*, published a complete discussion of **Tartaglia**'s solution for cubic equations. *Ars Magna* also contained Ludovico **Ferrari**'s method of solving the quartic equation by reducing it to a cubic.
In 1546, **Fracastoro** published the idea that diseases were caused by disease-specific seeds "that could multiply within the body and be transmitted directly from person to person or directly on contaminated objects, even over long distance; moreover, he proposed that variations in the intensity of epidemics could be attributed to changes in the virulence of germs" (Ewald 1994:184).
In 1546, Pedro **Nunes**, in *De arte atque ratione navigandi*, described how to sail a great circle course.
In 1551, Erasmus **Reinhold** published a revised and enlarged version of **Copernicus**'s planetary tables, known as the *Prussian Tables*, which greatly extended knowledge of Copernicus's theories among astronomers.
In 1552 or later, Konrad **Gesner**, in *Opera Botanica* and *Historia Plantarum*, distinguished genus from species and order from class.
In 1553, Pierre **Belon**, in *De Aquatilibus*, observed that Cetaceans breathe air with lungs and depicted new-born dolphins still in their fetal membrane and porpoises attached to umbilical cord and placenta.
In 1553, Miguel Servet y Reves, better known as Michael **Servetus**, said that the blood circulates from the heart to the lungs and returns to the heart.
In 1554, **Cardano**, in *De Subtiltate*, wrote of **da Vinci** that "he demonstrates that nothing has perpetual motion" (Cardano, quoted in Duhem 1905:44) and recounts his demonstration. He also demonstrated that the momentum of a suspended body increases in proportion to the velocity of its descent. Later, Cardano appended his *Opus novum de proportionibus*, on statics, to this work.
In 1555, **Belon**, in *L'Histoire naturelle des oyseaux*, illustrated birds and man in which homologous bones were given the same names.
In 1555, Guillaume **Rondelet**, in *L'histoire Naturelle des Poissons*, pointed out "differences between the respiratory, alimentary, vascular, and genital systems of gill- and lung-breathing aquatic vertebrates, and depicted the vivaparous dolphin and ovoviviparous shark.... He considered the teleostatean swim-bladder, which he discovered, to be a kind of lung" (Crombie 1952:377).
In 1556, Georg Bauer, better known as Georgius **Agricola**, in *De re metallica*, classified minerals and observed physical geography.
Between 1556 and 1560, **Tartaglia**, in *General trattato di numeri et misure*, showed how to fix position and survey land by compass-bearing and distance.
In 1562 or earlier, Gabriel **Fallopio** described the ovaries and uterus and the tubes connecting them.
By 1562, **Cardano** had written *Liber de ludo alaea,* the first systematic computation of probabilities, which was not published, however, until 1663.
In 1564, Julius Caesar **Arantius** asserted that "although the fetal and maternal vascular systems were brought into close contact with the placenta there was no free passage between them" (Crombie 1952:381).

In 1569, Michel Eyquem de **Montaigne**, in *Apologie de Raimond Sebond*, wrote that "unless some one thing is found of which we are completely certain, we can be certain of nothing" (Montaigne, quoted in Toulmin 1990:42).
In 1569, Gerard de Cremer, better known as Gerardus **Mercator**, published the projection map of the world which bears his name.
In 1572, Tycho **Brahe** observed a supernova in the constellation *Cassiopeia*, now known as Tycho's star.
In 1576, Thomas **Digges** made the claim that **Copernicus**'s 'Celestial Sphere' does not exist, that the stars are at different distances from the Earth, and that Copernicus's heliocentrism was a "most ancient doctrine of the Pythagoreans" (Digges, quoted in Nicholl 1992:207)
By 1578, **Brahe** completed the first eight chapters of *De mundi aetherii recentioribus phaenomenis*, a book on the comet of 1577, in which he showed that the comet "was beyond the Sun [an impossibility in the Aristotelian view] and that its orbit must have passed through the solid celestial spheres, if these existed" (Crombie 1952:314). In the ninth chapter, he offers a new system in which the Earth is immoble and the planets, except for the Earth, revolve around the Sun, thus rejecting both **Ptolemy**'s and **Copernicus**'s systems. This was published in 1588.
In 1582, the reform of the calendar, by which the so-called 'Gregorian calendar' was created, was based on tables constructed by means of the theories of **Copernicus**. This in no way implied an endorsement of his heliocentrism, but just that his tables were dealt with as contrivances which better 'saved the appearance' of the heavens.
In 1583, **Cesalpino**, in *De Plantis*, classified plants with seeds according to the number, position, and shape of the parts of their fruit.
In 1583, **Galileo** Galilei discovered by experiment that the oscillations of a swinging pendulum took the same amount of time regardless of their amplitude.
In 1583, Giordano **Bruno** first preached "the doctrine of the decentralized, infinite and infinitely populated universe [and] also gave a thorough statement of the grounds on which it was to gain acceptance from the general public" (Lovejoy 1936:116). Shortly thereafter, he published *De l'infinito universo e mondi* in which he maintained that "the infinite cannot be the object of sense-perception; [it is rather found] in the sensible object as in a mirror; in reason, by a process of argument and discussion. In the intellect.... In the mind" (Bruno, quoted in Koyré 1957:45-46). Bruno's infinite universe, governed by the identity of its fundamental laws, may be contrasted to the "closed unity of a qualitatively determined and hierarchically well-ordered whole in which different parts (heaven and earth) are subject to different laws" (Koyré 1968:2). But Bruno's interest in **Copernicus**'s heliocentrism was also "that of a magician imbued in all the currents of Renaissance occultism" (Nicholl 1992:207). Indeed, Bruno seems to have been the prototype for Christopher Marlowe's *Dr Faustus*.
In 1585, Giovanni Battista **Benedetti**, in *Diversarum speculationum*, foreshadowed the inertial concept: "Every body moved naturally or violently receives in itself an impression and impetus of movement, so that separated from the motive power, it would be moved of itself in space in some time" (Benedetti, quoted in Clagett 1959:663). He studied **Archimedes** and applied mathematics to the study of nature.
In 1586, Simon **Stevin** began a book on statics and hydrostatics, *De Beghinselen der Weeghconst*, with the assumption that perpetual motion was impossible and that therefore any given mass of water was in equilibrium in all its parts. On this basis, he concluded that the pressure of a liquid on the base of a container depended only on depth. He also demonstrated that the center of gravity of a triangle lies on its median. He demonstrated the same for parabolic segments.
About 1586, **Galileo** wrote a manuscript, *De motu gravium*, which showed that the ratio between the gravity of a moving body on an inclined plane and gravity acting on free fall is the sine of the angle which the plane forms with the horizontal.
In 1590, Zacharias and Hans **Janssen** combined double convex lenses in a tube, producing the first telescope.
In 1591 and 1592, Thomas **Harriot**, or sometimes Hariot, measured an angular distance of 2 degrees 56 minutes between the celestial north pole and the North Star.
In 1591, François **Viète**, in *In artem analyticam isagoge*, demonstrated the value of symbols to represent unknowns and suggested the use of letters. He also introduced the term 'coefficient.'
About 1592, **Galileo** found that the path of a projectile is a parabola by assuming that the uniform motion preserved in the absence of an external force is rectilinear. The acceptance of a straight

rather than a circular path as natural became a crucial turning point in planetary mechanics.

In 1593, **Viète** represented π as an infinite product in what is thought to be the earliest use of that symbol.

In 1600, William **Gilbert**, in *De Magnete*, held that the earth behaves like a giant magnet with its poles near the geographic poles. He coined the word '*electrica*' (from the Greek word for amber, *elektron*), and distinguished electricity from magnetism.

About 1601, **Harriot** discovered that the *extensa*, or refractive index, is the same for all angles of incidence. This enabled him to compute refractions for one-degree intervals.

In 1603, **Harriot** computed the area of a spherical triangle: "Take the sum of all three angles and subtract 180 degrees. Set the remainder as numerator of a fraction with denominator 360 degrees. This fraction tells us how great a portion of the hemisphere is occupied by the triangle" (Harriot, quoted in Lohne 1978:125).

In 1604, **Kepler**, in *Ad Vitellionem Paralipomena*, said that the intensity of light varies inversely with the square of the distance from the source. He also said that vision is the consequence of the formation of an image on the retina by the eye's lens and described the causes of near- and far-sightedness.

In 1604, **Kepler** and many other astronomers witnessed the outburst of a supernova in the constellation *Serpens*. At its peak, it was as bright as Venus and then faded away over the next year. It was the last supernova seen in the Milky Way galaxy.

In 1605, Francis **Bacon**, with the *Advancement of Learning*, began the publication of his philosophical works, in which he urged collaboration between the inductive and experimental methods of proof, as opposed to scholasticism's *a priori* method. "It is chiefly to his skill and value as a propagandist that Bacon owed his popularity among seventeenth- and eighteenth-century scientists" (Koyré 1965:5n3).

In 1608, **Stevin** deduced the law of the lever not merely from reasons, as **Archimedes** had, but from physical assumptions, or "instinctive knowledge" (Mach 1883:26-29).

About 1608, Jan **Lippershey**, and others independently, invented the telescope by combining lenses empirically.

In 1609, **Kepler**, in *De Motibus Stella Martis*, published the results of **Brahe**'s calculations of Mars' orbit, which were inconsistent with then current assumption that it was a circle. He claimed to base his "whole astronomy upon **Copernicus**'s hypotheses..., the observations of Tycho **Brahe**, and lastly upon the Englishman William **Gilbert**'s philosophy of magnetism" (Kepler 1614:850). This publication included the first two of what became known as Kepler's laws. Their gist is that the sun is off-center in the planetary ellipses, that the speed of planetary motion increases as their distance from the sun decreases, and, hence, the areas of the angles subtended by the sun and a given interval of time are the same. Cosmic space is no longer governed by the mechanism of spheres; it is spoken of in the abstract. The Sun's magnetic force, which he took to consist of elastic chains, does the work of gravity and provided the model for the inverse varience of speed and distance. On the other hand, his term "*inertia* means for him the resistance that bodies oppose...solely to movement;...he needs a cause or a force to explain motion, and does not need one to explain rest" (Koyré 1968:11). For example, in his quest for a numerically ordered solar system, Kepler postulated an unobserved planet in the gap between Mars and Jupiter.

In 1609, **Galileo** built a telescope with which he discovered the mountains on the moon, that the Milky Way consisted of innumerable stars, the four largest satellites of Jupiter, the phases of Venus, and sunspots. He announced these discoveries in *Sidereus nuncius*, and seems at this time to have become convinced of the correctness of **Copernicus**'s theory. Also seeking to solve the navigational problem caused by the variability of the time value of a degree of longitude, he built tables showing the appearance and disappearance of Jupiter's moons. By 1650, his method was generally accepted on land.

About 1610 or 1611, William **Shakespeare** created the earliest remembered opposition of 'nature' and 'nurture' when he had Prospero describe Caliban, in the *Tempest*, as "a born devil, on whose nature, nurture can never stick" (Shakespeare 1944:51).

In 1611, **Kepler**, in *Dioptrice*, explained the principles involved in the convergent/divergent lenses of microscopes and telescopes and suggested that telescopes could be built using only convergent lenses. Astronomical lenses became this type.

In 1612, **Galileo**, in *Discorso intorno alle cose cho stanno in su l'acqua*, observes that the roles of a lever, a windlass, a capstan, a pulley, and a block and tackle each consist "in transporting a great resistance very slowly and without dividing it by means of a small force moving rapidly" (Duhem 1905:179).

In 1614, **Kepler**, in the *Epitome Astronomiae Copernicanae*, said that an astronomer "ought to be able to provide reasons for the hypotheses [they] claim as the true causes of appearances, [and they] ought, therefore, at the outset, to seek the foundationsof [their] astronomy in a higher science, I mean, in physics or metaphysics" (Kepler, quoted in Duhem 1908:103). For example, in his quest for a numerically ordered solar system, Kepler postulated an unobserved planet in the gap between Mars and Jupiter.

In 1614, John **Napier**, in *Mirifici logarithmorum canonis descriptio*, created the first logarithmic tables and the first use of the word 'logarithm.' It was not published until 1619. Napier also introduced the decimal point in writing numbers.

In 1614, Isaac **Casaubon** demonstrated that the Hermetic writings in the *Pimander* were not the magical practices of a very ancient Egyptian priest but dated from post-Christian times. This "is a watershed separating the Renaissance from the modern world. It shattered at one blow the build-up of Renaissance NeoPlatonism" (Yates 1964:398).

In 1615, **Kepler**, in *Steriometria doliorum*, showed, following **Cusa**'s exhaustion method, that the volume of a sphere is one-third the product of its radius times the surface area of an infinite number of cones, and that of all right circular cylinders inscribed in a sphere, that one is the greatest which has the diameter and altitude in the ratio of the square root of 2 to 1. Kepler was concerned with statics and 'indivisibles' and expressed himself in numerical increments.

In 1619, **Kepler**, in *Harmonica mundi*, published his third law: The square of the length of a planet's year varies with the cube of the mean radius of its orbit. His three laws "are the *only* three exact and general mathematical laws of planetary motion, applying not only to this but to all similar planetary systems. And he contributed a further revolutionary idea: that the planets move in their orbits...because the Sun exerts a force that causes them to move as they do" (Park 1990:157). However, none of Kepler's laws was deduced from a consistent theoretical framedwork, which work was left for **Newton**.

In 1620, Gaspar **Bauhin**, in *Prodomus Theatri Botanici*, gave precise, diagnostic descriptions to about 6000 plants.

About 1620[?], Joachim **Jung** made precise definitions of the parts of plants.

In 1620, F. **Bacon**, in *The New Organon*, pointed out, as an "instance of resemblance," that maps of Africa and South America show "similar isthmuses and similar promontories, and that does not happen without a reason" (Bacon 1620:147).

About 1620[?], Gasparo **Aselli** discovered the lacteal vessels, lymphatic vessels which conduct fatty substances into the blood stream at the jugular vein.

In 1621, Willibrord **Snell**, in *Cyclometricus*, discovered the law of refraction which says that the ratio of the sines of the angles of incidence and refraction is a constant and the index of refraction varies from one transparent substance to another. This law implies that the velocity of light in a medium is inversely proportional to its refractive index. *Cyclometricus* was published after Snell's death by René **Descartes**.

In 1621, **Galileo** discerned that the acceleration of a falling body is proportional to the time and independent of weight and density.

In 1623, Edmund **Gunter** devised a logarithmic scale of equal parts and trigonomic functions which, with the aid of a compass, served as a slide rule.

In 1623, Wilhelm **Schickard** built a six digit calculator, driven directly by gears, which could add, subtract, and indicate overflow by ringing a bell.

In 1624, Pierre **Gassendi** , in *Exercitationes paradoxicae adversus Aristoteleos*, revived the "Democritean (or Epicurean) ontology,...modified [it] by doing away with the *clinamen*..., but...retained the essential feature, namely, atoms and vacuum" (Koyré 1968:119). He revived **Hippocrates**' ideas about the brain and maintained that animals have memories, reason, and other psychological characteristics of man.

About 1625, **Gregory** of Saint Vincent said that "parallelepipeds [a solid contained by six parallelograms] can be so multiplied that they *exhaust* the body within which they are inscribed" (Gregory, quoted in Boyer 1949:136), which is the earliest recorded use of the word 'exhaust' in this context. "Instead of thinking of static indivisibles, he reasoned in terms of a varying subdivision [that is, an infinite geometric progression], thus approximating the method of limits" (Boyer 1949:137).

In 1627, William **Harvey** was able to confirm his observation that the blood circulates throughout the body, which he inferred from the structure of the venal valves. The following year, in *Exercitatio Anatomica*, he published these conclusions as well as a description of the heart as a mechanical pump.

Between 1628 and 1634, Giles Persone de **Roberval** invented a theory of indivisibles; however, "after dividing a figure into small sections, he allowed these continually to decrease in magnitude, the work being carried out largely arithmetically and the result being obtained by summing an infinite series"(Boyer 1949:142). The arithmetic furthered the logical basis of the 'infinitessimal calculus,' but this new analysis would be the result of "suggestions drawn from geometry" (*ibid*.:104).

About 1629, Pierre de **Fermat** discovered that the equation $f(x,y) = 0$ represents a curve in the *xy*-plane. This is the fundamental principle of analytic geometry, and was first published by Descartes in 1637. He also formulated a method for determining the maximim and minimum values which give single solutions for problems which in general have two solutions. This procedure is "almost precisely that now given in the differential calculus" (Boyer 1949:156).

In 1630, Jean **Rey** said that the slight increase in weight of lead and tin during their calcination "could only have come from the air, which he said mixed with the calx and became attached to its most minute particles" (Crombie 1952:359).

In 1631, **Gassendi** obderved the transit of Venus across the Sun, establishing that its orbit lies closer to the Sun than does the Earth's orbit.

In 1632, **Galileo** published a work in Italian for the non-specialist, the *Dialogo*, comparing the Ptolemaic system unfavorably to the Copernican. For this, he was tried by the Inquisition in 1633 and forced to abjure belief that the Sun was central and that the Earth moved. In addition, *Due massimi sistemi* contains Galileo's construction of the concept of 'inertia,' perpetual motion being the limiting case: In an ideal world without friction, given the acceleration and retardation of a body by gradually sloping planes tending toward horizontal, momentum persists indefinitely. "Force could therefore be defined as that which produced, not velocity, but a *change* of velocity from a state of rest or of uniform velocity" (Crombie 1952:301). When a body is acted on by two forces, each is independent of the other. "Galileo's conception of science as a mathematical description of relations enabled him to...free [methodology] from the tendency to excessive empiricism" (Crombie 1953:305). Thus 'gravity' was only the name for an observed regularity, with antecedent cause to be discovered by experiment, and not an 'essential cause;' i.e., "mathematical substance was substituted for Aristotelian qualitative substance as the identity persisting through change" (*ibid.*:310).

Probably in 1633, **Descartes** wrote *Le Monde* wherein "subtle matter, his celestial matter, what his contemporaries called 'the Cartesian aether,' comprises the second element [i.e., 'air'] permeated, as always by the first [i.e., 'fire']" (Cantor and Hodge 1981:12). The third and final element is 'earth.' It was published posthumously in 1664.

In 1635, Bonaventura Francesco **Cavalieri** published a purely geometric theory of indivisibles.

In 1636, **Galileo** finished his final book, *Discorsi e dimostrazioni matematiche interno a due nuove scienze*, which contained most of his physics and some strenghtened arguments. The two sciences are statics and dynamics. The *Discorsi*, together with the *Dialogo*, both works of popular science, "helped create a new age of scientific thought with their emphasis on observation, common sense, clear language, and persuasion by reasonable arguments" (Park 1990:206).

In 1637, **Descartes**, in *Discours de la Méthod pour bien conduire sa raison, et chercher la vérité dans les sciences*, held that science begins with observation which is followed by analysis, leading to the intuition of the self-evident nature of a proposition, and synthesis, or the reconstitution of the original observation. Included with this work were three exemplary treatises: *La Dioptrique*, where 'matière subtile' includes whatever particles transmit light, *La Gèometrie*, where he demonstrated the so-called Cartesian coordinates and Cartesian curves, and, in algebra, where he contributed the convention of exponent notation, a study of negative roots, and the convention whereby known quantities are represented by letters near the beginning of the alphabet and unknowns by letters at the end; and *Météores*, where he showed that the primary rainbow was produced by sun rays coming to the eye at an angle of about 41 degrees.

About 1640, Jeremiah **Horrocks** showed that the moon travels in an elliptical orbit and thought of it as "continually falling toward Earth" (Park 1990:179).

In 1640, **Fermat** wrote his so-called 'lesser theorem;' namely, if *p* is prime, then $a^{p} - a$ is divisible by *p*.

In 1641, **Descartes** published his principle philosophical work, *Meditationes de prima philosophia*, with the goal of refuting the scepticism of the Renaissance humanists. The kernal of this philosophy is universal doubt: What one can know is based in logic and rationalization, or *res cogitans*, whereas

the physical world, or *res extensa*,the geometer's three dimensions, is mechanistic and entirely divorced from the mind. "The real truth about nature is learned from reason and not from the trial and error procedures of experimental science" (Park 1990:217). The maintenance of this distinction is Cartesian dualism. Thinking, and the awareness of thinking, are the substrates of being: "*Je pense donc je suis*." This, so Descartes thought, was the necessary connection between what thinks and what is extended, and 'spirit' was the medium of their interaction. He also thought he had confounded **Montaigne**'s one 'certain' thing. 'Soul' is not alive, so it must be immortal. This 'mechanical philosophy' caused the phantom of the imminent end of the world to begin to fade from peoples' consciousness: The mathematical principles underlying nature would continue to operate despite human sin.
In 1642, **Gassendi**, in *De motu impresso a motore translato*, extended **Galileo**'s definition of inertia to include motion in any direction, not simply horizontal motion.
In 1643 or earlier, **Fermat** determined the center of gravity of a paraboloid segment "by means equivalent to those of differential calculus, instead of by means of a summation resembling those of integral calculus" (Boyer 1949:159).
In 1644, **Descartes** published *Principia philosophiae* which philosophically is essentially a Latin version of *Meditationes*, hence "*Cogito, ergo sum*." Scientifically, the physics is much more extensive including notably the notion that "the most general cosmic processes produce magnetism," with the Earth's magnetic vortices appearing in a pattern similar to iron nails around a lodestone (Heilbron 1979:32).
In 1644, Evangelista **Torricelli** devised the mercury barometer and created an artificial vacuum. He was also a mathematician who restricted himself to geometric considerations and showed great facility in his handling of indivisibles.
In 1644, Blaise **Pascal** built a five digit adding machine, driven by rising and falling weights. The 'Pascaline' became well-known in its time and established the computing machine concept.
In 1645, Marc Aurelio **Severino**, in *Zootomia Democritaea*, "discovered the heart of the higher crustacea..., recognized the respiratory function of fish gills, [and] recognized the unity of vertebrates, including man" (Crombie 1952:383).
In 1647, **Cavalieri** derived the relationship between the focal length of a thin lens and the radii of a surface's curvature.
In 1648, Jean Baptiste **van Helmont**, in *Ortus Medicinae*, published posthumously, concluded that plants derive their sustenance from water, demonstrated that acid digestion was neutralized by bile thus proving that physiological changes have chemical causes, coined the name 'gas' from the Greek *chaos*, distinguished gases as a class with liquids and solids, and showed that metals dissolved in the three main mineral acids could be recovered.
In 1648, **Pascal** said that barometric pressure results from atmospheric pressure and that pressure applied to a confined fluid is transmitted equally to all areas and at right angles to the surface of the confiner.
In 1649 or earlier, Daniel **Sennert** conceived a corpuscular theory of matter, and considered "fermentation to be a process in which whole bodies are separated into their smallest indivisible parts, followed by the reunion of these atoms to form new bodies" (Fruton 1972:30).
In 1649, **Descartes**, in *Traité des passions de l'âme*, held that emotions were basically physiological.
In 1649, **Gassendi**, in an appendix to *Animadversiones in decium librum Diogenis Laertii*, reported an experiment which demonstrated that the variation in the height of a column of mercury in a Torricellian tube is a function of the altitude at which it is placed. Later, discussing this experiment in *Syntagma Philosophicum*, he explained that the weight of the column of air "compresses it, and it is this pressure that causes the mercury to rise in the tube" (Koyré 1968:129).
In 1650, Francis **Glisson** published an account of infantile ricketts.
In 1651, **Harvey** published the concept that all living things originate from eggs. Harvey believed that in principle organisms could be spontaneously generated, and that the process was the self-generation of a complicated machine.
In 1651, Thomas **Hobbes**, in *Leviathan*, argued from a mechanistic theory that man is a selfishly individualistic animal at constant war with others. In the state of nature, life is "nasty, brutish, and short."
In 1652, Thomas **Bartholin** discovered the lymphatic system and determined its relation to the circulatory system.
In 1654, Otto **von Guericke** removed the air from within two metal hemispheres. Teams of

horsemen were challenged to pull them apart, which they failed to do.
[In 1654, James **Ussher**, Protestant archbishop of Armagh, determined by a close reading of scriptural genealogies that the events described on the first page of the Book of Genesis occurred in 4004 B.C.]
In 1654, William **Petty**, working on Irish estates confiscated by Oliver Cromwell, carried out the first large scale attempt at a scientific survey.
In 1655, Christiaan **Huygens** discovered 'Titan,' Saturn's largest moon, and that what **Galileo** had thought were moons were actually rings. He was the first to note markings on Mars. He also applied Galileo's idea that a falling body does so in a straight line to planetary orbits, calculating "the radial force necessary to keep a planet in a circular path [is] mv^2/r, where m is the mass, v the velocity, and r the orbital radius" (Grosser 1979:9).
In the mid-1650s, Thomas **Sydenham** promoted the idea that diseases were organisms inside a host. He advocated direct observation and classification to determine the nature of disease, and introduced quinine and laudanum to English medicine.
In 1656, John **Wallis**, in *Opera mathematica*, made the transition from the geometry of lines to the arithmetic of numbers where he made the first use of the category 'infinity' in the field of arithmetic and invented its symbol.
In 1656, **Huygens** built the first pendulum-regulated clock. Two years later, Huygens, in *Horologium*, claimed that his clock could establish longitude at sea which was not then possible and had led to many maritime disasters. This claim was not borne out.
In 1657, **Fermat** stated the 'least time' principle according to which a light ray follows the path to its destination in the shortest possible time.
In 1657, **Huygens** wrote the first textbook on probability, *Calculating in Games of Chance*.
In 1658, Henry **More**, in *Immortality of the Soul*, argued "the first primary matter must be atoms and that matter may be so small as to be indiscernible" (Newton, quoted in White 1997:55).
In 1659, **Pascal**, in *Traité des sinus du quart de cercle*, used the language of infinitesimals when writing of the sum of all the ordinates. In *De l'esprit géometric*, he held that in numbers the infinitely large and the infinitely small are complementary.
In 1661, Marcello **Malpighi**, in *De pulmonibus*, reported his observation of blood movement through the capillaries. He is also noted for his studies of the glands.
In 1661, Robert **Boyle**, in the *Sceptical Chymist*, separated chemistry as corpuscles, from alchemy, as qualities, and gave the first precise definitions of a chemical element, a chemical reaction, chemical analysis, and made studies of acids and bases. It was only after this that scientists generally abandoned the ancient notion that matter was compounded of 'Fire, Earth, Air, and Water.'
In 1662, **Boyle**, using a vacuum pump of his own invention, determined that the volume and pressure of a gas are inversely proportional. This is known as 'Boyle's law.' He also determined that sound doesn't travel in a vacuum.
In 1662, Antoine **Arnauld** and others contributed to a book known as the Port Royal *Logic, or the Art of Thinking*, where the question was first taken up of the two sorts of non-deductive reasoning, inference and decision under uncertainty, on the one hand, and theorizing, or what Charles Sanders **Peirce** later called 'abduction,' on the other.
Beginning in 1662, Isaac **Barrow** lectured on geometry. The results of his investigations include many theorems on tangents and quadratures and an atomistic conception of a line: "Time has many analogies with a line...; for time has length alone, is similar in all its parts, and can be looked upon as constituted from a simple addition of successive instants or as a continuous flow of one instant" (Barrow 1662:37). All of his propositions were cast in geometric forms which **Newton**, his student, recast in the analytic symbolism of **Fermat**, **Descartes**, and **Wallis**.
In 1662, John **Graunt**, in *Observations upon the Bills of Mortality*, using London population data, noted that life expectancy is 27 years, with nearly two/thirds dying before 16 years.
In 1663, James **Gregory**, in *Optica Promota*, described the reflecting telescope which he had built and which used a convergent mirror as its object in order to cure aberrations.
In 1664, Thomas **Willis**, in *Cerebri anatome*, identified the corpus striatum, now called the basal ganglia, as the initiator of motor acts as well as being the receiver of sensory data. and distinguished the cortical gray matter from the deeper white matter. He also abandoned **Galen**'s doctrine of the ventricles and gave primacy to the cerebral cortex.
In 1665, Francesco Maria **Grimaldi**, in *Physico-Mathesis de lumine, coloribus, et eride*, published

posthumously, discovered that light going through a fine slit cannot be prevented from spreading on the farther side, a phenomena which he named 'diffraction' and postulated was caused by its wave-like motion.
In 1665, Robert **Hooke**, in *Micrographia*, named and gave the first description of cells. He also described plant and animal fossils, comparing their microscopic structure to that of living organisms. Hooke also noted the 'black spot' in soap bubbles, and, independently of Grimaldi, hypothesized that light is "a 'very short vibrative motion' transverse to straight lines of propagation through a 'homogenous medium.' Heat [is] defined as 'a property of a body arising from the motion or agitation of its parts'" (Koyré 1965:223n2).
In 1665, Gian Domenico **Cassini**, while attempting to map Jupiter, discovered the Great Red Spot, an area about 48,000 by 11,000 kilometers that drifts across the planet's south temperate zone.
By 1666, **Newton** had discovered the essentials of calculus, the law of universal gravitation, and that white light is composed of all the colors of the spectrum.
In 1668, Francisco **Redi** described a series of experiments which showed that the maggots in meat were the larva of flies.
In 1668, **Cassini** published an ephemerides of great accuracy and included the rotational periods of Jupiter, Mars, and Venus. This won him the directorship of the Paris observatory the following year where both **Huygens** and Olaus **Roemer** worked under him.
In 1669, **Newton** circulated a manuscript, *De analysi per aequationes numero terminorum infinitas*, the first notice of his calculus, which gave "a generally applicable procedure for determining an instantaneous rate of change and to invert this in the case of problems involving summations" (Boyer 1949:192). A more extensive exposition of the calculus, *Methodus fluxionum et serierum infinitarum*, with the introduction of his characteristic terminology, was available in manuscript about two years later. The former was not published until 1711; the latter, 1736.
In 1669, Nils Steensen, known as **Steno**, by postulating a sequence of distinct geological phases, was able to explain how land acquired its current conformation: E.g., marine fossils indicate a former sea bed, which was violently uplifted, and, afterward, undermined by subterranean forces, causing the strata to breakup, become eroded, and, in due course, form another sea bed.
In 1670, **Boyle** produced hydrogen by reacting metals with acid.
In 1670, the editors of the Port Royal *Logic* published **Pascal**'s *Pensées*, eight years after his death. In it, he discusses probabilty in terms of a wager on the existence of God: If God exists, wagering that he doesn't brings damnation and that he does brings salvation. Since salvation is better than damnation, 'God exists' dominates the wager.
Between 1671 and 1684, **Cassini** discovered four of Saturn's moons and studied the division in its ring system that bears his name. Also, in 1671, he made the first successful measurement of the parallax of Mars in an effort in which Jean **Richer** led an expedition to Guiana in order to create a base sufficient for the triangulation.
In 1672, **More**, in *Enchiridium metaphysicum*, asserts "the real existence of infinite void space...as a real precondition of all possible existence [and] as the best and most evident example of non-material--and therefore spiritual--reality and thus the first and foremost...subject-matter of metaphysics" (Koyré 1957:137). More had taught **Newton** in his first years at Cambridge ten years earlier
About 1674, Hennig **Brand** discovered phosphorus in a distillation of human urine.
In 1674, Nicolas **Malebranche** elaborated the conception that each embryo is encased in the embryo of its parent.
In 1674, Anton **van Leeuwenhoek** reported his discovery of protozoa.
In 1675, Nicolas **Lémery** published a chemistry textbook in which he espoused the corpuscle theory.
In 1676, Nehemiah **Grew** suggested the true nature of ovules and pollen.
In 1676, **Roemer** proved that light travels at a finite speed by repeated observations of eclipses of Jupiter's moon, Io. The period of the orbits of Jupiter's moons had previously been perceived to vary, but Roemer pointed out that it is the Earth's movement plus light's constant speed which create this appearance, that is, what we would call a '**Doppler** effect.'
In 1677, Guillaume **Lamy**, in *Explication mécanique et physique des fonctions de l'âme sensitive*, used the words soul and animal spirits without differentiation: "J'ay pris indifféremment les mots d'*âme* et d'*esprits*, ce qui ne doit point faire de confusion, car c'est la mesme chose"(Lamy 1677:176).

In 1678, **Huygens**, in a communication to the *Academie des Science*, propounded a wave theory of light propagated through 'aether,' and held that every point on a wave is itself asource of new waves. At the same time, he reported his discovery of the double refraction of light when viewed in calcite. This theory was published in 1690 as *Traité de la lumière.*

In 1678, Edmond **Halley** returned from St. Helena where he had added 341 stars to the southern hemisphere catalogue with the aid of a telescope. After observing a transit of Mercury across the Sun, he recognized the possibility of using Venus's transit of the Sun--known to occur in 1761--for determining the distance of the Sun by measuring solar parallax.

In 1679, Giovanni Alfonso **Borelli**, in *De motu animalium*, interpreted the locomotory apparatus of vertebrates from a strictly mechanical point of view. In a study of disease, he concluded that something entered the body which could be remedied chemically.

In 1679, Denis **Papin** devised a vessel in which the boiling point of water is raised by an increase in steam pressure. This demonstrated the influence of atmospheric pressure on boiling points.

In 1682, John **Ray** described empirically 18,000 species of plant.

By 1683, Anton **van Leeuwenhoek**, with microscopes, some of which magnified 270 times, had seen red blood cells, sperm cells, and almost all classes of microorganism known today. He hypothesized that these were carried in the air, not spontaneously generated. Also, van Leeuwenhoek was able to faithfully describe the nervous system and was the first to describe the life cycle of an ant, from egg to larva to pupa to adult.

In 1684, Gottfried Wilhelm von **Leibniz** published his system of calculus, developed independently of **Newton**. It is Leibniz's notation which has been adopted. He also invented a scheme for a logical syntax which he called the 'Universal Characteristic' and which "was supposed to enable us to compute the probabilities of disputed hypotheses relative to the available data" (Hacking 1975:140).

In 1687, **Newton** published *Philosophiae naturalis principia mathematica*, a summary of his discoveries in terrestial and celestial mechanics in which he makes continual use of Euclidean theorems and constructions, and the first published account of his calculus. In contrast to **Kepler**, he did not explain the features of the solar system by deducing them from a purpose. In contrast to **Descartes**, he carefully preserved the distinction between mathematical descriptions and theories about matter and causation. For example, writing of gravitational attraction, he said that "our purpose is only to trace out the quantity and properties of this force from this phenomena, and to apply what we may discover in some simple cases [e.g., the moon] as principles by which, in a mathematical way, we may estimate the effects thereof in more involved cases [e.g., the planets]".... Absolute, true, and mathematical time, of itself, and from its own nature, flows equably without relation to anything external, and by another name is called duration (Newton 1729:550). The first part of the *Principia* concerns dynamics and includes his laws of motion, the second concerns fluid motion, and the third, the mechanical unity of his principle of gravitational attraction in relation to the 'centripetal force' of the planet's motion, that is, **Kepler's** laws of planatary motion. "Newtonian mechanics [may be] understood as the combination of two laws: the law of motion, according to which force is equal to mass times acceleration; and the law of universal gravitation, according to which the force of attraction between two bodies is proportional to the product of their masses and inversely proportional to the square of the distance separating them" (Sokal and Bricmont 1998:64). "In opposition to the pre-Galilean and pre-Cartesian conception, which understood motion as a species of becoming..., the new, or classical, interpretation interprets motion as a kind of being, that is, not as a process, but as a *status*, a *status* that is just as permanent...as rest" (Koyré 1965:9). Holding that the Earth's rotation, its motion, is relative to absolute space, Newton finds it necessary to distinguish "time, space, place, and motion...into absolute and relative, true and apparent, mathematical and common. [E.g.,] absolute space, in its own nature, without relation to anything external, remains always similar and immovable".... Absolute, true, and mathematical time, of itself, and from its own nature, flows equably without relation to anything external, and by another name is called duration (Newton 1729:6).

At the same time, **Newton** wished to demonstrate that the world which obeyed these laws was compatible with the sort of atoms which he imagined, atoms which were aethereal forces as everything else. These forces counted among their number, *at a minimum*, inertia and gravity, which are proportional to each other, cohesion, or the mutual attraction and repulsion that the particles have for each other, and fermentation, and were, so Newton believed, "capable of holding identical particles in a sufficient variety of patterns to explain all the manifold diversity of Nature" (Thackray 1970:15). Between the gravitating bodies are particles of a rarified medium, or aether, which are the repelling force. Similar particles also account for the force which deflects the light through a prism (Cantor and Hodge 1981:1-2). In addition, these forces were also capable of alchemical

transmutation, i.e., "every body can be transformed into a body of another kind, and can take on all the intermediate grades of qualities" (Newton, quoted in Koyre 1965:14). This, from the first edition, was modified in the 1713 edition and that modified in the 1729 edition, reflecting shifts in Newton's thought.
In other words, there are two trends: The panmathematism of **Galileo** and **Descartes** and the empirical, experimental 'corpuscular philosophy' of **Gassendi**, **Roberval**, **Boyle**, and **Hooke**. "From this perspective...**Newton** presents us with a synthesis of both trends, of both views" (*Ibid*.:12). As for Newton's particles *vis à vis* **Huygens**' waves, it was not understood until the nineteenth century that these conceptions were not contradictory but complementary.
In 1690, **Papin** invented a pump with a piston raised by steam.
In 1690, John **Locke**, in *Essay Concerning Human Understanding*, repudiated the traditional notion of innate ideas and described the mind at birth as a *tabula rasa*, or blank slate, upon which the world describes itself through the experience of the five senses. He also dealt with the probability of inferences. In the same year, he published *Two Essays on Civil Government*, in which he maintained that it is the nature of man to be good, the state is formed by a social contract, and each man has the right to the product of his own labor.
About 1692, **Newton** wrote *De Natura Acidorum* in which he set up a hierarchy from irreducible particles to particles of the first and second composition, and claimed that "if the particles of the first, or perhaps of the second composition of gold could be separated, that metal might be made to become fluid, or at least more soft. And if gold could be brought once to ferment and putrefie, it might turn into any other body whatsoever" (Newton, quoted in Thackray 1970:24).
In 1693, **Ray**, in *Synopsis of Quadripeds and Snakes,* disproved **Descartes**' claim that animals are unconscious.
In 1693, Edmund **Halley** discovered the formula for the focus of a lens: If *o* is the distance of the object from the lens, *i* is the distance of the image, and *f* is the distance of the focus, then $^1/_o + ^1/_i = ^1/_f$.
In 1694, Rudolph Jakob **Camerarious**, in *De Sexu Plantarum Epistola*, reported the existence of sex in flowering plants.
In 1698, Thomas **Savery** patented an engine which produced a vacuum by condensing steam. It was employed for raising water from a mine and supplying water to several country houses.
In 1704, **Newton**, in *Opticks*, presented his discoveries using light and elaborated his theory that it was composed of particles. These particles, he assumed, were composed of uniform matter and space but of varying density depending on the amount of space between the particles. Writing of **Huygens** work with calcite where light has 'sides,' Newton found "an analogy between the two *sides* of the light beam and the two ends of a magnet that constitute its *poles* [and called] this property *polarized* light" (Fisher 2001:362). He also inferred from the cohesion of "homogeneal hard Bodies...that their Particles attract one another by some force which in immediate contact is exceedingly strong" (Newton 1730:388-389).
In 1704, Johann Sebastian **Bach** began composing music--music which was related to the musical consequences of the Pythagorean-Platonic proportional number systems, i.e., "the creation of the universe according to...the *Timaeus*, the best exposition of the numerical world-order Bach intended to depict" (Humphreys 1983:30-13). This was the same year in which **Newton**, in *Opticks*, chose to add 'indico' to the spectrum of violet-blue-green-yellow-orange-red because "he wants the colors to correspond to the seven notes of the [Pythagorean] music scale" (Park 1990:264).
In 1705, **Halley**, in *Synopsis of Cometary Astronomy*, observed that the comet which had appeared in 1682 was the reappearance of comets which had appeared in 1531 and 1607 and predicted its reappearance in 1758.
In 1708, Hermann **Boerhaave**, in *Institutiones Medicinae*, recommended the Hippocratic method of bedside instruction and post-mortem examination where, for example, the relation between lesions and symptoms could be studied.
In 1709, Gabriel Daniel **Fahrenheit** constructed an alcohol thermometer and, five years later, a mercury thermometer.
In 1710, Jean **Bernoulli** pointed out that **Newton** had not proved **Kepler**'s law of ellipses but only its converse and did so himself using calculus, solving "the general problem by reducing it to the same integral that is used to solve it today" (Park 1990:416).
In 1710, George **Berkeley**, in *Principles of Human Knowledge*, attacked **Newton**'s notion of 'absolute space.' He believed that qualities, not things, are perceived and that perception is relative to the perceiver.

In 1713, **Newton**, in a new edition of *Principia*, introduced the electric effluvium or aether as a "subtle, all-pervasive spirit, by whose 'force and action' material particles 'attract one another at near distances..., as well repelling as attracting the neighboring corpuscles' " (Newton, quoted in Heilbron 1979:239).

In 1713, Jakob **Bernoulli**, in *Ars conjectandi*, expounded the theorem that, in an increasing number of binary trials, an increasing proportion of the total probability is concentrated in the neighborhood of the original probability of success in a single trial. Bernoulli's theorem forms today the simplest case of the Laws of Large Numbers.

In 1714, **Leibniz**, in *Monadology*, said that the Universe's ultimate constituents are 'monads,' simple substances, each of which perceives the Universe from a different point of view. Their perceptions are harmonius, and what is needed, he said, is a mathematics which will demonstrate the universality of the relations between these points of view.

[In 1714, the British parliament set up the **Board of Longitude**, consisting of scientists, naval officers, and government officials, which was "perhaps the world's first research and development agency" (Sobel 1995:54). The Board was empowered to make financial awards in pursuit of a means to determine longitude at sea. The two competing methods were astronomical calculation, which meant plotting the position of the moon against known stars, and by chronometer, which meant timing the position against a known land longitude.]

In 1715, Thomas **Fairchild** produced the first artificial hybrid plant.

In 1715 and 1716, **Leibniz** corresponded with Samuel Clarke to whom he strongly criticized the philosophy and the theological implications of **Newton**'s work. "The parts of space are not determined and distinguished, but by the things which are in it;" "instants, considered without things, are nothing at all" (Clarke 1717:78, 27). In other words, Leibniz sees space and time as orders of coexistent and successive phenomena, not real substances but rather relations.

In 1717, Jean **Bernoulli** propounded the 'Principle of Virtual Displacements: "Any time there is a state of equilibrium of given forces..., then, the sum of the positive energies will be equal to the sum of the negative energies taken positively" (Bernoulli, quoted in Duhem 1905:432).

In 1718, Louis **Joblot** demonstrated that the microorganisms observed in solutions were the result of being brought in from the ambient air, which confirmed **van Leeuwenhoek**'s conclusion.

Beginning in 1718, Mary Wortley **Montagu** publicized the use of inoculation against smallpox in Turkey.

In 1718, **Halley** said that stars move, i.e., they are not fixed to a single framework, since they had changed position since **Ptolemy**'s *Almagest*.

In 1718, Abraham **de Moivre**, in *Doctrine of Chances*, said chance can neither be defined nor understood, but probabilities could be calculated.

In 1720, Wilhelm Jacob van **'sGravesande** began the publication of the first modern survey of physics, *Physices elementa mathimatica experimentis confirmata, sive introductio ad philosophiam newtonianam*, in which he took physics to be a branch of mathematics. Of electricity he said that it is that "Property of Bodies by which they attract, and repel lighter Bodies at a sensible distance" ('sGravesande, quoted in Heilbron 1979:241).

In 1725, John **Flamsteed** completed the *Historia coelestis Brittannica*, a star catalogue far more accurate than its predecessors.

In 1725, Giovanni Battista **Vico**, in *Principi di Scienza Nuova*, maintained that history is a man-made account of societies and their institutions.

In 1727, George **Graham** and Anders **Celcius**, independently, determined that a disturbance on the sun was a magnetic storm.

In 1727, Stephen **Hales** studied the ascent of water in plants and applied physical principles to the study of plant physiology.

In 1728, Pierre **Fauchard**, in *The Surgeon Dentist*, described preventive measures to keep teeth healthy as well as inventing the word 'dentist.'

In 1729, Stephen **Gray** discovered electrical induction, which he called 'communication,' and announced it in 1732. He also distinquished between conductors and insulators (Heilbron 1979:245-249).

In 1729, James **Bradley** announced his discovery of the aberration of starlight, which is occasioned through the joint effect of the Earth's motion and the non-instantaneous transmission of light. His efforts to gauge the distance to the stars provided the first concrete evidence that the Earth moves through space and also the true value of the speed of light, improving on **Roemer**'s estimate.

In 1730, George **Brandt** discovered cobalt.

In 1730, Charles François de Cisternay **Dufay** found that "almost everything except metals and very hard gems could be made phosphorescent" (Heilbron 1979:251).

In 1731, John **Hadley** and, independently, Thomas **Godfrey** built reflecting quadrants by which the elevation of two celestial bodies and the distance between them could be measured at sea. This instrument, by adding a telescope and a wider measuring arc, quickly evolved into the sextant.

In 1733, **Hales** measured blood pressure.

In 1733, Chester More **Hall** built an achromatic compound lens using glasses with different refractive indexes.

Beginning in 1733, **Dufay**, in *Mémoires sur l'électricité*, summarized and generalized what was known about electricity: E.g., that all materials, except metals and those too soft to rub, can acquire electricity and all materials, especially metals, can "display the virtue after *contact* with an excited electric" (Heilbron 1979:252). This latter principle became known as 'Dufay's rule.' ' He made discoveries, e.g., "objects with dissimilar electrifications attract, those with like electrifications repel," but his explanations were transient (*ibid*.:254-260).

In 1733, John **Kay** patented the flying shuttle loom.

In 1734, David **Hume**, in *A Treatise on Human Understanding*, described the mind as a bundle of perceptions, causal relation as the conjunction of two events, and and apparent sequence of events as, in fact, a sequence of perceptions. Thus the connections which science establishes are "entirely arbitrary," and the "utmost effort of human reason is to reduce the principles, productive of natural phenomena, to a greater simplicity" (Hume 1738:30).

In 1736, Leonhard **Euler**, in *Mechanica*, solved the Königsberg Bridge Problem, that is, whether it were possible to perambulate the seven bridges of Königsberg without retracing one's steps. He did so by means of the first graph theoretic model ever published. His theorem is this: To be traversable every pair of points, or in this case land areas, can reach each other, and the number of lines, or bridges, is even.

In 1736, John **Harrison** finished building and tested at sea what proved to be the first accurate chronometer for timing longitude.

[By 1737, fifty years after the publication of **Newton**'s *Principia mathematica*, the opposition to Newtonism had crumbled away. "The uncommon incomprehensibility became a common incomprehensibility," as Ernst **Mach** expressed it (Mach, quoted in Koyré 1965:17). The real world is no longer "conceived as a finite and hierarchically ordered...whole, but as an open, indefinite, and even infinite universe, united not in its immanent structure but only by the identity of its fundamental contents and laws...; a universe in which...astronomy and physics became interdependent and united because of their common subjection to geometry. This, in turn, implies the disappearance...from scientific thought of all considerations based on value, perfection, harmony, meaning, and aim" (*ibid.*:7). "The Newtonian law of attraction...is not only the only law of that kind that explains the facts but, besides, is the only one that can be uniformly and universally applied to large and small bodies, to apples and to the moon. It is the only one, therefore, that it was reasonable for God to have adopted as a law of creation" (*ibid*.:15). "If order and harmony so obviously prevailed in the world of nature, why was it that, as obviously, they were lacking in the world of man? The answer seemed clear: disorder and disharmony were man-made.... The remedy seemed clear too: let us go back to nature, to our own nature, and live and act according to its laws.... So strong was the belief in 'nature,' so overwhelming the prestige of the Newtonian (or pseudo-Newtonian) pattern of order arising automatically from interaction of isolated and self-contained atoms, that nobody dared to doubt that order and harmony would in some way be produced by human atoms acting according to their nature, whatever that might be--instinct for play and pleasure (**Diderot**) or pursuit of selfish gain (A. **Smith**)" (*ibid*.:22).]

In 1738, Daniel **Bernoulli**, in *Hydrodynamica*, asserted the principle that as the speed of a moving fluid increases, the pressure within the fluid decreases.In the process of determining this, he invented the 'molecular theory of gases,' now known as the 'kinetic theory of gases,' which introduced the notion that the gas particles were moving around rapidly, colliding and rebounding according to the laws of elementary mechanics; i.e., a gas's temperature is a function of the average speed of its particles.

In 1738, François Marie Arouet de **Voltaire**, in *Éléments de la philosophy de Newton*, contributed to the popularization of science and Newton's views.

In 1742, Jean Le Rond **D'Alembert** introduced the principle which permitted the reduction of a problem in dynamics to one in statics: Kinetic equilibrium is obtained by inventing a fictional force equal in magnitude to the body in question and opposite in acceleration. This showed that **Newton**'s Third law of motion applies also to bodies free to move.

In 1742, Pierre Louis Moreau de **Maupertius**, in *Discours sur la Figure des Astres*, observed that the nebulous stars, or 'nebulae,' "present the figure of ellipses more or less open" (Maupertius, quoted in Kant 1755:50).

In 1742, Jean **Bernoulli**, in *Opera omnia*, proved that the orbits of objects bound by the inverse square force are conic sections.

In 1742, **Celcius** developed the centigrade temperature scale which carries his name.

In 1744, Guillaume François **Rouelle** described his neutral saline theory, namely, that salt consisted of a generic component, a chrystalline acid, and a specific component, or whatever substance served to coagulate the acid into a solid.

In 1744, Georges Louis Leclerc de **Buffon** announced that the earth had developed for at least 75,000 years.

In 1744, a 1679 letter from **Newton** to **Boyle** was published which described aether in terms of the resistence of the air pushed aside when two glass panes were pushed together and which once together were held thus by the surrounding aether. British electricians took this to be the latest word on electrical attraction and repulsion (Heilbron 1979:69).

In 1745, **Maupertius**, in *Venus Physique*, proposed the notion of descent from a common ancestor. He also proposed that particles from all parts of the body were gathered in the gonads.

In 1745, Charles **Bonnet** demonstrated the regenerative ability of annelid worms.

In 1746, **Bonnet** discovered that aphids are parthenogenic.

In 1746, Étienne Bonnet de **Condillac**, in *Essai sur l'origine des connaissances humaines*, developed the theory that all knowledge comes from the senses and there are no innate ideas.

In 1746, Andreas **Cunaeus** invented the 'Leyden jar,' a form of capacitor. It consists of "a glass jar with a layer of metal foil on the outside and a similar layer on the inside. Contact to the inner foil is by means of a loose chain hanging inside the jar" (*Dictionary of Physics* 2000:264). This contraption created a small current which shocked experimenters who quickly demonstrated that a circuit could be extended to hundreds of people (Heilbron 1979:312-318).

In 1747, Julien **de la Mettrie** argued, in *L'Homme Machine,* that thought was a property of organized matter.

In 1747, Bernard Siegfried **Albinus**, with the engraver Jan **Wandelaar**, published *Tabulae Sceleti et Musculorum Corporis Humani*, a series of illustrations of the human skeleton and successive muscle layers.

In 1747, **Maupertius** showed that the impact of a collision between two objects can be analyzed by the 'principle of least action,' in which the path of the motion will follow that which minimizes the action.

In 1748, **Bradley** announced that there were tiny deviations in the Earth's axis caused by the pull of the Moon.

In 1749, **Buffon** began the publication of the 44 volumes of *Histoire Naturelle*, in which he drew attention to vestigial organs and asserted that species are mutable.

In 1750, Thomas **Wright**, in *An Original Theory or New Hypothesis of the Universe*, described the *Via Lactea*, or Milky Way, as a disc, saying we must imagine the stars "all moving the same Way, and not much deviating from the same Plane, as the Planets in their heliocentric Motion do around the solar body" (Wright 1750:137). Saying that "we have no reason to suppose that the nature of our Sun is different from the rest of the Stars," he took it that there was a great "Multiplicity of Worlds" (*ibid.*:131). He also took the 'cloudy stars' to be 'nebulae,' or "an infinite Number of small Stars" (*ibid.*:101) and speculated that some of these 'spherical' galaxies "may be external Creation," that is, outside the Milky Way, which was at that time considered to be coextensive with the Universe (*ibid.*:177-178).

In 1750, **Euler**, in "Découverte d'un nouveau principe de mécanique," introduced a notation which gives a name and address to every possible point: "Pour trouver le vrai lieu du corps par rapport à chaque instant, on n'aura qu'à le rapporter en même tems à trois plans fixes, qui soient perpendiculaires entr'eux" (Euler 1750:89) (To find the true place of the body at each instant, one only needs to locate it at the same time in respect to the three fixed planes, each perpendicular to the

others).
In 1751, **Maupertius**, in *Système de la Nature*, put forward a theory of pangenesis, in which an embryo contained particles derived from all parts of the parent, and heritable novelties arose from changes in fluids or were induced by the environment.
In 1751, Axel Fredric **Cronstedt** discovered nickel.
In 1751, Benjamin **Franklin** published *Experiments and Observations on Electricity* after several years of experiments done with several friends. In this book Franklin suggested an experiment to prove that lightning is a large-scale electrical discharge, a task which later he took upon himself, using a kite. This led to the invention of the lightning rod. In Franklin's theory of electricity, "positively electrified bodies repel one another via short-range forces between the particles of their respective atmospheres." Such an 'atmosphere,' or "aura of electrical matter" is a once the 'charge,' an aether, and the source of the 'electric field' (Heilbron 1981:190), and flowed from the more highly charged body to the less highly charged, on analogy to hydrodynamical principles (Cantor and Hodge 1981:30). He invented many the terms which are still used: positive, negative, conductor, battery, etc.
In 1752, René Antoine Ferchault de **Réaumur** showed by experiment that gastric juice liquifies meat.
In 1752, James **Lind** called attention to the value of fresh fruit in the prevention of scurvy.
In 1752, Thomas **Melvill** noticed that "the spectra of flames into which metals or salts have been introduced show bright lines characteristic of what has been introduced" (*History of Optics* 2001:3).
In 1752, **Euler** published the proof of the equation relating the number of faces, edges, and vertices of a polyhedron, $f+v=e+2$.
In 1753, Carl **Linné**, better known as Carolus Linneas, published *Species plantarum*, in which he distinguished plants in terms of genera and species.
In 1753, **Albinus** and **Wandelaar** published *Tabulae Ossium Humanorum*, an anatomical study of bones.
In 1753, **Euler**, in *Theoria motus lunae*, attempted to solve by analytic function the motions of three interacting bodies, and, though that is not possible by those means, he succeeded in reducing "the relative movements of the Sun, the Earth, and the Moon to a series of elegant equations" (Sobel 1995:970).
In 1754, Joseph **Black** heated calcium carbonate which separated into calcium oxide and carbon dioide and then recombined back into calcium carbonate. He called carbon dioxide 'fixed air' because it could be fixed into solid matter.
In 1754, Nicolas Louis de **Lacaille** returned from the Cape of Good Hope where in a four year period he made nearly two thousand additions to the star catalogue.
In 1754, **D'Alembert**, in the *Encyclopédia* article "Différentiel," said that the term 'infinitesimal' meant, not infinitely small, but indefinitely small: "A quantity is something or it is nothing." He called one quantity the limit of another if the difference is absolutely unaccountable. "The ratio of the first of these quantities to the second is always much smaller than the second quantity as is the latter than a given quantity" (D'Alembert, quoted in Boyer 1949:249). This test for convergence is known as 'D'Alembert's ratio.'
In 1755, **Maupertius**, in *Essai de Cosmologie*, wrote, "In the fortuitous combinations of the productions of Nature..., only those with certain adaptive relationships could survive.... In the other, infinitely greater part, there was neither adaption nor order. All these have perished...and the species we see today are only the smallest part of those which a blind destiny produced" (Maupertius, quoted in Hardy 1965:53).
In the 1755, **Buffon**, in a new edition of *Histoire naturalle*, suggested that species were directly subject to moulding by their environment, and that these changes were perpetuated by heredity.
In 1755, Immanuel **Kant**, in *Allgemeine Naturgeschichte und Theorie des Himmels*, said that "the chaos begins to take form at the points where the more strongly attracting particles are [and fashions] itself by a natural evolution" into stars and planetary systems (Kant 1755:62), conjectured "that new planets will perhaps yet be discovered beyond Saturn" (*ibid.*:55), and asserted his belief that "most of the planets are certainly inhabited and those that are not, will be at one time" (*ibid.*:xx), in other words, that if life is supportable, it will occur. Kant is reputed to have been the first to describe nebulae as 'island universes.'
In 1755, Johann Tobias **Mayer**, grasping "an advance that applied directly to the longitude problem..., created the first set of lunar tables for the Moon's location at twelve-hour intervals" (Sobel 1995:97).

In 1756, Franz Ulrich Theodosius **Aepinus**, while studying the electrical properties of a 'Tourmaline crystal,' was struck by its analogy to a magnetized piece of iron and realized that "the causes of magnetic and electrical phenomena were extremely similar" (Aepinus 1759:238). This led him to generalize the principle of the Leyden jar to include any 'capacitator,' two conducting plate separated by an insulator. That "made it impossible to maintain the theory of literal atmospheres [and necessitated the admission] that similarly charged bodies repell and dissimilarly charged bodies attract one another" (Heilbron 1979:388).
In 1757, **Black** discovered latent heat, i.e., he distinguished between heat and temperature.
In 1757, **Harrison** completed his third timekeeper. The numerous innovations include a bi-metallic strip which compensates for temperature change and caged ball-bearings to eliminate friction.
In 1758, **Linné** published the 10th edition of *Systema Naturae*, where he applied the genera and species system to animals based on their external appearance.
In 1758, Ruggero Giuseppe **Boscovich** (or Rudjer Boskovic), in *Philosophiae naturalis theoria: redacta ad unicam legam virium in natura existentium*, claimed that "the particle...is not a thing at all but only a force. All its actions are actions at a distance, repulsive at short distances and attractive at long ones" (Park 1990:201). "The force varies in a continuous fashion from attractive to repulsive and back to attractive. The number of such variations can be multiplied at will to account for phenomena. [Combinations of the centers of force, or points or atoms, yield] the chemical elements, combinations of elements [yield] the chemical compounds, and so on. Ultimately, then, all 'matter' is one; observable complexities [are] the result of successive levels of complexity of particulate arrangements" (L. Williams 1976:529). By defining "force solely in terms of a mathematical function describing the change of motion," Boscovich had no intention of examining "the ultimate nature of force" (Cao 1997:26), the truth being unattainable according to his Lockean natural philosophy.
In 1758, Alexis Claude **Clairaut** conjectured that **Halley**'s comet might be subject to unknown forces, such as another comet or unknown planet.
In 1759, Caspar Friedrich **Wolfe** examined the developmental anatomy of chick embryos and observed that the different organic systems were formed successively; in other words, that specialized organs develop out of unspecified tissue.
In 1759, Mikhail Vasilevich **Lomonsov** said the earth's topography was the result of very slow natural activity, including uplift and erosion.
In 1759, **Aepinus**, in *Tentamen theoriae electricitatis et magnetismi*, says that the forces exerted by electricity "repel each other mutually even over rather large distances," but he does "not approve the doctrine which affirms the possibility of action *in distans*.... [He does] not consider either the repulsive force discovered here, or the attractive force called universal gravity, to be forces inherent in matter [but rather] each force arises from some extrinsic cause" (Aepinus 1759:241,240,259). When he uses the words vortex and atmosphere, he says he is only denoting "the sphere of activity" (*Ibid*.:392). He designed the requisite theory-laden experiments to prove that "induction played an important role in even this simplest of all electrical phenomena" (Home 1979:121). Probably under **Euler**'s influence, he introduced algebra to the study of electricity. Few of Aepinus' ideas penetrated the thoughts of most electricians before the late 1770s and by then, it was considered, and is still considered, that he fathered the action-at-a-distance/localization of charge theory of electricity and magnetism.
In 1759, the return of **Halley**'s comet confirmed **Newton**'s mechanics.
In 1761, Giovanni Battista **Morgagni** published a book which recommended studying body's organs rather than its parts, and proposed that the symptoms of disease resulted from pathological changes in the organs.
In 1761, Johann Heinrich **Lambert**, in *Cosmologische Briefe über die Einrichtung des Weltbaues*, arrived, independently of both T. **Wright** and **Kant**, at the idea that we live in an ordinary galaxy.
Between 1761 and 1766, Joseph Gottlieb **Kölreuter** published accounts of 136 experiments in artificial hybridization and drew the conclusion that inheritance was quantitative.
In 1761, **Euler**, in *Lettres à une Princesse d'Allemagne*, writing of the aether-filled pores in a lodestone, said "ces pores sont disposés de manière à avoir communication entre eux, et costituent des tuyaux ou canaux par lesquels la matière magnétique passe d'un bout à l'autre" (Euler 1789:453). [These pores are disposed in a manner to have communication between them, and constitute tubes or canals through which the magnetic material passes from one end to the other.]
In 1762, Marcus Antonius **Plenciz**, in *Opera medico-physica*, said that living agents were the cause of infectious diseases.

In 1762, Johan Carl **Wilke** designed a dissectible condenser, a precursor of the 'electrophorus,' or electrostatic generator, a device to build up an electric charge. Explaining his theory, he distinquished "between the *communication* of electrical matter and the *segregation* of the normal supply of one body by the action of the atmosphere of another" (Heilbron 1979:419).

In 1763, Thomas **Bayes**, in an essay on the doctrine of chances, attempted to establish the rule that the probability of an event in no way depends on any prior observations.

In 1764, James **Hargreaves** invented the spinning jenny.

In 1765, Lazzaro **Spallanzani** reconfirmed **Joblot's** results and extended them, establishing that microbes are never spontaneously generated. Nonetheless, spontaneous generation continued to find adherents until Louis **Pasteur's** 1862 paper.

In 1766, Nevil **Maskelyne**, in the *Nautical Almanac and Astronomical Ephemeris*, introduced the determination of longitude by lunar distances and calculated these annually until he died in 1811.

In 1766, Johann Daniel **Titius** said that if one took "the Earth's distance from the Sun as 10, the mean radial distances of the planets [are] almost exactly proportional to the terms of the expression $4 + 3 (2^n)$" (Grosser 1979:27). In 1772, Johann Elert **Bode** began publicizing Titius' insight to the extent that it became known as Bode' law (though it is not, being neither invariant nor universal).

In 1766, Henry **Cavendish** isolated and described 'inflammable air,' later named hydrogen by Antoine Laurent **Lavoisier**, and distinguished it from carbon dioxide.

In 1768, **Euler** proposed that the wave length of light determines its color.

In 1769, James **Watt** patented a new type of steam engine with a separate condensing chamber and an air pump to bring steam into the chamber and equipped it with a simple 'governor' for safety: if the engine started to go too fast, the power would be automatically cut back. He coined the term 'horsepower' and later loaned his name to the unit of power, or work, done per unit of time.

In 1769, Denis **Diderot**, in *Le Rêve de **D'Alembert***, dealt with, among other things, animal reproduction, mutation, eugenics, the mechanical system of the body, and the nervous system.

In 1770, **Lambert**, in *Vorlóufige Kenntnisse für die, so die Quadratur und Rectification des Circuls suchen*, provided a mathematical proof that the ratio of the circumference of a circle to its diameter, or π, is an irrational number.

In 1771, **Cavendish**, in "An Attempt to explain some of the Principle Phaenomena of Electricity by Means of an Elastic Fluid," observed that "a body can be both positively electrified and undercharged or, to use modern terminology, to have a positive potential and a net negative charge" (Heilbron 1979:481). He dispensed with aether and made do with "localized charge, actions at a distance between elements of the electric fluid, and even repulsions between the particles of common matter" (*Ibid*.:478).

In 1772, Daniel **Rutherford** described nitrogen, which he called 'residual air.'

About 1773, Karl Wilhelm **Scheele** isolated oxygen from silver carbonate, but did not publish his discovery until later than Joseph Priestly. He also showed that nitrogen was a constituent of air, and isolated glycerol and numerous acids including tartaric, lactic, uric, prussic, citric, malic, and gallic.

After 1773[?], Otto Frederik **Müller** distinguished two types of bacteria, bacillum and spirillum.

Between 1773 and 1776, James Burnett **Monboddo** published a three-part work, *On the Origin and Progress of Language*, that argued for an evolutionary view of human origins, and contemplated educating orang-outangs.

In 1773, David **Bushnell** designed and built the first submarine, the *Turtle*, a diving-bell-like craft, which seated one-man who propelled it with a hand-crank.

Before 1774, **Priestly** discovered sulphur dioxide, ammonia, and 'dephlogisticated air,' later named oxygen by **Lavoisier**.

In 1774, Franz Anton **Mesmer** began the psychotherapeutic practive of hypnotism, which he called 'animal magnetism' and conceived it to be an actual fluid. Apparently he had some success with psychosomatic illnesses. Part of his technique seems to have been used earlier by exorcists.

In 1774, **Lavoisier** recognized that the gas 'fixed air,' or carbon dioxide, was a chemical and produced it by combining oxygen with carbon obtained from charred vegetables. In subsequent papers, the main idea was that combustion processes, including vegetative metabolism and fermentation, took place by the decomposition of water which supplied the oxygen. The addition of oxygen to the organic substances accounted for their weight increase.

Beginning in 1774, Pierre Simon **Laplace**, with "Mémoire sur la probabilité des causes par les événements," set out to establish 'probability' as the mathematical basis "for statistical inference, philosophic causality, estimation of scientific error, and quantification of the credibility of evidence, to use terms not then coined" (Gillispie 1976:280). Forty years later, he wrote *Essai philosophique sur les probabilités* to serve as an introduction to the second edition of *Théorie analytique des probabilités*, both intended to be read by laymen.

In 1775, Johann Friedrich **Blumenbach** published *De generis humani varietate nativa*, which marked the beginnings of physical anthropology.

In 1775, Alessandro **Volta** invented the 'electrophorus' and **Wilcke** explained the theory of its operation.

In 1775, John **Landen**, in an article in the *Philosophical Transactions of the Royal Society*, demonstrated that "every arc of a hyperbola can be measured by two arcs of an ellipse.... The term 'Landen's theorem' was applied not only to this result but also to the first known transformation of elliptic integrals" (Itard 1976:139).

In 1776, **Cavendish**, in "Some Attempts to imitate the Effects of the *Torpedo* [an electric eel] by Electricity," demonstrated that "by multiplying the number of [a battery's] elements one can preserve the stroke while decreasing the electrification" (Heilbron 1979:489). This was a continuation of his research into the comparative 'resistance' of solutions, never published, where he "established that fresh water resisted 100 times better than salt" (*Ibid*.:487).

In 1776, Adam **Smith**, in *The Wealth of Nations*, advanced the idea that businesses survive through successful trading in pursuit of their self-interest, and that the resulting equilibrium was not by design.

In 1778, Joseph **de Herbert**, in *Theoriae phenomenorum electricorum*, wrote, "Electrical actions do not originate in the transition of fluid from a body with a surplus to one deficient, but...by action at a distance" (Heilbron 1979:425).

In 1779, Jan **Ingelhousz** showed that plants use carbon dioxide and that they require light in order to produce oxygen.

In 1780, **Spallanzani** demonstrated that contact between the sperm and egg is necessary for fertilization.

In 1780, **Lavoisier** and **Laplace** developed a theory of chemical and thermal phenomena based on the assumption that heat is a substance, which they called 'caloric' and deduced the notion of 'specific heat,' which they expressed in terms of the heat absorbed in raising one pound of water one degree. They also concluded that respiration is a form of combustion.

In 1781, **Cavendish** synthesized water by exploding hydrogen in oxygen.

In 1781, Frederick William **Herschel** discovered the planet Uranus by its movement, although at the time he supposed it to be a comet. Later the same year, Anders Johann **Lexell** concluded that it was a planet. The radius predicted by **Bode**'s law agreed within two percent of the observed radius. Earlier, it had many times in various locations been identified as a star.

In 1781 and 1787, **Kant**, in *Kritik der reinen Vernunft* (*Critique of Pure Reason*), said that reason's function is to synthesize sense data, a process in which the mind relies on certain intuitive principles, such as causality, which, since they cannot be induced from sense data, "must be 'a priori,' i.e., logically prior to the materials which they relate.... These formal elements [are] 'transcendental'.... They transcend or are distinct from the sensuous material" (*Dictionary of Philosophy* 1984:175). In other words, Kant turned the object of philosophy from modes of being, or ontology, to ways of knowing, or epistomology, and space and time into forms for the intuitive representation of objects.

In 1782, Peter Jacob **Hjelm** discovered molybdenum.

In 1783, **Spallanzani** said that digestion is not merely chewing but is a chemical process.

In 1783, Lazare Nicolas Marguerite **Carnot**, in *Essai sur les Machines en Général*, specified the optimal and abstract conditions for the operation for all sorts of actual machines. In this subject it was "the first truly theoretical treatise. A machine is an intermediary body serving to transmit motion between two or more primary bodies that do not act on one another.... Wishing to attribute to machines no properties except those common to all parts of matter, Carnot envisaged them as intrinsically nothing more than systems composed of corpuscles [in which] the net effect of mutual interaction among the corpuscles constituting the system is zero" (Gillispie 1976:72,73). He also introduced the idea of 'geometric motion,' or 'displacement,' what in later mechanics was called 'virtual displacement.'

In 1783, John **Michell** pointed out that a star that was sufficiently massive and compact would have such a strong gravitational field that light could not escape.

In 1783, Joseph Michel **Montgolfier** and Jacques Étienne **Montgolfier** invented the first practical hot air balloon. Later the same year, Jacques Alexandre César **Charles** became the first person to

ascend in a hydrogen balloon, for which he "invented the valve line (to enable the aeronaut to release gas at will for descent), the appendix (an open tube through which expanded gas could escape, thus preventing rupture of the balloon sack), and the nacelle (a wicker basket suspended by a network of ropes covering the balloon and held in place by a wooden hoop)" (Gough 1976:208).
In 1784, John **Goodricke** identified *Delta Cephei* as a variable star.
In 1785, **Laplace**, in *Théorie des attractions des sphéroides et la figure des planètes*, reformulated the theory of gravitating bodies, building it around a function *V*, the "integral of the quotients of the gravitational mass *dm* [divided] by their respective distances from the point *P* at which *V* is to be computed.... The function *V* simplified the calculations...by allowing work with a scalar, additive quantity, rather than with force" (Heilbron 1979:498). Laplace also encouraged his theory's application to electricity.
In 1785, Charles Augustin de **Coulomb**, in "Oú l'on détermine suivant quelles lois le fluide magnétique ainsi que le fluide électrique agissent," said that "the reciprocal attraction of the electrical fluid called *positive*, on the electrical fluid ordinarily called *negative*, is in the inverse proportion of the squares of the distances" (Coulomb, quoted in Heilbron 1979:473).
In 1785, Adrien-Marie **Legendre**, in "Recherches sur la figure des planètes," made "an account of the law of reciprocity of quadratic residues and [stated] a theorem which later became famous: Every arithmetical progression whose first term and ratio are relatively prime contains an infinite number of prime numbers" (Itard 1976:135).
In 1786 and 1787, **Coulomb**, in "Oú l'on démontre deux principles propriété du fluide électrique" and "Sur la manière dont le fluide électrique se partage entre deux corps conducteurs mis en contact," said that the electrostatic force between two charged bodies is proportional to the product of the amounts of charge on the bodies divided by the square of the distance between them. "He represented the distribution as the varying density of one or the other electrical fluid," which density he arrived at by using torsion beams, 'proof planes,' and accounting for leakage (Heilbron 1979:494-495).
In 1786, **Kant**, in *Metaphysische Anfangsgründe der Naturwissenschaft* (*Metaphysical Foundations of Natural Science*), suggested the doctrine of the unity and convertibility of forces.
In 1786, **Franklin**, in *Maritime Observations*, published a chart of the Gulf Stream.
In 1787, **Charles** determined by experiment that "the volume of a fixed mass of gas at constant pressure is proportional to its thermodynamic temperature" (*Dictionary of Physics* 2000:70). This was published by Joseph Louis **Gay-Lussac** in 1802.
In 1787, **Herschel** discovered the two largest satellites of Uranus and, two years later, the Saturnian satellites *Mimas* and *Enceladus*. His observations of double stars established that many are in orbit around each other.
In 1788, Jean **Senebier** demonstrated that it is light, not heat, from the sun that is effective in photosynthesis.
In 1788, Joseph Louis **Lagrange**, in *Mécanique analytique*, developed that part of mechanics which deals with particles and rigid bodies using procedures general enough that they were, and still are, applicable to all calculations. **Newton**'s "dynamical theory contains truth but not method. Lagrange's *Mécanique* is a method. First, one looks to see whether the system under analysis has a symmetry of some kind.... Corresponding to any symmetry there is some dynamical quantity that remains constant." Thus, often the solution to an equation "follows at once from the existence of the symmetry," which is called a 'Lagrangian' (Park 1990:248-249). This work is presented solely by algebra and calculus, with no diagrams and no geometry.
In 1789, Antoine Laurent de **Jussieu,** in *Genera Plantarium*, stressed the significance of the internal organization of organisms.
In 1789, **Lavoisier** proved that mass is conserved in chemical reactions and created the first list of chemical elements. This classification is the basis of the modern distinction between elements and compounds. He also demonstrated that glucose itself could be fermented and was made up of ethanol and carbon dioxide.
In 1789, Jean Baptiste Joseph **Fourier**, in a paper submitted to the *Académie des sciences*, explicated his discovery of a new proof of **Descartes**' rule of signs, $f(x)$. "The details of the proof may be seen in any textbook dealing with the rule, for Fourier's youthful achievement quickly became the standard proof" (Ravetz and Grattan-Guinness 1976:99).
In 1789, Jeremy **Bentham** reoriented semantics "whereby the primary vehicle of meaning came to be seen no longer in the term but in the statement, [that is,] as the unit accountable in the empiricist

critique" (Quine 1953:39,42).
In 1790, **Kant**, in *Kritik der Urtheilskraft*, said that the analogy of animal forms implied a common original type and thus a common parent.
In 1790, Johann Wolfgang von **Goethe**, in *Metamorphose de Pflanzen*, sought to discover the 'primal plant,' and coined 'morphology.'
In 1791, Franz Joseph **Gall**, in *Untersuchungen über Natur und Kunst im kranken und gesunden Zustande des Mensch*, described the nervous system as a series of separate but interrelated ganglia. "The inclusion of the cerebral cortex in this scheme was an important development away from lingering glandular and humoral conceptions" (R. M. Young 1978).
In 1791, Luigi **Galvani**, in *De viribus electricitatis in motu musculari*, showed that it was possible to control the motor nerves of frogs using electrical currents, i.e., that the nerves transmitted electricity. He used a measuring instrument of his own invention involving a wire coil around an iron core between the poles of a magnet. The movement of the sides of the coil when a current passes through it causes a measurable deflection of a light beam. This became known as a 'galvanometer.'
In 1791, **Goethe** published "Zur Optik," which led, in 1810, to the publication of *Farbenlehre*, a compendium of chromatic phenomena. He sought a personalized relation to a holistic continuity of inorganic and organic nature which he opposed to Newtonian reductionism's dependence on theoretical constructs.
In 1791, Pierre **Prévost** proposed the theory that when a body is not at the same temperature as its surroundings, heat will flow between them.
In 1792, Jeremias Benjamin **Richter** published his measurements of 'equivalent weight,' that is, how much of a given acid is required to neutralize a given base.
In 1792, T. **Wedgwood** noticed that various materials, when heated, all turn red at the same temperature.
In 1794, Erasmus **Darwin**, Charles' grandfather, proposed that "warm-blooded animals have arisen from one living filament...possessing the faculty of continuing to improve by its own inherent activity, and of delivering those improvements by generation to its posterity." He also suggested that the conflict between males over which "should propagate the species" had the final cause that the species "become improved" (E. Darwin 1794:505,503).
In 1794, Eli **Whitney** patented the cotton gin
In 1795, James **Hutton**, a proponent of the vast antiquity of geological formations, wrote *Theory of the Earth*, the earliest comprehensive treatise which can be considered a geologic synthesis. Confining his attention to the earth's dynamics, he deplored speculative attempts to account for the origin of processes which could be observed in current operation. James **Hall** succeeded in devising experiments which reproduced in miniature the processes which, according to Hutton, are responsible for the formation of rock strata under the conditions prevailing in the earth's crust.
In 1796, Edward **Jenner** investigated the folk tale that milk maids were immune to small pox, the virus *variola major*, and in a brief series of experiments confirmed that exposure to cow pox, the virus *vaccinia*, rendered immunity. The principle that a survivor of a disease such as smallpox or the plague was usually able to resist a second infection had long been observed. By the late eighteenth century, vaccination was understood and employed in Turkey for smallpox. The method involved the inoculation of children on the skin with 'matter' from the pustule of a mild case. In most instances, the child showed mild symptoms and was subsequently immune.
In 1796, **Lagrange** called dynamics a four-dimensional geometry.
In 1796, **Laplace**, in *Exposition du système du monde*, hypothesized that the solar system was created from a spinning cloud of gas. "Gravity pulled most of the gas to the center, thereby creating the sun. At the same time, some of the material, because of its spin, could not be absorbed by the young sun and instead settled into a disk. Eventually these dregs became the planets" (Ray 2000:43). In the nineteenth century, this theory of the origins of the solar system was known as the **Kant**-Laplace theory.
In 1796, Carl Friedrich **Gauss** discovered that the regular heptagon was inscribable in a circle, using only a compass and a straightedge--the first discovery in Euclidian construction in over 2000 years.
In 1797, Frederick Wilhelm Joseph von **Schelling**, in *Ideen zu einer Philosophie der Natur*, said that, while the difference between the forces of mind and nature must be only a matter of degree, nature is subordinate to mind and that knowledge is absorbed in the unity of mind and matter.
In 1798, Thomas Robert **Malthus**, in his *Essay on the Principle of Population*, contended that population increses by a geometric ratio whereas the means of subsistence increase by an arithmetic

ratio.
In 1798, **Cavendish** constructed a torsion balance by which he measured the mean density of the Earth.
In 1799, Joseph Louis **Proust** ennunciated the 'Law of definite proportions,' which he had arrived at by showing that copper carbonate contained definite proportions of copper, carbon, and oxygen, independent of the method of preparation.
In 1799, Humphrey **Davy**, in "An Essay on Heat, Light, and the Combinations of Light," hypothesized that heat was not caloric, as **Lavoisier** had asserted, but was 'motion,' as **Newton** had asserted.
In 1799, **Laplace** began the publication of *Traité de mécanique céleste*, "an encyclopedia of calculations relating to the six known planets and their satellites, to the shapes of the rotating planets, and to the tides in the earth's oceans" (Park 1990:252). *Systéme du monde* served as an outline for this larger work.
In the beginning of the nineteenth century, Franz Joseph **Gall** speculated that the cerebral cortex represented the highest level of the brain and that its development characterized mammals. His aim was to localize cerebral functions by introspection, i.e., phrenology, and theorized that abstract mental functions, such as secrecy or mother love, occur in discrete areas of the cerebral cortex. He further believed that each mental function, that is, each bump on the cortex, would grow through use, on analogy to muscles.
In 1800, Marie François Xavier **Bichat** published the first of several books dealing with the pathology of tissues.
In 1800, Karl Friedrich **Burdach** introduced the term 'biology,' which replaced 'natural history,' which traditionally had three components, zoology, botany, and mineralogy.
Beginning in 1800, **Gall**, with the assistance of Johann C. **Spurzheim**, discovered the origins of the first eight cranial nerves, traced the fibers of the medulla oblongata to the basal ganglia, and, in the cerebral cortex, established the contralateral decussation of the pyramids.
In 1800, William **Nicholson** and Anthony **Carlisle** showed that chemical reactions could be produced by electricity by decomposing water into hydrogen and oxygen in a process which came to be known as 'electrolysis.'
In 1800, **Herschel**, noting a temperature rise on a thermometer placed beyond the visible red light cast by a prism, hypothesized the existence of infrared and of radiant heat.
In 1801, John **Dalton**, in "New Theory of the Constitution of Mixed Aeriform Fluids, and Particularly of the the Atmosphere" and three supplementary papers, formulated, independently of **Charles**, the law of gaseous expansion at constant pressure and the law of gaseous partial pressures which stated that the total pressure exerted by a mixture of gases is equal to the sum of the partial pressure of the individual gases; i.e., "when two elastic fluids, denoted by *A* and *B*, are mixed together, there is no mutual repulsion amongst their particles; that is, the particles of *A* do not repel those of *B*, as they do one another. Consequently, the pressure or whole weight upon any one particle arises solely from those of its own kind" (Dalton, quoted in Thackray 1976:541). Thus did Dalton dismiss the Newtonian gospel of chemical affinity as a force in the atmosphere.
Later in 1801, William **Henry** found that "at a given temperature the mass of gas absorbed by a given volume of water is directly proportional to the pressure of the gas" (Thackray 1976:541). This is known as Henry's law.
In 1801, Thomas **Young**, in "On the theory of light and colors," proposed that light striking the retina creates vibrations and the frequency of the vibrations excites a particular nerve filament, "one for each principle colour" (Young 1802:20). He also made the observation that if light from a single source is split into two beams, then recombined and projected on a screen, dark and light fringes appear. This he interpreted as wave motion: The dark fringes occur when the crest of one beam coincides with a trough of the other. At that time, **Newton**'s particle theory was thought by most physicists to exclude the possibility of light moving in waves. As the transmission medium Young proposed the undulatory motions of aether which he supposed to be an elastic fluid (Cao 1997:28). Aether, according to a contemporary source, "being no object of our sense, but the mere work of imagination, brought only on the stage for the sake of hypothesis, [so] authors take the liberty to modify it as they please" (*Encyclopedia Britannica*, 1797, quoted in Heibron 1981:187).
In 1801, William Hyde **Wollaston** established the equivalence of galvanic and frictional electricity.
In 1801, John **Robison**, in a treatise in the *Encyclopedia Brittanica*, explained electrostatic theory, citing the theories of **Aepinus** and **Coulomb**. About 1770, Robison had devised an apparatus for measuring the force of an electrical charge, but it was published only in 1822.

In 1801, Giuseppe **Piazza** discovered *Ceres*, a 'planetoid,' or asteroid, as it came to be known.
In 1801, Johann Georg **von Soldner**, acting on **Newton**'s assumption that light is a stream of particles, calculated the gravitational effect on light rays from distant stars passing close to the Sun, stating that the position of a star seen near the edge of the Sun should shift relative to where it is seen when the Sun is elsewhere in the sky by 0.84 arcsecond. However, as **Einstein** pointed out, the angle is twice as large: "Half of this deflection is produced by the Newtonian field of attraction of the Sun, and the other half by the geometrical modification ('curvature') of space caused by the Sun" (Einstein, quoted in Wambsganss 2001:66).
In 1801, **Gauss** employed his 'least squares' approximation method, which fits a regression line to a set of data, to calculate the orbit of *Ceres*.
In 1801, **Gauss's** research into infinitesimal calculus and algebra culminated in the publication of *Disquisitions arithmeticae.*
In 1801, Joseph-Marie **Jacquard** invented the punched-card loom.
In 1802, **Wollaston** discovered that the spectrum of sunlight is crossed by a number of dark lines (Wollaston 1802:365-386).
In 1802, Heinrich Wilhelm Matthias **Olbers** discovered *Pallas*, an asteroid in an orbit similar to the of *Ceres*, causing him to hypothesize that they were remnants of an exploded planet. This would fill **Kepler**'s gap and confirm **Bode**'s law. Two more asteroids were discovered in this area: In 1804, *Juno* by Karl Ludwig **Harding**, and, in 1807, *Vesta* by Olbers.
In 1803, L. **Carnot**, in *Principes fondamentaux de l'équilibre et du mouvement*, revised his 1783 book by simplifying the idea of 'geometric motions' to motions which "involve no work done on or by the system," along with the notions that "process consisted in the transition between successive 'states' of a system" and these transitions occur "in infinitesimal and reversible changes" (Gillispie 1976:74,75).
In 1803, **Dalton** , in "The Absorption of Gases by Water and Other Liquids," applied atomic theory to a table of atomic weights. In the common and acceptable sense, an atom was merely "a term for a particle which was divisible only with the loss of its distinguishing characteristics" (Thackray 1976:543), and neither Dalton nor anyone else realized the implications of atomic weights. There was no reaction to this paper which was only intended to explain why water treats different gases differently, that is, to defend his 1801 papers.
In 1803, **Wollaston** discovered the element 'palladium.'
In 1804, Nicholas-Theodore de **Saussure** published a description of the action of photosynthesis.
In 1805, Friedrich **Sertürner** isolated morphine from the poppy plant.
In 1805, Alexander **von Humboldt** noted that species had not arisen at a single place.
In 1805, Ludolf Christian **Treviranus** said that spermatozoa were analogous to pollen.
In 1806, Louis Nicolas **Vauquelin** and Pierre Jean **Robiquet** isolated the first amino acid, 'asparagine,' from asparagus.
In 1806 and 1807, **Laplace**, in supplements to *Traité de mécanique céleste*, described his theory of the production of liquid surface energy in capillaries as the perpendicular inward attraction, exerted on the surface particles by the underlying ones, according to the formula $p = K + \frac{1}{2} H (1/R + 1/R')$, where K is a constant pressure, H is a constant on which all capillary phenomena depend, and R and R' are the radii of the curvature of any two sections of the surface which are at right angles to each other. Surface tension parallel to the surface does not exist.
In 1806, **Gay-Lussac** demonstrated that if an ideal gas expands without doing work, its temperature remains constant.
In 1806, Jöns Jacob **Berzelius**, in a book on animal chemistry, noted that muscle tissues contain lactic acid, previously found by **Scheele** in milk.
In 1806, **Legendre**, in "Nouvelles méthodes pour la détermination des orbites des comètes," invented, independent of **Gauss**, a least squares method and was the first to publish it.
In 1807 through 1812, **Davy**, in successive Bakerian Lectures, approached chemistry as if were the key to the ultimate mysteries of the Universe and concluded that "chemical properties were a function not simply of the components of a substance but also of their relative arrangements. Thus he finally put it beyond doubt that carbon and diamonds were chemically identical; that neither all acids nor all alkalies contained oxygen; and that oxygen enjoyed no unique status as the supporter of combustion [as **Lavoisier** had hypothesized], but that heat was a consequence of any violent chemical change" (Knight 1976:602). He revealed that alkalies and, later, earths were metallic oxides, isolated

potassium, sodium, magnesium, calcium, strontium, and barium, obtained boron and silicon, and proved that chlorine and iodine are elements. He also advanced the theory that hydrogen is generically present in acids, and classed chemical affinity as an electric phenomena.
In 1807, T. **Young**, in *Lectures on Natural Philosophy and Mechanical Arts*, coined the word 'energy,' for the fundamental quantity created by the heat which moved particles in D. **Bernoulli**'s kinetic theory. Also, Young presented experiments which verified that color was created by the wave theory of light and described the eye defect, now called 'astigmatism.'
In 1807, Robert **Fulton** ushered in the era of self-propelled ships with his construction of a commercially viable paddle-wheel steamboat.
In 1808, **Gay-Lussac** ennunciated the 'Law of combining volumes,' which said that when gases combine they do so in small whole number ratios.
In 1808, **Dalton**, in *New System of Chemical Philosophy*, launched the chemical atomic theory, which "reduced all kinds of matter to a finite number of elements (only eighteen in those days)" (Cercignani 1998:203). He postulated the radical notion that atoms can neither be created nor destroyed and that all atoms of an element were identical. He showed how "the laws of chemical combination demanded the existence of atoms, [and is] generally regarded as the founder of the atomic hypothesis" (Glashow 1991:101). After this the main thrust of his work was in "providing experimental measurements of atomic weights of known chemical compounds" (Thackray 1976:543).
In 1808, **Gauss**, in *Theoria motus corporum coelestium in sectionibus conicis solem ambientum*, found methods of determining an orbit from at least three observations. It also contained his presentation of the least squares method.
In 1809, Jean-Baptiste Monet de **Lamarck**, in *Philosophy Zoologique*, stated that heritable changes in 'habits,' or behavior, could be brought about by the environment, that acquired characters could be achieved by selective breeding, and that the use and disuse of parts could lead to the production of new organs and the modification of old ones. His knowledge was much broader than E. **Darwin's** and he was the first important proponent of evolution, that is, that species, including man, were mutable over generations and adaptible to changed environments.
In 1809, T. **Young** applied wave theory to refraction and dispersion phenomena which led to a description in terms of transverse vibrations. In turn, this led to raising questions about the nature of aether since it was assumed to be fluid-like: Fluids can't transmit transverse waves.
In 1810, **Wollaston** isolated a second amino acid, 'cysteine,' from a bladderstone.
Between 1810 and 1819, **Gall** published four volumes entitled *Anatomie et physiologie du système nerveux en général, et du cerveau en particulier, avec des observations sur la possibilité de reconnoitre plusiers dispositions intellectuelles et morale de l'homme et les animaux, par la configuration de leurs têtes*. This book established psychology as a biological science, but the popular application of his theories in the form known as 'phrenology,' i.e., every aspect of behavior had its own organ which correlated with prominences on the the skull, eventually was seen to be pseudoscience. "The list of prominent political, philosophical, and literary figures who took it seriously is astonishing and includes G. W. F. Hegel, Otto von Bismarck, **Marx**, Balzac, the Brontës, George Elliott, President James Garfield, Walt Whitman, and Queen Victoria..., as well as in the scientific writings of Auguste **Comte**, G. H. **Lewes**, **Spencer**, **Chambers**, and A. R. **Wallace**" (R. M. Young 1978).
In 1811, Amedeo **Avogadro** proposed that equal volumes of gases at the same temperature and pressure contain the same number of molecules. He used 'integral molecules' and 'elementary molecules' to denote what were later called the molecules of a chemical compound and the atoms of the elements of which it was composed. Later physicists determined the number of atoms in a 'mole' to be 6.02552×10^{23}, and called it Avogadro's number. The reality of molecules came to be accepted by organic chemists after about 1860, but in the early twentieth century physicists still doubted their reality. In other words, molecules are "recurrent groupings of atoms" (Hoffman and Torrence 1993:16).
In 1811, **Berzelius** simplified chemistry through his suggestion that they be represented by the first letter of each elements Latin name, with the addition of the second letter when necessary. To indicate the proportions in a compound he wrote the appropriate number as subscript.
In 1811, Pierre Louis **Dulong** discovered nitrogen trichloride, a spontaneously explosive oil.
In 1811, Siméon-Denis **Poisson**, in "Sur la distribution de l'électricité à la surface des corps conducteurs," found **Laplace**'s integral *V* function "by expressing the integrands as series. [Later this was called the 'potential function.'] Poisson's *V* is the analytic form of **Cavendish**'s 'electrification' and **Volta**'s 'tension.' It is more supple than either, for it permits the statement of the classical

problems of electrostatics-finding the distribution of electricity and the resultant forces-in full generality" (Heilbron 1979:499). Poisson attributed to electricity the material properties of actual fluids.
In 1811, **Fourier**, in a paper on heat diffusion, invented the formula for a trigonomic series by which any repeated physical event can be defined by its phase and its amplitude and represented as a set of simple wave forms. As this was incapable of expressing initial conditions in infinite bodies, he also created an integral theorem. Today these are known as Fourier series and Fourier integrals.
In 1812, Georges **Cuvier**, in *Discours sur les révolutions de la surface du globe*, maintained the stratigraphic succession proved that fossils occur in the chronological order of creation: fish, amphibians, reptiles, and mammals. He applied the new **Jussieu** approach to animals, but read the paleontological evidence to justify a succession of cataclysms, each followed by creation of new flora and fauna. At this time paleotology was still a branch of geology. Cuvier supported the idea of the fixity of species and opposed **Lamarck's** conception.
In 1812, **Berzelius**, in the second volume of his textbook *Lärbok I kemien* and in subsequent volumes, in journals, and in his annual reports, denied the generic and hierarchical classification of chemicals and showed that acidity and basicity are composed of specific components, for example, a certain degree of electro-negativity or positivity. Similarly, in his theory of salts, the oxides of qualitatively opposed radicals lay on the same ontological plane. The specificity of the radicals, not the degree of oxidation, became the chief determinant of properties. He also drew the line between organic and inorganic, showing that in the former "a sufficiently large number of atoms entered...to permit the manifestation of apparent transitions occasioned by relatively small differences in composition" (Melhado 1981:123).
In 1813, **Davy** published the first book on agricultural chemistry.
In 1814, Joseph von **Fraunhofer** devised a primitive spectroscope by allowing light to pass through a narrow slit and then a prism, obtaining **Newton's** rainbow with numerous sharp, narrow dark lines in fixed positions.
In 1815, Konstantin Sigizmundovich **Kirchhof** reported that wheat glutin is capable of being converted to dextrin and sugar.
In 1815, William **Prout** proposed that the atomic weights of elements are multiples of that for hydrogen.
In 1816, Augustin Jean **Fresnel** showed that diffraction and interference can be explained in terms of the wave theory of light.
In 1816, **Fresnel** and Dominique François **Arago** discovered that perpendicular beams of polarized light do not interfere with each other. This led to the transverse theory of light waves, which replaced the longitudinal theory.
In 1817, Christian Heinrich **Pander** described three germ layers in chick embryos.
In 1817, **Berzelius** discovered the element 'selenium' and, in 1828, 'thorium.' Also in 1817, in Berzelius' laboratory, J. A. **Arfwedsen** isolated 'lithium.' Also, in Berzelius' lab, in 1830, N. G. **Sefström** found 'vanadium.'
In 1818, Étienne Geoffrey **Saint-Hilaire** defined the concept of 'homologous,' that is, having the same evolutionary origin, e.g., a wing and an arm, although he didn't come up with the word until 1825. A friend of **Lamarck's**, he found numerous evidences of the environmentally-induced disuse of parts. He "tried to combine continuity of descent with discontinuity of form by the hypothesis that new species and higher categories start from the occasional appearance of monsters capable of flourishing in an appropriate environment" (Wright 1948:916).
In 1818, W. C. **Wells** enunciated the principle of natural selection among human populations, suggesting that African populations are selected for their relative resistance to local diseases.
In 1818, Michael **Faraday** began a series of successful experiments on alloys of steel which were, however, not commercial because of the alloyed materials. Later work on steel alloys is based on Faraday's work.
After 1818, **Gauss** was employed doing geodesic surveys where, aside from writing numerous papers on differential geometry, he invented the 'heliotrope,' a device used to measure distances by means of reflected sunlight. One of the papers had to do with 'potential theory,' and another with 'Gaussian curves.'
In 1819, **Dulong** and Alexis Thérèse **Petit**, in "Recherches sur quelques points importante de la théorie de la chaleur," determined that the atomic weights of chemical elements were inversely proportional to their specific heats and that "the atoms of all simple bodies have exactly the same

capacity for heat" (Dulong and Petit, quoted in Crosland 1976:241). This is known as the law of constant atomic heats.
In 1819, Arthur **Schopenhauer**, in *Welt als Wille und Vorstellung*, called "the genital organs the focus of the will [adding that] indeed, one may say man is incarnate sexual instinct, since he owes his origin to copulation and the wish of his wishes is to copulate" (Schopenhauer 1819:314).
In 1820, **Lamarck** described the origin of living things as a process of gradual development from matter.
In 1820, Christian Friedrich **Nasse** said that while hemophilia occurs only in males, it is passed through the female line.
In 1820, J. B. **Caventou** and P. J. **Pelletier** isolated quinine from cinchona bark.
In 1820, Hans Christian **Øersted** initiated the study of electromagnetism by placing a needle parallel to a wire conducting electric current and discovering that this produces a magnetic field that curls around the wire. He gave as explanation for this action of a magnetic pole and an electric current, an apparently heterogenous pair, the "impetus of [their] contending powers" (Øersted, quoted in Heilbron 1981:199).
Later in 1820, André Marie **Ampère** published his conjecture that "the fundamental [electrical] *force* is a rectangular push or pull between elements of current: attraction between elements moving parallel, repulsion between ones moving in opposite directions." Current is visualized as a sequence of squirts, a "succession...of decompositions and recombinations of the fluid formed by the union of the two electricities" (Ampère, quoted in Heilbron 1981:197). He further hypothesized that "a magnet owes its power to elementary current loops perpendicular to its axis" (*Ibid*.:200); i.e, all magnetism can be attributed to electric currents. He also originated the idea of the electric telegraph.
In 1821, **Fresnel** stated laws making possible the calculation of the intensity and polarization of reflected and refracted light. According to his law of reflection, if the transition between the air and a reflective medium "is absolutely abrupt, the light is completely plane polarized...., if the transition is gradual, the light is elliptically polarized" (Adam 1930:7). He also devised a method to produce circularly polarized light.
In 1821, **Wollaston** explained the interactions of **Ampère**'s wires "upon the supposition of an electromagnetic current passing round the axis of [each]" (Wollaston, quoted in Heilbron 1981:200). **Davy** adopted Wollaston's interpretation.
In 1821, **Faraday**, published "History of the Progress of Electro-Magnetism," in which he accepted **Wollaston**'s interpretation of electricity. He also demonstrated that the elementary phenomena was "the [continuous] rotation of a pole about a wire, or of a wire about a pole, [using] apparatus that...allowed motions over 360 degrees" (Heilbron 1981:201). This rendered possible the production of continuous mechanical motion by electricity, i.e., the electric motor.
In 1821, John **Herapath**, in "A mathematical inquiry into the causes, laws, and principle phenomena of heat, gases, gravitation, etc.," proposed a kinetic theory of heat, i.e., it is movement, not a substance.
In 1821, Augustin-Louis **Cauchy**, in his *Cours d'analyse*, established the calculus on the formalism of his concept of analytic function, divorcing the idea from any reference to geometrical figures or magnitudes and unequivalently stating that the limit must be zero for higher order infinitesimals.
In 1821, Jean François **Champollion**, employing the Rosetta Stone, established the principles for deciphering Egyptian hieroglyphics. T. **Young**, also employing the Rosetta Stone, deciphered the demotic script.
Between 1822 and 1824, John **Goss**, Alexander **Seton**, and T. A. **Knight**, each independently, observed the segregation of a recessive trait in peas, but kept no records of later generations.
In 1822, Eilhard **Mitscherlich**, in "Om Förhållandet einellan Chemiska Sammansättningen och Krystalliformen hos Arseniksyrade och Phosphorsyrade Salter" (On the Relation Between the Chemical Composition and the Crystal Form of Salts of Arsenic and Phosphoric Acids), noted that "certain elements have the property of producing the same crystal form when in combination with an equal number of atoms of one or more common elements.... The crystal form does not depend on the nature of the atoms, but only on their number and mode of combination" (Mitscherlich, quoted in Szabadváry 1976:426). He arranged these in groups and called those in the same group 'isomorphous.'
In 1822, **Fourier**, in *Théorie analytique de la chaleur*, expanded his 1811 paper and made numerous additions, including time-dependent equations for heat flow and the formulation of physical problems as boundary-value problems in linear partial differential equations.

In 1823, **Faraday** discovered the liquifaction of chlorine.

In 1823, **Poisson**, in "Sur la chaleur des gas et des vapeurs," worked out a "quantitative theory of gases, in which the repulsion between atoms was attributed to the action of 'atmospheres' of caloric surrounding the atoms" (Brush 1964:7).

In 1823, János **Bolyai** invented a non-Euclidean geometry by assuming that one could be constructed without the parallel postulate. It was published in 1832.

In 1824, Marie-Jean-Pierre **Flourens**, in *Recherches experimentales sur les propriétés et fonctions du systèm nerveux dans les animaux vertébrés*, said that while every organ of the brain had its specific function these parts functioned as a whole and that all perceptions could concurrently occupy the same places in the forebrain. He was strongly opposed to **Gall**'s phrenology.

In 1824, Nicolas Léonard Sadi **Carnot** , in *Réflexions sur la puissance motrice du feu et sur les machines propres à développer cette puissance*, showed in a series of operations, known as Carnot's cycle, that even under ideal conditions a steam engine cannot convert into mechanical energy all the heat energy supplied to it. His theory was founded on the concept that heat is a substance, likening the operation of the heat engine to that of "a column-of-water device in which a quantity of water falling through a fixed distance from a given height produces an invariable quantity of motive power, the water being fully transferred from its original height to a reservoir at a lower level" (Buchwald 1976:378). Thus, heat, or *calorique*, a weightless fluid, could not be created nor destroyed.

In 1824, Neils Hendrik **Abel** proved that the general quintic equation was insoluble by radicals. The 'Abelian group' is named in his honor.

In 1825, Jean Baptiste **Bouillard** established the location of the language function, which in fact accorded with **Gall**'s phrenology, in the anterior cortical lobe and that there could be paralysis of this function without paralysis of the limbs.

In 1825, Christian Leopold **von Buch** concluded that varieties may become species through being segregated.

In 1825, George Poulett **Scrope**, in *Considerations on Volcanos*, wrote that all lava formations could be accounted for by volcanic action of an intensity no greater than current eruptions.

In 1825, **Øersted** isolated aluminum.

In 1825, **Faraday** discovered benzene.

In 1825, the Stockton and Darlington **Railway** began steam-powered freight and passenger service in England.

About 1826, Robert **Grant**, August **Schweigger**, and Friedrich **Tiedemann** declared themselves in favor of a common origin for both plants and animals.

In 1826, Nikolai Ivanovich **Lobachevsky** announced the development of a system of hyperbolic geometry in which **Euclid's** fifth postulate was replaced by one allowing more than one parallel line through a fixed point.

In 1826, **Olbers** expressed the paradox that if the Universe was infinite, the night sky would be bright with stars.

In 1827, Georg Simon **Ohm** discovered that the ratio of the potential difference between the ends of a conductor and the current flowing through it is constant, and is the resistence of the conductor.

In 1827, Robert **Brown** noticed random movement of microscopic particles contained in the pollen from plants when suspended in fluid. This is known as Brownian movement.

In 1828, Karl Ernst Ritter **von Baer**, having examined the fetal anatomy of numerous species, published the view that all animals have three germ layers and that that the ontogeny of embryos proceeds from initial homogeneity to heterogeneity by stages similar to other young animals, but not by the recapitulation of the adult forms of lower animals.

In 1828, Friedrich **Wöhler** synthesized urea by heating ammonium cyanate. This was the first synthesis of an organic compound from inorganic material.

In 1828, William Rowan **Hamilton**, in "Theory of Systems of Rays,", predicted the existence of conical refraction and developed general equations of motion in optics which related **Kepler**'s light rays to **Young**'s particles.

In 1828, William **Nicol** invented a polarizing prism made from two calcite components.

In 1828, George **Green**, in *An Essay on the Application of Mathematical Analysis to the Theories of Electricity and Magnetism*, coined the term potential function to denote the sum of the forces acting on a material point in a system and "expressed by a partial differential of a certain function of the coordinates which define the point's position in space" (Green 1828:9); in other words, electrical potential "suffices to determine both the forces and the distribution of electricity on conducting bodies and permits dispensing with **Poisson**'s postulate of an electrical layer of finite depth" (Buchwald 1976:376). Also, in this essay was "the formula connecting surface and volume integrals, now known as Green's theorem" (Wallis 1978:199).

In the late 1820s, Joseph **Henry**, by vastly increasing the number of wire coils around a magnet, created a powerful electromagnet.

In 1829, Charles **Lyell**, in *Principles of Geology*, built a synthesis on the methodological limitation that the past could be studied only by analogy to what natural agencies, given enough time, could accomplish in the present. His opinion that there was uniformity in the causes of change--rather than catastrophic floods--"implied that they must forever produce an endless variety of effects, *both in the animate and inanimate world"* (Lyell, quoted in Hardy 1965:62). In Thomas **Huxley**'s opinion, Lyell's work bore the primary responsibility for smoothing C. **Darwin's** path. **Wallace** credits Lyell's idea that the surface of the earth was in a continual state of slow modification for making obvious to him that life must be continually adjusting to these changed conditions.

In 1829, Thomas **Graham**, in "A Short Account of Experimental Researches on the Diffusion of Gases Through Each Other, and Their Separation by Mechanical Means," contained the essentials of what became known as Graham's Law: "The diffusion or spontaneous intermixture of two gases in contact is effected by an interchange in position of indefinitely minute volumes of gases, which volumes are not necessarily of equal magnitude, being, in the case of each gas, inversely proportional to the square root of the density of that gas, [i.e.,] diffusion takes place between the ultimate particles of gases, and not between sensible masses" (Graham 1833. "On the Law of the Diffusion of Gases," quoted in Kauffman 1976:493). He also pointed out that "mixture of gases could be separated by diffusion, a process employed during World War II..., to separate the fissionable isotope uranium 235 from the nonfissionable isotope uranium 238" (Kauffman 1976:495).

In 1829, Johann **Döbereiner** began the rationalization of the chemical elements when he observed triadic groups whose central member was the arithmetic mean of the two outer members.

In 1829, James **Mill** published the first volume of *Analysis of the Phenomena of the Human Mind* in which he said that resemblance can be reduced to co-occurrence, a special case of what he called synchronous order.

In 1830, **Robiquet** and others discovered the hydrolytic splitting of the glucoside, 'amygdalin.'

In 1830, Giovanni Battista **Amici** traced the growth of the pollen tube down through the 'style' and into the ovule of the flower.

In 1830, Joseph **Lister** showed lenses which corrected for aberration.

In 1830, **Gauss**, in *Principia generalia Theoriae Figurae Fluidorum in statu Aequilibrii*, invented a single expression for surface tension which aggregated all the potentials arising from the interaction between pairs of particles.

In 1830, Macedonio **Melloni** invented the thermocouple, by which the transmission of heat by various substances can be measured.

In 1830, Auguste **Comte**, in *Cours de philosophie positive*, maintained that intellectual development consisted in three stages: the theological, in which events are attributed to supernatural forces; the metaphysical, in which natural phenomena are attributed to 'fundamental' forces; and the positive, in which phenomena are explained by observation, hypothesis, and experimentation. He also coined the words 'sociology' and 'altruism.'

In 1831, **Brown** discovered the cell nucleus in the course of a microscopic examination of orchids.

After 1831, Friedlieb Ferdinand **Runge**, through the distillation of coal tar and extraction of its parts, isolated and named carbolic acid, leucol, pyrol, and cyanol. From cyanol he produced aniline black which he patented in 1834.]

In 1831, **Faraday** , in the first in a series of *Experimental Researches in Electricity*, discovered the means of producing electricity from magnetism, i.e., electromagnetic induction, the generation of an electric field by a changing magnetic field. Using a 'transformer ring,' an iron ring wrapped in a wire coil, he was able to induce a transient current in a galvanometer. This is the principle of the dynamo. He speculated that electromagnetic phenomena might be situated in the aether.

In 1831, Franz Ernst **Neumann**, in "Untersuchung über die specifische Wärme der Mineralien," extended the law that the specific heats of elements vary inversely as their atomic weights to include compounds and determined that the molecular heat of a compound is equal to the sum of the atomic heats of its constituents.

In 1831, **Berzelius** proposed the name 'isomerism' for different compounds with same chemical composition, such as that discovered by **Wöhler**.

In 1832, G. G. **Hällström** said that one should hear beats of the harmonics of the tones $f_1$and f_2; however, this was not confirmed until 1856 when Hermann Ludwig Ferdinand von **Helmholtz** did so.

In 1832, W. **Hamilton**, in the third supplement to "Theory of Systems of Rays," explained how the characteristic function in optics made the optical length a function of variable initial and final points. When applied to **Fresnel**'s wave surface, he was able to predict that "a single ray incident in the correct direction on a biaxial crystal should be refracted into a cone in the crystal and emerge as a hollow cylinder" (Hankins 1976:88). This was verified experimentally by Humphrey **Lloyd**.

In 1832, Évariste **Galois**, in a letter published posthumously, invented the concept of the group as the symmetries of a polynomial equation and "sketched the connection between groups and polynomial equations, stating that an equation is soluble by radicals provided its group is soluble" (Stewart 1989:xxii).

In 1833, Johannes Peter **Müller** published his discovery that sensation is not controlled by the stimulus but rather is dependent on the particular sense organ involved: Each sensory nerve produces its own specific sensation, e.g., any stimulation of the optic nerve results in a sensation of light.

In 1833, Marshall **Hall** described the mechanism by which a stimulus can produce a response independent of both sensation and volition, and coined the term 'reflex.'

In 1833, **Graham**, in "Researches on the Arseniates, Phosphates, and Modifications of Phosphoric Acid," elucidated the differences between the three phosphoric acids, triphosphate, biphosphate, and phosphate of water, and established the concept of polybasic compounds, i.e., "a class of hydrated acids with more than one proportion of water replacable by a basic metallic oxide so that several series of salts could be formed" (Kauffman 1976:493).

In 1833, W. **Hamilton**, in "On a General Method of Expressing the Paths of Light and of the Planets by the Coefficients of a Characteristic Function," explained how **Fermat**'s principle of least time led to the law of least action and pointed out that "in mechanics the action is only a local minimum or local maximum. The essential property...was not that of being greater or less but that of being stationary under small variations in motion" (Park 1990:348); i.e., "the Law of Stationary Action" (Hamilton 1833:316-318). This he later extended to dynamics, often called 'Hamiltonian mechanics.' "The classical Hamiltonian expresses the energy of a dynamical system in terms of coordinates q and momenta p, and therefore takes on a continuous set of values. It cannot lead to discrete energy levels. For this reason, the Hamiltonian H is replaced in quantum theory by the Hamiltonian operator H_{op}" (Prigogine 1996:133). In fact, for all its elegance, the Hamiltonian method was little used until the rise of quantum mechanics when it turned out to be "the one form of classical mechanics that carried over directly into the quantum interpretation" (Hankins 1976:89).

In 1833, **Gauss** invented the electric telegraph.

In 1833, Charles **Wheatstone** invented the 'stereoscope,' revealing the dependence of visual depth perception upon binocular double vision.

In 1834, **Berzelius**, in *Annalen der physikalisches Chemie*, reported finding organic matter, humic acid, in a meteorite. Such meteorites are called 'carbonaceous chondrites.'

In 1834, Anselm **Payen** and Jean-François **Persoz** isolated 'diastase' from barley malt and postulated the importance of enzymes in biology.

In 1834, **Faraday** , in the seventh series of *Experimental Researches*, having proved the identity of electricities, went on to add another link in the chain of the convertibility of forces by establishing two fundamental laws of electrochemistry or electrolysis, i.e., the passage of electricity through ionic solutions: "The amount of chemical change produced is proportional to the quantity of electricity passed [and] the amount of chemical change produced in different substances by a fixed quantity of electricity is proportional to the electrochemical equivalent of the substance" (*Dictionary of Physics* 2000:167). Moreover, he proved to his own satisfaction that these changes were not effected by action at a distance. To prepare the way for a successful challenge to the prevalent theory, Faraday introduced a new and neutral nomenclature. "Instead of poles, which implied centers of force, [he] used the term 'electrode,' which had no such implication. Similarly 'cathode,' 'anode,' 'electrolysis,' 'electrolyte,' 'anion,' and 'cation' were merely descriptive terms. William **Whewell**...was the source of most of these neologisms" (Williams 1976:537).

In 1834, John Scott **Russell**, in the course of studying waves, observed a solitary wave, which "consists in a motion of translation of the whole mass of the fluid from one place to another, to another in which it finally reposes" (Russell 1844:317). Such ' waves of translation' led to the idea of a soliton, or solitary wave-state that is a solution of certain physical propagation equations.

In 1834, Charles **Babbage** designed a programmable mechanical calculating machine, or 'analytical engine,' that could carry out arithmetic operations specified on punch cards and choose the sequence of operations. Although the design was never built, Augusta Ada **Byron** wrote programs to demonstrate its potential power.
In 1835, **Berzelius** suggested the name 'catalysis' for reactions which occurred only in the presence of some third substance, "as one designates the decomposition of bodies by chemical affinity analysis" (Berzelius, quoted in Leicester 1976:95). He classified fermentation as a catalyzed reaction.
In 1835, George Biddell **Airy** calculated the form of a diffraction pattern produced by a circular aperture. He also designed a cylindrical lens for correcting astigmatism.
In 1835, Jean Élix Benjamin **Valz**, Friedrich Bernhard Gottfried **Nicolai**, and Niccolo **Cacciatore**, each independently, conjectured that a trans-Uranian planet caused the otherwise inexplicable discrepancies in the historical record of the orbits of both **Halley**'s comet and Uranus.
In 1836, Theodor **Schwann** reported the action of 'pepsin' and described its properties.
In 1836, Wilhelm von **Humboldt**, in *Über die Verschiedenheit des Menschlichen*, published posthumously, maintained that, "for an individual, learning is largely a matter of *Weidererzeugung*, that is, of drawing out what is innate in the mind" (Chomsky 1965:51).
In 1837, Heinrich Gustav **Magnus** determined that carbon dioxide released in the lungs had been carried there by blood and that more oxygen and less carbon dioxide was contained in arterial than in venous blood. (Magnus 1837)
In 1837, René **Dutrochet** observed that chlorophyll is necessary for photosynthesis.
In 1837, Hugo von **Mohl** described 'chloroplasts' as discrete bodies within the cells of green plants.
In 1837 and 1838, **Schwann**, Charles **Cagniard de la Tour**, and Friedrich Traugott **Kützing**, working independently, said that "yeast was a living organism which was responsible for fermentation. This began a lengthy debate over whether fermentation was a chemical or a vital process" (German Life Science Information Service 1993:6).
In 1837 and 1838, **Faraday**, in "On Induction," the eleventh and twelfth in the series of *Experimental Researches*, presented a coherent and general theory of electricity. "Faraday, in his mind's eye, saw lines of force traversing all space where the mathematicians saw centres of force attacting at a distance: Faraday saw a medium where they saw nothing but distance: Faraday sought the seat of the phenomena in real actions going on in the medium, they were satisfied that they found it in a power of action at a distance impressed on the electric fluids.... Faraday's methods resembled those in which we begin with the whole and arrive at the parts by analysis, while the ordinary mathematical methods were founded on the principle of beginning with the parts and building up the whole by synthesis" (Maxwell 1873:ix).
In 1837, Ralph Waldo **Emerson** observed, "The ancient precept, 'Know thyself,' and the modern precept, 'Study nature,' become at last one maxim" (Emerson 1837:56). He also said that life consists of what a man is thinking all day.
In 1838, Mattias Jakob **Schleiden** put forward the theory that plant tissues are composed of cells, and recognized the significance of the nucleus.
In 1838, **Purkinje** found that nerve cells consist of two parts, later named axons and dendrites. About this time, he also coined the term 'protoplasm,' and, with **Mohl**, established that the protoplasm is the living contents of a cell.
In 1838, Carlo **Matteucci**, in "Sur le courant électrique ou presque de la grenouille," recorded the production by a muscle of an electric current with a galvanometer.
In 1838, Friedrich **Bessel** solved the sidereal trigonomic parallax problem in the course of working with 61 *Cygni*, a nearby star with a large 'proper motion,' or transverse velocity. This was closely followed by Thomas **Henderson**, working with *Alpha Centuri*, in 1839, and Frederick **von Struve**, working with *Vega*, in 1840. At this point, the isolation of the Solar System was realized.
In 1838, Gerardus Johannes **Mulder** published **Berzelius**' term 'protein.'
In the late 1830s, Richard **Owen** distingushed between 'homology' and 'analogy:' A wing of a bird and a bat are analogous since for flight one has feathers and the other membrane, but the bones and musculature are homologous. He supported the fixity of species.
In 1839, **Schwann**, in *Mikroskopische Untersuchungen über die Uebereinstimmung in der Struktur und dem Wachstume der Tiere und Pflanzen*, claimed that animal tissues are composed of cells with nuclei. It concludes with a methodological discussion in which he says that a teleological explanation

is admissible only when a physical explanation is unattainable and in that case both operate "like physical forces in service to strict laws of blind necessity" (Schwann 1839:).
In 1839, **Mohl** described the appearance of the cell plate between the daughter cells during cell division, or 'mitosis.'
In 1839, Johann **Schoenlein**, using a microscope, discovered a microbial parasite of humans, *Trichophyton schoenleinii*, which causes ringworm of the scalp.
In 1839, Christian **Swann** discovered the existence of ozone.
In 1839, Louis Jacques Mandé **Daguerre** made public his invention of the first photographic process. "The first daguerrotype of the disk of the Sun was obtained by two physicists in Paris in 1845" (Gribbin and Gribbin 2000:54), and subsequent improvements in emulsion speeds had enormous repercussions for astronomy.
In 1839, George **Boole** developed analytic transformations, the basis of Boolean algebra, which is of fundamental importance in the study of the foundations of mathematics, logic, and computer simulation.
In 1840, T. L. **Hünefel** , in *Der Chemismus in der thierischen Organization*, reported his observation of crystals in the bloo
In 1840, **Whewell** introduced the word 'scientist.' Until then, science had retained its medieval denotation, truth derived from first principles, or moral science, as opposed to natural philosophy.
In 1840, Louis **Agassiz** published a demonstration of the existence of a glacial epoch in the temperate zones.
In 1840, Christian Friedrich **Schönbein** isolated 'ozone,' naming it from the Greek word *ozein*, to smell.
In 1840, **Berzelius** suggested the name 'allotropy' for the occurence different forms of the same element.
In 1841, Albrecht von **Kölliker** showed that spermatozoa are sex cells which arise by a transformation of cells in the testes.
In 1841, Julius Robert **Mayer**, working with established experimental results, derived the general relationship between heat and work, which is the first law of thermodynamics, a form of the law of conservation of energy: The form of energy can be changed, but it can neither be created nor destoyed. The idea of energy, a thing without weight which could neither be seen nor felt and had a constant value through many transformations, was not quickly adopted.
In 1842, Johann Japetus **Steenstrup** described the alternation of sexual and asexual generations in animals and plants. In some jellyfish, the 'medusoid' stage usually reproduces sexually, giving birth to the 'polyp,' or 'hydroid,' stage, which reproduces asexually. Ferns have a 'sporophyte' generation which produces spores which give rise to a 'gametophyte' generation which reproduces sexually (Hale and Margham 1991:26).
In 1842, Christian **Doppler** developed the theory that the frequency of energy in the form of the form of waves changes depending on the motion of either the sender or the receiver.
In 1842, William **Thomson**, in "On the Uniform Motion of Heat in Homogenous Solid Bodies, and its connection with the Mathematical Theory of Electricity," concluded that "any two theories dealing with the same phenomena...cannot conflict if their most elementary laws can be connected mathematically" (Buchwald 1976:376).
In 1843, Justus von **Liebig** speculated that organic acids, such as malic, tartaric, and oxalic, are intermediates in a plant's production of carbohydrates.
In 1843, James **Braid** suggested changing the term 'animal magnetism' to 'hypnotism,' from the Greek *hypnos*, to sleep.
In 1843, James Prescott **Joule**, working without awareness of **Mayer**'s proof, demonstrated experimentally the "strict equivalence of the heat produced [by an induced current] and the mechanical work spent in the operation..., thus [obtaining a] determination of the coefficient of equivalence" of heat and work (Rosenfeld 1976:182). "Thus it is that order is maintained in the universe-nothing is destroyed, nothing ever lost, but that the entire machinery, complicated as it is, works smoothly and harmoniously" (Joule, quoted in Buchwald 1976:380). One crucial aspect is Joule's conception of latent heat, the heat absorbed or released when a substance undergoes a phase change without a temperature change, e.g., water into ice or into steam. Latent heat is thought of as "the work done against the internal, molecular forces of a body [which] then store it in the resulting molecular configuration, [or] 'attraction through space,' in Joule's terminology"

(Buchwald 1976:381). He did not publicly announce his discovery until 1847 in a newspaper article entitled "On Matter, Living Force, and Heat."
In 1844, Karl Friedrich Wilhelm **Ludwig** showed that waste products are passively filtered by the 'Malpighian corpuscle' in the kidney and then concentrated as they pass through the tubules.
In 1844, Robert **Chambers**, anonymous author of *Vestiges of the Natural History of Creation*, wrote that "mental action...passes at once into the category of natural things. Its old metaphysical character vanishes..., and the distinction usually taken between physical and moral is annulled" (Chambers, quoted in Gillispie 1951:157). Chambers developed his "evolutionary theory as a metaphorical extension of **von Baer's** principle" (Gould 1977:110). He was crucially influenced by **Comte's** positivism.
In 1844, C. **Darwin** wrote, but didn't publish, an essay presaging the theory of the origin of species.
In 1844, Samuel Finley Breese **Morse** demonstrated a telegraph, using a code of his own invention, similar to semaphore.
In 1845, J. **Dzierzon** reported that among bees the drones hatch from unfertilized eggs while workers and queens are from fertilized eggs.
In 1845, Adolf Wilhelm Hermann **Kolbe** synthesized acetic acid.
In 1845, Jacques-Joseph **Moreau** maintained that mental illness with its delusions and hallucinations was not the reult of stimulation, but rather the result of "a diminution of intellectual function and a disproportionate development of vestigial psychic activities" (Ellenberger 1970:290).
In 1845, **Faraday**, writing his nineteenth series of *Experimental Researches* in response to a query by W. **Thomson**, described the 'effect' made by rotating a plane of polarized light through a transparent body glass in a strong magnetic field; i.e., "the angle of rotation [is] directly proportional to the strength of the magnetic force" (L. Williams 1976:538). "That which is magnetic in the forces of matter has been affected, and in turn has affected that which is truly magnetic in the force of light.... The magnetic forces do not act on the ray of light directly and without the intervention of matter, but through the mediation of the substance in which they and the ray have a simultaneous existence" (Faraday 1845:paragraphs2146n2,2224). That the magnetic force acts through glass suggested to Faraday that all materials "*pass onward* electrical lines of force-in Faraday's terminology, all are *dielectrics*. Moreover, each material transmits the lines of force with a characteristic degree of efficacy, which Faraday called its *specific inductive capacity*" (Fisher 2001:380). Subsequent *Experimental Researches* and a final article in 1852, "On the Physical Character of the Lines of Magnetic Force," were focused on the reality of the lines of force as represented by the curves of magnetized iron filings, rather than the affected materials, and formed the background for James Clerk **Maxwell**'s 'field' formulation.
In 1845, W. **Thomson**, in "On a Mechanical Representation of Electric, Magnetic, and Galvanic Forces," on the basis of the **Faraday** effect, linked electrical and magnetic "forces to the internal processes of a single medium...; [i.e., they, though different phenomena,] were linked to a common element" and were mechanically, i.e., formally, analogous (Buchwald 1976:377).
In 1845, **Mayer** published the suggestion that the Sun could maintain its heat for millions of years if it were fueled by a steady supply of asteroids.
In 1846, William **Morton** demonstrated the effective use of ether as an anesthesia.
In 1846, Carl Gustav **Carus** published *Psyche*, which begins, "The key to the knowledge of the nature of the soul's conscious life lies in the realm of the unconscious.... The first task of a science of the soul is to state how the spirit of Man is able to descend into these depths" (Carus, quoted in Ellenberger 1970:207).
In 1846, Ascani **Sobrero** discovered nitroglycerin.
In 1846, Johann Gottfried **Galle** discovered the planet Neptune where Urbain Jean Joseph **Le Verrier** and, independently, John Couch **Adams** had predicted that a planet would be found. Their predictions were based on perturbations in the orbit of Uranus. **Bode**'s law broke down in the case of Neptune.
In 1846, Henry Creswicke **Rawlinson** published his deciphering of the cuneiform of the Behistun Inscriptions.
In 1857, **Pasteur** demonstrated that lactic acid fermentation is carried out by living bacteria.
In 1847, K. B. **Reichert** saw under a microscope blood which consisted of tetrahedral crystals and went some way toward demonstrating that it is protein (Reichert 1849).
In 1847, Henry **Bence-Jones** discovered distinctive proteins in the urine of myeloma patients.

In 1847, **Flourens** discovered the anesthetic properties of chloroform.

In 1847, W. **Bergmann** pointed out that populations of warm-blooded species living in cool climates tend to be larger on average than members of the same species living in warmer climates because the surface area to volume ratio in the larger animals is less and, therefore, heat loss is reduced.

In 1847, A. **Derbés** observed the progressive lifting of the egg's vitelline membrane which begins at the point of sperm entry in the course of fertilization.

In 1847, James **Esdaile** made the first systematic use of hypnotism for anesthetizing surgical patients.

In 1847, Hermann Ludwig Ferdinand von **Helmholtz** , in "Über der Erhaltung der Kraft," formulated the law of the conservation of energy in an equation which expresses the most general form of the principle. "Science [Helmholtz began] views the world in terms of two abstractions, matter and force. The goal of science is to trace phenomena to their ultimate causes...; such ultimate causes are unchangable forces [which we can know] virtually *a priori*. If we imagine matter dispersed into its ultimate elements, then the only conceivable change which can occur in the relationship is spatial. Ultimate forces, then, must be moving forces radially directed. Only the reduction of phenomena to such forces constitutes an explanation to which we may ascribe the status of 'objective truth'" (Turner 1976:243-244).

In 1847, Lambert **Babo** said that the addition of a solute to liquid vapor decreases the vapor pressure proportional to the amount of the solute.

In 1847, Augustus **de Morgan** published *Arithmetical Books From the Invention of Printing to the Present Time. Being Brief Notices of a Large Number of Works Drawn up From Actual Inspection*, the earliest significant work of scienntific bibliography.

In 1848, Emil **Du Bois-Reymond** ,in the first volume of *Untersuchungen über tierische elektrizität*, demonstrated that the signal propagated along a peripheral nerve was a wave with a negative electrical charge and hypothesized that the impulse consisted in the rearrangement of molecules.

In 1848, Louis **Pasteur** discovered molecular dissymmetry, or chirality. Later, he coined the distinction between users and non-users of oxygen, 'aerobic' and 'anaerobic.'

In 1848, Claude **Bernard** discovered the glycogenic function of the liver.

In 1848, **Müller** showed that one of the biological mechanisms necessary for human speech is a superlaryngeal vocal tract.

In 1848, W. **Thomson**, in "On an Absolute Thermometric Scale, Founded on [N.] **Carnot**'s Theory of the Motive Power of Heat, and Calculated From the Result's of Regnault's Experiments on Steam," proposed what, after 1892, became known as the 'Kelvin scale,' after the title bestowed on him by the British government.

In 1848, Armand Hypolite Louis **Fizeau**, applying the **Doppler** effect to a moving light source, described the 'redshift' and 'blueshift' effects: The amount of the shift to red depends on the speed with which the light is receding from us, and vice-versa.

In 1849, **Fizeau**, "using a rotating toothed wheel to break up a light beam into a series of pulses,...made the first non-astronomical determination of the speed of light (in air)..., 313,300 km s^{-1}" (*History of Optics* 2001:4).

In 1849, Édoard Albert **Roche** stated the maximum value that distance imposes on the diameter of a satellite of a planet. This limit explains the proximity of ring systems to planets.

In 1850, Franz von **Leydig** discovered interstitial cells in the connective tissue of the testes.

In 1850, **Helmholtz** measured the velocity of the impulse in the sciatic nerve of a frog.

In 1850, Jean Baptiste **Boussingnault** demonstrated that plants need only nitrogen from the soil and obtain carbon from the atmosphere.

In 1850, **Runge**, in *Zur Farbenchemie: Musterbilder für Freunde des Schöne*, demonstrated the separation of inorganic chemicals by their differential adsorption to paper. This is forerunner of chromatographic separations.

In 1850, Rudolph Julius Emanuel **Clausius**, generalizing N. **Carnot**'s principle, introduced the concept of 'entropy,' a measure of disorder in a system. This, the 'second law of thermodynamics,' states that entropy can never decrease in a closed system, and will increase until it comes to a state of thermodynamic equilibrium where it must remain; i.e., all particles of gases will move randomly with equal average energy. It is "law of nature which says that things wear out. [Another] expression of the second law...is that heat cannot flow from a cold object to a hotter object of its own volition" (Gribbin 1998b:359). Thus was introduced irreversibility, i.e., time's arrow, to classical physics.

In 1850, Jean Bernard Léon **Foucault**, using a rotating mirror, determined the speed of light in the air as 298,000 km s^{-1} and slower than that in stationary water.
In 1851, **Helmholtz** invented the 'opthalamoscope,' a small instrument which when pressed against the eye enables the vessels to be seen.
In 1851, **Foucault** demonstrated that a pendulem's swing, seen relative to the Earth, would gradually precess. This is evidence of the the Earth's rotation.
In 1851, Samuel **Schwabe** announced his discovery of the 11-year sunspot cycle.
In 1851, Bernhard Placidus Johann Nepomuk **Bolzano**'s study of paradoxes was published, three years after his death. In this work, he gives examples of one to one correspondences between elements of a set and its subset.
In 1852, Franz **Unger** put forth his theory of the common descent of plants.
In 1852, George Gabriel **Stokes**, exploring the blue light produced at the surface of a solution when it absorbed invisible ultraviolet light from the Sun, devised a method for artificially producing the phenomena and called the phenomena 'fluorescence.'
In 1852, Georges **Newport** observed the penetration of the vitelline membrane of a frog egg by sperm.
In 1853, Alexander **Wood** introduced the hypodermic syringe which was used as a morphine delivery system in the American Civil War.
In 1853, L.**Teichmann** discovered and named 'heme,' the non-protein, iron-bearing part of blood (Teichmann 1853).
In 1853, Florence **Nightingale** first recommended the regimen of cleanliness which dramatically reduced the death rate in hospitals.
In 1854, Rudolph **Virchow** published the idea that the mechanism of disease could only be found at the level of cellular chemistry.
In 1854, **Helmholtz** predicted the heat death of the Universe on the basis of thermodynamic theory.
In 1854, Georg Friedrich Bernard **Riemann**, in *Ueber die Hypothesen, welche der Geometrie zu Grunde liegen*, proposed another substitute for **Euclid**'s fifth postulate representing elliptic space. He also said that "the empirical notions on which metrical determinations of space are founded, the notions of a solid body and a ray of light, cease to be valid for the infinitely small.... In a continuous manifold..., we must seek the ground of its metric relations outside it, in binding forces which act upon it" (Riemann, quoted in Cao 1997:372).
In 1855, **Wallace**, in "On the law which has regulated the introduction of new species," also known as the 'Sarawak Law,' published the principle that species are always in proximity to an allied species which precedes it in the fossil record. He deduced this from evidence in the Malay Archipelago, "which is traversed near Celebes by a space of deep ocean [which] separates two widely distinct mammalian faunas" (Darwin 1872:335; Wallace 1855).
In 1855, **Bernard** maintained that the constancy of a body's internal environment was aided by secretions from tissues in all organs.
In 1855, Thomas **Addison** described a syndrome associated with the degeneration of the adrenal cortex, subsequently known as 'Addison's Disease.
In 1855, David **Alter** described the spectrums of hydrogen and other gases.
In 1855, John **Snow**, investigating London's piped water supply, showed graphically that cholera could be transmitted by water from a particular pump.
Between 1855 and 1860, Stanislao **Cannizzaro** showed that common gases like hydrogen exist as molecules and drew up a "table of atomic and molecular weights based on the the atomic weight of hydrogen as the fundamental unit of mass.... He also coined the name 'hydroxyl' for the OH radical" (Gribbin 2000:67).
In 1855, Julius **Plücker** drove an electric current through a vacuum tube, producing a glow of light.
In 1855, Herbert **Spencer** began publishing a projected ten volume work concerning the principles of synthetic philosophy, in which evolution was invoked as a universal principle that involved progress through stages toward greater complexity.
In 1856, fossils identified as an early variant of *Homo sapiens* were found in Neanderthal.
In 1856, William **Ferrel** published *Essay on the Winds and Currents of the Ocean.*
In 1856, **Ludwig** developed perfusion techniques which kept animal organs alive after their removal from the body.

In 1856, W. **Thomson**, in "Dynamical Illustrations of the Magnetic and Heliocoidal Rotary Effects of Transparent Bodies on Polarized Light," explained the **Faraday** effect in terms of the rotation of molecules, i.e., **William John Macquorn Rankine**'s hypothesis, and argued that, "from any galvanic current, there extends a moving spiral that coils about the line of magnetic force passing through the center of the axis of the current" (Buchwald 1976:384). A few years later, in a lecture, "Atmospheric Electricity," he stated what he took to be proved, namely, "that electricity in motion IS *heat*; and that a certain alignment of axes of revolution in this [vortical] motion IS *magnetism*" (Thomson 1860:224).
In 1856, Wilhelm Eduard **Weber** and Rudolph Herrmann Arndt **Kohlrausch** collaborated on the measurement of the ratio between the electrodynamic and electrostatic units of charge. This was found to be 3.1074×10^8 meters per second, close to the speed of light.
In 1857, **Pasteur** demonstrated that lactic acid fermentation is carried out by living bacteria.
In 1857, Albert von **Kolliker** described what were later named 'mitochondria' in the nucleus of muscle cells.
In 1857, **Clausius**, in "Ueber die Art der Bewegung, welche wir Wärme nennen," derived a much improved formula connecting pressure and volume, $3/2\ pV=nmu^2/2$ and ascribed rotational, vibratory, and translational motion to gas molecules. "By supposing that translational velocities would vary among the molecules, Clausius offered an explanation for the evaporation of a liquid. [He also] presented the first physical argument in support of **Avogadro**'s hypothesis that equal volumes of gases at the same temperature and pressure contain equal numbers of molecules" (Daub 1976:306-307).
In 1857, Cyrus **Field** made his first attempt at laying a trans-Atlantic telegraph cable. In 1866, his fourth attempt was successful.
In 1858, **Darwin's** friends, including **Lyell**, arranged for the simultaneous announcement of **Wallace's** and Darwin's idea of natural selection.
In 1858, Friedrich August Kekulé von **Stradonitz** suggested that carbon atoms are formed in chains.
In 1858, **Helmholtz**, in *Handbuch der physiologischen Optik, Volume II*, amended **Young**'s trichromatic color theory, proposing that any wavelength of light, regardless of how strongly it excites one set of receptors, will always excite the other two sets, thus accounting for the lower saturation of spectral colors as compared to the physiological primaries. This theory was henceforth known as the Young-Helmholtz theory.
In 1858, Arthur **Cayley**, in *Memoir on the theory of matrices*, defined a 'matrix,' showed that the "coefficient arrays studied earlier for quadratic forms and for linear transformations are special cases of his general concept[, and] gave an explicit construction of the inverse of a matrix in terms of the determinant of the matrix" (O'Connor and Robertson 1996:4).
In 1858, August Ferdinand **Möbius**, while investigating the properties of one-sided surfaces, invented the so-called 'Möbius strip.'
In 1859, **Darwin** in *On the Origin of Species by Means of Natural Selection or the Preservation of Favored Races in the Struggle for Life,* asserted all life had a common ancestor and that the origin of species was natural selection acting on variants within a population and yielding differential reproduction of the most adapted, and that this was comparable to the artificial selection practiced by plant and animal breeders. Until Darwin, the conception of mutation was confused by its application to what **Linnaeus** identified as species, which were actually aggregates of species. Subsequently, leading anatomists, like Ernst Heinrich **Haeckel**, reoriented their work to the tracing of evolutionary relationships among animal groups. Darwin was an experienced geologist--in fact, he served as the secretary of the Geological Society from 1838 to 1841, and a large part of *On the Origin of Species* is devoted to describing geological evidence, from which he drew illustrations of "what was then a generally admitted proposition: that the forms of organic life which had succeeded each other on the earth were progressive in character.... But uniformitarianism as an attitude toward the course of nature could not be carried to its logical conclusion in a theory of organic evolution until a formulation sufficiently scientific to be compelling could attack the idea of a governing Providence in its last refuge, the creation of new species" (Gillispie 1951:217-218).
In 1859, cocaine was isolated and patented by Merck three years later.
In 1859, **Kolbe** synthesized salicylic acid.
In 1859, Robert Wilhelm **Bunsen** discovered that each element produces its own characteristic set of lines in the spectrum. Thus was 'spectography' invented, which, with photography, enabled the subsequent advances in astronomy. Gustav Robert **Kirchhoff** followed up Bunsen's discovery and "made the first identification of the presence of any element outside the Earth when he found the

characteristic sodium lines in the spectrum of light from the Sun" (Gribbin and Gribbin 2000:57).
In 1859, **Kirchhoff** proved a theorem about blackbody radiation, namely, the energy emitted *E* depends only on the temperature *T* and the frequency *v* of the emitted energy, i.e., *E = J(T,v) and is independent of the nature of the body.* The correct formula for the function *J*, despite the efforts of Josef **Stefan**, Ludwig **Boltzmann**, John William **Strutt**, and Wilhelm Carl Werner Otto Fritz Franz **Wien**, was not found until Max Karl Ernst Ludwig **Planck** did so in 1900.
In 1859, **Riemann**, in *Beweis des Satzes, dass eine einwerthigemehr als 2*n*fach periodische Function von* n *Verónderlichen unmöglich ist*, generalized to *n* dimensions **Gauss's** differential geometry. This created the tools for the mathematical expression of the general theory of relativity.
In 1860, Pierre Eugöne Marcelin **Berthelot**, in *Chimie organique fondeé sur la synthöse*, described the synthesis of several carbon compounds.
In 1860, **Bunsen** and **Kirchhoff**, in *Chemische Analyse durch Spektralbeobachtungen*, recounted their discovery of cesium and rubium and explained the **Fraunhofer** lines in the solar spectrum as being dark absorption lines which are created by cooler gaseous clouds absorbing energy from the Sun. Bunsen also explained the action of geysers. Kirchhoff formulated two laws concerning electricity: At any instant the sum of the voltages around any loop is zero and at any node the sum of the arriving and departing currents is equal.
In 1860, Gustav Theodor **Fechner**, in *Elementen der Psychophysik*, attempted to explain how the psychical and the physical are two aspects of one reality. He formulated the rule that, within limits, the intensity of a sensation increases as the logarithm of the stimulus. Sigmund "**Freud** took from Fechner the concept of mental energy, the 'topographical' concept of the mind, the principle of pleasure-unpleasure, the principle of constancy, and the principle of repetition" (Ellenberger 1970:218).
In 1860, **Maxwell**, in "Illustrations of the dynamical theory of gases," showed that viscosity is independent of density, or pressure.
In 1860, Joseph Wilson **Swan** made an incandescent lamp using a carbon filament.
In 1860, **de Morgan**, in *Syllabus of a Proposed System of Logic* [?], invented a logic of relations, built on the idea of subject and predicate, e.g., the notation *X..LY* represents the statement that *X* is one of the objects in the relation of *L* to *Y*.
By 1861, Paul **Broca** was able to further isolate the language function and showed that a lesion in the left cortical lobe causes the loss of speech, or 'aphasia,' thus demonstrating an asymmetry that **Gall** had not suspected (Broca 1861).
In 1861, Ignaz Philipp **Semmelweis** published his deduction that childbirth fever was transmitted on the hands of doctors during their examinations.
In 1861, William **Crookes**, using a spectroscope, announced a new element, 'thallium.'
In 1861, **Maxwell**, in "On Physical Lines of Force," announced his discovery that some of the properties of the vibrations in the magnetic medium are identical with those of light: "The velocity of transverse undulations in our hypothetical medium...agrees so exactly with the velocity of light...that we can scarcely avoid the inference that *light consists in the transverse undulations of the the same medium which is the cause of electric and magnetic phenomena*" (Maxwell 1861:500).
In 1861, Anders Jonas **Ångström**, using a spectroscope, confirmed the presence of hydrogen in the Sun.
As early as 1861, Karl Wilhelm Theodor **Weierstrass**, in lectures, showed that "a function which is continuous throughout an interval need not be derivative at any point in this interval.... Inasmuch as it was apparent to Weierstrass that intuition could not be trusted, he sought to make the bases of his analysis as rigorous and formal as possible.... In order to [accomplish this, he] wished to establish the calculus (and the theory of functions) upon the concept of number alone, thus separating it completely from geometry" (Boyer 1949:284-285). Weierstrass' lectures were published, as *Die Elemente der Arithmetik*, by one of his students in 1872.
In 1862, Henry Walter **Bates** said that in 'lepidoptera,' a class of butterflies and moths, mimicry in appearance of unpalatable species by palatable species suggests that the mimics enjoy protection from predation.
In 1862, **Pasteur** published the 'germ theory:': Infection is caused by self-replicating microorganisms, and that attenuated viral cultures granted immunity. These beneficent antigens he named 'vaccines' in honor of **Jenner** and his *vaccinia* virus.
[**Pasteur** was a proponent of 'vitalism,' which "accepted the word 'life' as a substitute for specific chemical information" (Kornberg 1989:34); hence, fermentation was "a physiological process,

inseparably connected with the vital act of a microorganism known as the 'fungus of fermentation'" (Sönderbaum 1929:1). "The various vitalist theories, more or less scientific in appearance, all presuppose the existence of a teleonomic principle [or goal or end], of a special guiding force present in living matter, absent in inanimate matter" (Monod 1969:5). Thus there is no reason that physics should illuminate the processes of life since they are essentially different and not reducible to one another.]
In 1862, Béguyer de **Chancourtois** proposed a pattern of twenty-four elements on a cylindrical table with periodicity of properties.
In 1862, Julius von **Sachs** produced experimental evidence that starch was a product of photosynthesis.
In 1862, W. **Thomson**, in "On the Age of the Sun's Heat," deduced a maximum limit for the age of the Sun and said that the Earth "must have solidified from its primordial molten state not less than 20 million and not more than 400 million years ago. These limits were rigorous deductions from **Fourier** laws applied to the case of a molten sphere cooling through emission of radiant heat" (Buchwald 1976:383).
In 1863, **Helmholtz**, in *Die Lehre den Tonempfindungen als physiologische Grundlage für die Theorie der Musik*, formulated a theory of hearing in which the transverse fibers of the basilar membrane in the cochlea act as resonators.
By 1863, William **Huggins** had collected several stellar spectra which showed that stars consisted in the same gases as the Sun.
In 1863, Thomas Henry **Huxley**, in *Evidence of Man's Place in Nature*, expounded **Darwin**'s theory of evolution.
In 1864, John Alexander Reina **Newlands** prepared the first two-dimensional periodic table of the elements. This was arranged in the order of atomic weights and remarked the 'law of octaves,' i.e., that every eighth element known at that time had similar properties. In the same year, William **Odling** published a chart with fifty-seven regions including some gaps. Still in the same year, Julius Lothar **Meyer** showed that the ability of elements to form compounds with one another varied periodically with atomic weight.
In 1865, O. F. C. **Deiters**, in *Untersuchungen über Gehirn und Rückenmark des Menschen und der Säugetiere*, proposed the image of the nerve cell which is accepted today: cell body with its nucleus, multiple, branching dendrites, and a single axon.
In 1865, **Bernard** observed, in *Introduction à l'étude de la médecine expérimentale*, that the internal environment was balanced or self-correcting, that disease states are often extreme manifestations of normal processes, and that, between living matter and the physical world, the difference is in the degree of complexity, which is greater in living systems (Bernard 1865:111-117). He was explicit in his attack on biological vitalism.
In 1865, **Lister**, using carbolic acid as antiseptic and sterilizing his instrument, proved the efficacy of antiseptic surgery.
In 1865, **Stradonitz** devised a ring model for the structure of benzene.
In 1865, **Maxwell**, in "A Dynamical Theory of the Electromagnetic Field," concluded that the known electric, magnetic, and electromagnetic phenomena are explained by mathematical equations restating **Coulomb**'s law, **Ampère**'s conjecture, **Faraday**'s law of induction, with the addition of the inversion of Faraday's law, namely, that a magnetic field could be generated by a changing electric field, and the dynamical basis of the theory is the transmission of energy in the required medium, an electromagnetic field-required in order to avoid 'action at a distance.' "The mechanical analogy for [this] field is explicated in terms of energy relations, rather than the pictorial mechanical model contrived in 'On the Physical Lines of Force'" (Harman 1998:116).
In 1865, **Clausius**, in "Ueber verschiedene für die Anwendung bequeme Formen der Hauptgleichungen der mechanischen Wärmetheorie," reformulated "the fundamental laws of the Universe which correspond to the the two fundamental theorems of the mechanical theory of heat. 1. *The energy of the universe is constant*. 2. *The entropy of the universe tends to a maximum*" (Clausius 1865:365).
In 1866, **Haeckel**, in *Generelle Morphologie der Organismen*, challenged the plant/animal division of the living world, recognizing that single-celled forms, the protists, did not fit into either category, and must have arisen separately from plants and animals. At the same time, he published his 'biogenetic law' wherein ontogeny is erroneously said to recapitulate phylogeny. However, in attempting to rationalize it, he invoked the mechanism of changes in developmental timing, coining the word 'heterochrony.' He also coined 'ecology,' 'ontogeny,' and 'phylogeny.' The recapitulation theory of

development was widely held at the time, and earlier by **Goethe**, Johann Gottfried von Herder, and biologists associated with *naturphilosophie*. Haeckel's version of Darwinism persisted, e.g., in the ideas of the socialist Karl Kautsky, August **Weismann**, **Freud**, Carl Gustave **Jung**, and the Hitlerite Monist League (Gould 1977:115-116). Haeckel also published misleading illustrations in support of his theory.
In 1866, Max **Schultze** discovered two sorts of 'receptors' in the retina.
In 1866, Alfred **Nobel** patented *kiselguhr*, or dynamite, in Sweden.
In 1866, **Huggins** made the first spectroscopic observations of a nova.
In 1866, Giovanni Virginio **Schiaparelli** postulated that meteors are debris from comets.
In 1867, Theodor **Meynert** showed that the laminated form of the cortex was due to the distribution in parallel layers of different categories of neurons (Meynert 1867-1868)
In 1867, **Helmholtz**, in *Handbuch de Physiologischen Optik*, *Volume III*, said that "disparate images from corresponding retinal points enter the sensorium distinct and intact, and that their union into a single image is an unconscious act of judgement dependent on prior experience" (Turner 1976:248).
In 1867, Fleeming **Jenkin**, in a review of *Origin of Species*, pointed out that variation would be eliminated with an inheritance which was a blend of the parents. Blending inheritance is analogous to mixed paints. This criticism caused **Darwin**, in subsequent editions, to resurrect **Lamarck's** theory of acquired characters, which was not finally put aside until the rediscovery of **Mendel** and unit characters in 1900.
In 1867, **Darwin**, working on his theory of sexual selection and failing to understand why caterpillars are often brightly adorned, wrote **Wallace**, who explained his theory of warning coloration, which today is proven.
In 1867, Aleksander Onufriyevich **Kovalevsky** extended the germ layer concept to invertibrates.
In 1867, Wilhelm **Griesinger** published the second edition of his psychiatric textbook in which he said that mental diseases are brain diseases and that the onset of psychosis was experienced as an intrusion of a 'thou' on the 'I,' or ego.
In 1867, Karl **Marx**, in *Das Kapital*, maintained the value, or exchange relation, of commodities is characterized by its alienation from its use-value, and thus its value as the product of human labor, which the capitalist treats as a variable and against which he accounts his surplus.
In 1868, Josef **Breuer** and Ewald **Hering**, by occluding the trachea at the end of inhaling or exhaling, demonstrated that the lungs 'self-regulate' breathing, i.e., they contain receptors that detect the degree to which they are stretched. These receptors transmit signals to the brain via the vagus nerve which initiates the opposite signal back to the lungs. This was one of the first 'feedback' mechanisms demonstrated in mammals.
In 1868, **Ångström**, in an atlas of the solar spectrum, measured the wavelengths of over a thousand spectral lines in units which came to be called an 'angstrom' in his honor.
In 1868, **Boltzmann**, in "Studien über das Gleichgewicht der lebendingen Kraft zwischen bewegten materiellen Punkten" on thermal equilibrium, extended **Maxwell**'s theory of the distribution of energy among colliding molecules in equilibrium in a conservative force field. By assuming a fixed amount of energy divided among a finite number of molecules, i.e., all combinations of energies are equally probable, the problem could treated by combinatorial analysis. "The result was a new exponential formula, now known as the 'Boltzman factor' and basic to all modern calculations in statistical mechanics" (Brush 1976:261).
In 1868, **Maxwell**, in "On Governors," published a mathematical analysis of governors, the first significant paper on feedback mechanisms.
In 1869, Dmitri Ivanovich **Mendeléev** and, independently, Julius Lother **Meyer** formulated the 'Periodic law.' Meyer showed that **Newlands**' 'Law of octaves' only holds for the first two periods. He also evolved the atomic volume curve which represented graphically the relation between the atomic weights and the volumes of the elements, expressed by dividing atomic weights by specific gravities. Mendeléev placed the chemical elements in seven rows in an order where those elements having similar chemical properties were aligned vertically. He also left gaps in his table where he predicted elements would be found, which, in due course, they were, removing any doubt as to the validity of the periodic table.
In 1869, Eduard **von Hartmann** published *Philosophie des Unbewussten*, in which the '*unbewussten*',' or 'unconscious,' included both Georg Frederick Hegel's 'idée' and the 'will' of **Schopenhauer** and others. Modern discussions of the unconscious are generally dated from this time.
In 1869, George M. **Beard** distinguished 'neurasthenia,' a nervous disease of men, from hysteria, a women's disease, as, in an earlier time, men's 'hypochondriasis' had been distinguished from women's ' vapeurs.' Subforms of neurasthenia came to be called phobias.

In 1869, Karoly Maria **Benkert** invented 'homosexuality' as a behavioral category.
In 1869, Francis **Galton**, in *Hereditary Genius*, suggested a genetic basis for intelligence. He established that the science of heredity could be concerned with deviations measured in statistical units. His discovery of the standard deviation gave him the mathematical machinery to handle variability and to treat population as a unit of explanation.
In 1869, Ludwig Valentin **Lorenz**, as a result of his optical research and his wave equation, developed an equation relating the density of a body and its index of refraction and verified it in the case of water. In 1878, Hendrik Antoon **Lorentz**, independently, developed the same constant, now known as the Lorentz-Lorenz formula.
In 1869, Elwin Bruno **Christoffel**, in "Ueber die Transformation der homogen Differentalausdrücke zweiten Grades," introduced an operation which transformed one quadratic differential form into another, i.e., two types of curvature components. This was a basic question arising from **Riemann**'s geometry and was later called 'covariant differentiation' by C. Gregorio **Ricci-Curbastro** (Ehlers 1981:527-542).
In 1869, Georg **Cantor** published his proof of the apparent paradox which stated says that an infinite class has the unique property that the whole is no greater than *some* of its parts. The proof involves acknowledgement that the class of integers is infinite and countable and, then, establishing a one-to-one correspondence between the class of integers and its subset, the class of even numbers. This was the beginning of set theory. The first transfinite number was created to describe the cardinality of countable infinite classes.
In 1869, Charles Joseph **Minard**, in a graph showing Napoleon's march to Moscow and back, set a new standard for such representations plotting multivariate data: The size of the army, its location on a two-dimensional surface, its direction, and the temperature on various dates during the retreat.
In 1869, John **Hyatt** produced 'celluloid,' the first synthetic plastic to be put into wide use.
In 1870, Gustave **Fritsch** and Edward **Hitzig** demonstrated an inseparable link between electricity and cerebral function, but did not show where the electricity was produced.
In 1870, Camillo **Golgi** established that neurons in the brain sent information to the motor nerves and received it from the sensory nerves. He developed a silver impregnation method that allowed microscopic visualization of the anatomy of the whole neuron.
In 1870, Friedrich **Goltz** suggested that the semicircular canals of the inner ear are the sense organs that detect the position of the head relative to to the gravitational field.
[The demonstrations of the 1870s and 1880s that the internal processes of cell division were fundamentally the same in plants and animals magnified the cell as a universal unit of structure.]
In 1870, William Kingdon **Clifford**, introducing the details of non-Euclidean geometry to the English, raised the question of "variation in the curvature of space," describing it as "analogous to little hills on the surface [of the Earth] which is on average flat," that "the ordinary laws of geometry are not valid in them[, and] that this property of being curved or distorted is continually being passed on from one portion of space to another after the manner of a wave" (Clifford 1876:21-22).
In 1871, St. George **Mivart**, in *On the Genesis of Species*, claimed that, contrary to **Darwin**, species arise suddenly with large-scale changes already intact: Inheritance by blending, as Darwin proposed, meant that variation would have to be sustained by an extremely high mutation rate.
In 1871, **Darwin**, in *The Descent of Man, and Selection in Relation to Sex*, suggested that there was no sharp discontinuity between the evolution of humans and animals, that "the difference was one of degree and not of kind" (Darwin 1871:127), and that, therefore, not only was the behavior of animals guided in part by primitive reasoning processes, but human behavior must also be guided in part by instincts, e.g., the "instinctive tendency to speak" (*ibid*.:101).
In 1871, Johann Friedrich **Miescher** isolated a substance from the nuclei of white blood cells which is soluble in alkalis but not in acids. This substance came to be called 'nucleic acid.' (Miescher 1871).
In 1871, **Maxwell**, in *Theory of Heat*, proposed the idea that an intelligent being, named by W. **Thomson** 'Maxwell's Demon,' could by simple inspection of molecules (i.e., without doing work) violate the second law. "The demon points to...the problem of reconciling the irreversible increase in entropy of the universe demanded by thermodynamics with the dynamical laws governing the motion of molecules, which reversible with respect to time" (Everitt 1976:227). Maxwell also introduced the terms 'vector' and 'scalar potential.'
In 1871, **Crookes**, in the course of trying to weigh thallium, created a vacuum "on the order of one millionth of an atmosphere [which] made possible the discovery of X-rays and the electron" (Brock 1976:475).
In 1871, **Strutt**, also known as Baron Rayleigh, propounded a general law relating the intensity of light scattered from small particles to its wavelength when the dimensions of the particles are much less than the wavelength. He expressed this scattering as a function of the inverse fourth power of the

wavelength of the incident light.
In 1872, John Thomas **Gulick** pointed out the inevitability of divergence among isolated groups even without environmental difference.
In 1872, **Ludwig** and Edward **Pfünger** showed that oxidation occurs in tissues, not in the blood.
In 1872, **Boltzmann**, in "Weitere Studien über das Wärmegleichgewicht unter Gasmolekülen," argued that the second law of thermodynamics, and the spontaneous increase in entropy which it predicts, can only be understood in terms of large populations of particles, not individual trajectories, the primitive object of classical physics. Influenced by **Darwin**, he replaced the study of individuals "with the study of populations, and showed that slight variations taking place over a long period of time can generate evolution at a collective level" (Prigogine 1996:20; Boltzmann 1905:193-197). Assuming that all microscopic states of a system have the same probability, he established that entropy was statistical; however, by the same token he could not establish that long-term deviation from equilibrium was *not* impossible, even though very improbable. He proposed an equation which gives a mathematical description of a state and how it is changing; i.e., if the Maxwellian *E*-function (Boltzmann's *H*-function) is identical to entropy, then the definition of entropy can be extended to nonequilibrium states.
In 1872, Christian Felix **Klein** outlined his synthesis of geometric group transformations, in which he showed that there were three types of geometry: the **Bolyai-Lobachevsky** type where straight lines have two infinitely distant points, the **Riemann** type where the points are imaginary, and **Euclid**'s type. The so-called 'Klein bottle,' with no inside, came out of these studies. The best known of his transformations is the so-called 'Klein four-group,' which was exploited by the Structuralists after the second world war.
In 1872, Julius Wilhelm Richard **Dedekind**, in *Stetigkeit und die Irrationalzahlen*, maintained that the essence of the continuity of a line consists in the possibility of dividing that by a single point, i.e., an irrational number, e.g., a fraction. This division is known as a *Schnitt*, or 'Dedekind Cut.' By putting the points into a one-to-one correspondence with the rational numbers, a continuum can consist of rational numbers and the fundamental theorems on limits can be proved rigorously. Dedekind regarded arithmetic as a "natural consequence of the simplest arithmetic act, that of counting" (Dedekind 1872:4). The redefinition of number and limit as ordinal concepts make "calculus...not a branch of the science of quantity, but of the logic of relations" (Boyer 1949:294).
In 1872, Claude **Monet** painted "Impression: Sunrise," which has been used to mark the beginning of Modern Art because it lent its name to 'Impressionism.' This is a style concerned with portraying variations in light and color brought on by hour and season as deduced both from observation and optical principles. On the other hand, his contemporary, Paul **Cézanne** simplified forms to their basic geometric equivalents and was honored as their master by early abstract painters Henri Matisse and Pablo Picasso.
In 1873, Anton **Schneider** described chromosomes during the process of mitosis during cell division.
In 1873, Moritz **Wagner** emphasized the effects of different environments on isolated groups of animals.
In 1873 and 1874, Ernst **Mach**, **Breuer**, and Alexander **Crum Brown**, each independently and each based on **Goltz**'s 1870 suggestion, published the insight that the flow of endolymph in the canals of the inner ear during motion stimulates the receptors in the ampullae at the end of the canals. Crum Brown also pointed out that the two canals received their stimuli from motions in opposite directions.
In 1873, **Maxwell**, *A Treatise on Electricity and Magnetism*, tried to finish off the notion of action-at-a-distance and wrote a summary of his equations in terms of symmetry and vector structure. This relational Lagrangian method enabled him to forego any mention of mechanical aether, supposed by many physicists of the time to be the fundamental electromagnetic substance. Maxwell perceived that these equations had wave solutions and that electromagnetic waves of all frequencies were generated by accelerating electric charges and travelled at the same speed. Moreover, based on his electromagnetic theory, he established that light exerts a radiation pressure. This conclusion had many implications (Everitt 1976:212). He also proposed that these waves could be generated in the laboratory by creating an quickly oscillating current.
In 1873, Josiah Willard **Gibbs**, in "Graphical Methods in the Thermodynamics of Fluids," gave the fundamental equation for entropy, $dU = TdS - PdV$, where U is the internal energy, T is the absolute temperature, S is entropy, P is the pressure on the system, and V is its volume.
In 1873, Joseph Antoine Ferdinand **Plateau**, in *Statique expérimentale et théorique des Liquides soumis aux seules Forces moléculaires*, showed experimentally that liquid surfaces always assume a curvature, i.e., the smallest possible area, when there is no appreciable external force, like gravity, exerted (Adam 1930:1).
In 1874, W. **Betz** extrapolated to the telencephalon the posterior-anterior sensorimotor dichotomy that

prevails along the nerve axis, from the spinal cord to the brain.
In 1874, S. **Bodkin** published his observation that, in patients with leukemia, transcutaneous electrical stimulation of the enlarged spleen led to reduction in size and an increase in leukocyte count.
In 1874, Franz **Brentano**, in *Psychologie vom empirischen Standpunkte*, maintained that mental processes should be treated as intentional acts rather than passive processes. Among the auditors of classes which he taught were Edmund Husserl, Thomas Masaryk, Franz Kafka, Rudolf Steiner, and **Freud**.
In 1874, Marie Alfred **Cornu** described a graphical curve, known as the 'Cornu spiral,' for calculating light intensities in **Fresnel** diffraction.
In 1874, **Strutt**, in "The Kinetic Theory of the Dissipation of Energy," pointed out the 'reversibility paradox' occasioned by **Boltzmann**'s *H* -function, i.e., the "apparent contradiction between...the reversibility of individual collisions and the irreversibility predicted by the theorem itself for a system of many molecules" (Brush 1976:263).
In 1874, **Boltzmann**, in "Zur Theorie der elastischen Nachwirkung," introduced 'memory effects' into the relation between stresses and strains of an elastic continuum, i.e., "the circumstance in which a strain that occurred previously reduces the force required to produce a strain of the same kind" (Boltzmann, quoted in Cercignani 1998:161). This laid the foundations for 'hereditary mechanics,' a term introduced by E. Picard in 1907.
In 1874, William Stanley **Jevons**, in *Principles of Science*, demonstrated a symbolic and logical method, intended to supplant **Boole** and John **Venn**, that involved permutations of *ABC* corresponding to the eight compartments of Venn's three-circle diagram. Jevons also designed labor-saving logic machines for exploiting his method, among them an 'abacus' similar to a primitive **IBM** punchcard machine.
In 1875, Richard **Caton** demonstrated that the brain's electricity originated in the cerebral cortex.
In 1875, Eduard **Seuss** coined the term 'biosphere' for where life can exist, i.e., on the Earth's surface and adjacent atmosphere.
In 1875, **Galton** demonstrated "the usefulness of twin studies for elucidating the relative influence of nature (heredity) and nurture (environment) upon behavioral traits" (King and Stansfield 1997:382).
In 1875, **Crookes** developed a 'light-mill,' or radiometer. This is a sealed and evacuated (as far as possible) glass chamber containing a paddle wheel with vanes blackened on one side and silvered on the other. This spins rapidly when it is impinged upon by radiant heat; i.e., "a rise in pressure occurred on the hotter side of the vanes, which consequently moved away from the incident radiation" (Brock 1976:480n10).
In 1875, George Henry **Lewes**, in the second volume of *Problems of Life and Mind*, used 'emergent' to describe a 'resultant' which "arises out of...combined agencies, but in a form which does not display the agents in action.... The emergent is unlike its components in so far as...it cannot be reduced either to their sum or their difference" (Lewes 1875:368-369).
In the 1870s, **Mach** stated the principle that the inertia of a piece of matter is attributable to the interaction between that piece of matter and the rest of the Universe, i.e., "a body in an empty universe has no inertia" (Hiebert 1978:599). This idea has roots in the writings of **Leibniz** and was widely accepted among so-called Energists, e.g., **Mayer**, who held the energy was a substance, i.e., matter, and that atoms were only a convenience (Cercignani 1998:203).
Beginning in 1876 with anthrax, Robert **Koch** devised the method of employing aniline dyes to stain microorganisms. By this means he was able to isolate pure cultures of bacteria and showed the bacterial origin of many infectious diseases, including tuberculosis, cholera, bubonic plague, and sleeping sickness. This confirmed the germ theory of disease.
In 1876, **Wallace** published his special contribution to the study of evolution, *The Geography of Animal Distribution.*
In 1876, Carl **Wernicke** published a paper in which he described a new type of aphasia, involving an impairment of comprehension rather than execution, and located at a different locus from the aphasia described by **Broca**. According to Wernicke, interconnections between functional sites make more complex intellectual functions possible.
In 1876, Alexander Graham **Bell** invented the telephone.
In 1876, Nikolas August **Otto** designed the first four-stroke piston engine.
In 1877, Ernst **Abbé** published the first in a series of contributions to the theory of microscopic optics.
In 1877, **Maxwell**, in "On Boltzmann's Theorem on the Average Distribution of Energy in a System of Material Points," proved that "the densities of the constituent components in a rotating mixture of gases would be the same as if each gas were present by itself. Hence gaseous mixtures could be separated by means of a centrifuge" (Everitt 1976:224).
In 1877, **Schiaparelli** reported detailed observations of Martian '*canali*,' or channels.

In 1878, F. **Heinke** published a study on herring, which climaxed the focus on animal studies.
In 1878, Emil Hermann **Fischer** figured out the chemical formula for phenylhydrazine, a compound he had discovered. This led to his research on sugars, of which he synthesized glucose and about thirty others, purines, of which he synthesized about one hundred thirty, and to the development of synthetic drugs like novacaine.
In 1878, Wilhelm **Wundt** founded the first laboratory devoted to physiological psychology. He intuited that dreaming is the product of the simultaneous enhancement and impairment of different parts of the brain.
In 1878, J. W. **Gibbs**, in the abstract of "On the Equilibrium of Heterogenous Substances," asserted that "when the entropy of a system has reached a maximum, the system will be in a state of equilibrium" (Gibbs 1878:354). In the paper itself, published in two parts, in 1876 and 1878, he proceeded to generalize thermodynamic equilibrium theory, removing one restriction after another, and deriving, for example, the chemical phase rule: "In a heterogenous system composed of several homogenous phases, the fundamental equilibrium condition leads to the requirement that temperature, pressure, and the chemical potential of each independent chemical component must have the same values throughout the system" (Klein 1976:390). Other experimental facts, "such as the theories of catalysis, of solid solutions, and of the actions of semi-permeable diaphragms and osmotic pressure, [he] showed...are in fact simple, direct and necessary consequences of the fundamental laws of thermodynamics" (Bumstead 1903:xviii). He also defined what has came to be known as 'Gibb's function,' or 'free energy,' a measure of a system's ability to do work; i.e., that portion of the total energy "which can be freely converted to other forms of energy.... In any spontaneous reaction occurring at a constant temperature and volume the free energy must decrease. Hence the free energy, not the total energy change measured by the evolution of heat, determines the direction of any reaction" (Turner 1976:244).
In 1878, **Maxwell**, in "On Stresses in Rarefied Gases Arising From Inequalities of Temperature," explaining the action of a radiometer, noted that "when a viscous fluid moves past a solid body, it generates tangential stresses by sliding [i.e., 'slip' effects] over the surface with a finite velocity" (Everitt 1976:224). Indepenently, Osbourne **Reynolds** came to a similar conclusion about the same time.
In 1879, Walther **Flemming** named 'chromatin' and 'mitosis,' made the first accurate counts of chromosome numbers,and discerned the longitudinal splitting of chromosomes.
In 1879, **Crookes**, in "On the Illumination of Lines of Molecular Pressure, and the Trajectory of Molecules," attempted to determine the paths of the 'lines of molecular pressure,' or cathode rays, in an evacuated glass tube through which two electrodes are passed. When high voltage is applied, electrons are emitted from the radiometer vanes, which act as a cathode, and, under reduced pressure, the vane turns and the electrons are accelerated toward the anode. Many of these electrons, or cathode rays, miss the anode and, striking the tube wall, exhibit fluorescence.
In 1879, Jules-Henri **Poincaré** showed how automorphic functions can be used to express coordinates of any point in an algebraic curve as uniform functions of a single parameter.
In 1879, **Stefan**, in "åber die Beziehung zwischen der Wärmestrahlung," conjectured that that the radiant energy emitted by an enclosure equivalent to a black body is proportional to the fourth power of the body's temperature.
In 1879, **Planck**, in *Vorlesungen über Thermodynamik*, opposed the idea that the validity of the second law depends upon the existence of an observer or his lack of information. The implication is that irreversibility is natural.
In 1879, Albert Abraham **Michelson** determined the speed of light to be 186,350 miles per second + or - 30 miles per second.
In 1879, Edwin Herbert **Hall** discovered a component of an electric field which when crossed with a magnetic field becomes perpendicular to the electric field. Known as 'Hall current,' or the 'Hall effect,' it was not explained until the advent of quantum theory.
In 1879, Gottlob **Frege**, in *Begriffsschrift*, proffered the first system of propositional calculus, also known as the calculus of sentential conjunctions.
In 1880, Sydney **Ringer** studied the use of body temperature in diagnosis and inorganic ions in heart contractions, making possible the analysis of heart metabolism.
In 1881, **Wallace** proposed to date the beginning of the Cambrian period about 28 million years ago.
In 1881, Lucian **Galard** and John D. **Gibbs** obtained patents for systems of alternating electrical current.
In 1881, **Venn**, in *Symbolic Logic*, represented logical propositions diagrammatically.
In 1882, Eduard **Strasburger** coined the terms 'cytoplasm' and 'nucleoplasm.'

In 1882, Dmitri Iosefovich **Ivanovsky** demonstrated that tobacco mosaic disease is caused by "a self-replicating agent (or virus) that will pass through bacterial filters and can neither be seen with light microscope nor grown upon bacteriological media" (King and Stansfield 1997:382).

In 1882, **Helmholtz**, independently of **Gibbs**, distinguished between 'bound' and 'free energy' in chemical reactions, the formula for which, free energy equals internal energy minus the temperature of the system times its entropy, is known as the Gibbs-Helmholtz equation.

In 1882, **Michelson** described an 'interferometer,' an interference meter, which had a half-silvered mirror in order to split incident beams of light into two parts at right angles to each other.

In 1883, Ilia Il'ich, also known as Élie, **Metchnikoff** identified the phagocyte as a purveyor of cellular defense, thereby raising questions of organismic identity, i.e., how do organisms protect themselves from their environment? He recognized that phagocytes, cells capable of engulfing particles, such as bacteria, define the 'self' constituents; that is, they devour tadpole tails as frogs metamorphosize into adults. Viewing the immune system as "self-referential, not antigen-driven," he saw inflammation as "self-directed 'immune' surveillance" (Tauber 1990:566). This biological line of investigation developed into 'humoral theory,' after the classic term for body fluids, and was driven by the need to understand what identified non-host elements. It may be noted that bloodletting did not go out of fashion until about this time.

In 1883, Edouard **van Beneden**, studying nuclear division in the germ cells of a round worm, explained the "longstanding paradox that the maternal and paternal contributions to the character of the progeny seem often to be equal, despite the enormous difference in size between the egg and the sperm" (Alberts **et al.** 1994:1014). This explanation was made possible by his discovery that, while gamete nuclei, i.e., the sperm and egg nuclei, each have two chromosomes, the fertilized egg has four chromosomes. This implies that chromosomes carry genetic information and that germ cells, in contrast to somatic cells, must undergo a special sort of nuclear division in which the chromosome complement is halved. This process came to be known as 'meiosis,' a word which means that something appears to be of less size or significance than it really is.

In 1883, **Weismann** stated that his 'germ-line theory,' namely, that the separation of the germ-line from the phenotype of the body, or soma, is final from the point in the egg's development when it is determined which cells will become the ovary or the testes--and potentially immortal. In human beings, for example, this point occurs at the 59th day of gestation. This doctrine refuted **Lamarck's** theory that acquired characters can be inherited. It also made it possible to understand the genetics of animals (though not plants), and, hence, evolution without understanding development.

In 1883, Max **Rubner** said that a body's metabolic rate was proportional to its surface area.

In 1883, Oscar **Hertwig** described 'mesenchyme,' a term he coined for the protoplasmic network filled with a intercellular fluid which gives rise to connective and other tissue.

In 1883, Wilhelm **Roux** suggested that the filaments within the cell's nucleus carry the hereditary factors.

In 1883, Karl Georg Friedrich Rudolf **Leuckart** and A. P. **Thomas**, independently, working on the life cycle of sheep liver flukes, determined the snails were intermediate hosts.

In 1883, **Galton** advocated selective breeding of human beings, or 'eugenics,' which he coined from a Greek word meaning "hereditarily endowed with noble qualities" (Galton 1883:24). Eugenics was discredited through the uses to which it was put, especially during the 1930s and 1940s.

In 1883, George John **Romanes** published *Mental Evolution in Animals*, the first modern text comparing the psychology of humans and animals in objective terms.

In I883, Jean-Martin **Charcot** was able to obtain recognition of the neurological reality of hypnotism from the French Academy of Sciences. He thought only hysterics were susceptible to hypnosis, i.e., that hypnosis was itself a pathological condition.

In 1883, Pierre **Curie** discovered piezoelectricity, a form of electric polarity, in crystals.

In 1883, **Mach**, in *Die Mechanik in ihrer Entwicklung*, translated as *The Science of Mechanics: A Critical and Historical Account of Its Development*, attempted to eliminate metaphysics by reducing science to the sum of what appears to the senses, and, in particular, attacked **Newton**'s assumption that absolute rotation is observable. "The object of science [is] to replace, or *save* experiences, by the reproduction and anticipation of facts in thought...; [but] we never reproduce the facts in full..., only that side of them which is important to us, moved directly or indirectly by practical interest" (Mach 1883:481-482). Concepts both compete for adherents and adapt to facts and to one another in order to survive. Mach also did work in the field of ballistics, where the 'Mach number' borrows his name.

In 1883, **Boltzmann**, in "Ableitung des Stefan'schen Gesetzes," based on the fact that electromagnetic waves exert pressure on the walls of a radiation-filled enclosure, worked out theoretically a relation between thermodynamics and **Maxwell**'s electromagnetic equations, i.e., the

fourth power law previously found experimentally by **Stefan**.
In 1883, **Reynolds** introduced the 'Reynolds' number,' a dimensionless quantity associated with the smoothness of the flow of a fluid, which characterizes laminar and turbulent flow by relating kinetic to viscous forces.
In 1883, Gottlieb **Daimler** patented the gasoline combustion engine.
In 1884, A. **Kossel** isolated a protein from the nuclei of goose erythrocytes and called them 'histones.'
In 1884, Julius **Kollman** described the phenomena of 'neoteny' in his study of the axolotl form of *Ambystoma tigrinum*.
In 1884, J. Hughlings **Jackson** published his speculation that the neuropathological dissolution of function tends to roughly reverse the order of the acquisition of that function.
In 1884, **Freud** published a paper in which he found cocaine, an alkaloid in coca, effective against fatigue and neurasthenia.
In 1884, Jacobus Hendricus **van't Hoff** explained the principle of equilibrium in chemical dynamics and osmotic electrical conductivity.
In 1884, Edwin A. **Abbott**, in *Flatland: A Romance of Many Dimensions*, recounted the adventures of 'A. Square,' a character who inhabits a two-dimensional world populated by other geometrical figures--triangles, squares, pentagons, hexagons, etc. Toward the end of the story, on the first day of 2000, a spherical creature from 'Spaceland' carries A. Square off to show him the three-dimensional nature of the larger world. There A. Square speculates that Spaceland may itself exist as a subspace of a larger four-dimensional universe, an "infallible confirmation of the series [of end-points of a line, a square, a cube, etc.], 2, 4, 8, 16" (Abbott 1884:on line).
In 1884, Hilaire de **Chardonnet** invented the first artificial textile, which was made from cellulose. It was later named rayon.
By 1885, **Hertwig** and **Strasburger** developed the conception that the nucleus is the basis of heredity. Subsequently, Hertwig asserted that from the biological point of view sex is merely the union of two cells.
In 1885, **Roux**, testing **Weismann's** idea of heredity and germ plasm, did one of the first experiments in what became experimental embryology when he showed that embryonic chick cells could be maintained alive in a saline solution.
In 1885, Ernst **Hartwig** noticed a nova in the *Andromeda* nebulae. Before it faded, he noted its peak intensity which was as great as the rest of the galaxy combined.
In 1885, Friedrich Wilhelm **Nietzsche** completed *Also sprach Zarathustra* in which he created the term 'id,' meaning the resevoir of human instinctual drives. Other psychological terms employed frequently in his writings include sublimation and inhibition.
In 1886, Hippolyte **Bernheim** published his argument that hypnotism was a special case of general human suggestibility; i.e., anyone could be hypnotized.
[In the course of the nineteenth century, the practice of hypnotism brought with it greater popular, as well as medical, awareness of the split between conscious and unconscious behavior, as may be seen in the stories of E. T. A. Hoffman, E. A. Poe, Honoré de Balzac, Alexander Dumas, Victor Hugo, R. L. Stevenson, Fyodor Dostoevsky, and others (Ellenberger 1970:158-170). Greater experience with hypnotism also brought disillusion with its limitations, e.g., sensitized patients confirming their doctor's unspoken expectations, etc.].
In 1886, Pierre **Janet**, in *L'Automatisme Psychologique*, introduced the term 'subconscious' in the context of patients' fixed ideas.
In 1886, Richard von **Krafft-Ebing**, in *Psychopathia Sexualis*, included among his classifications the terms 'sadism' (after Donatien de Sade) and 'masochism' (after Leopold Sacher-Masoch).
In 1887, Wilhelm **His** , in "Zur Geschichte des menschlichen Rückenmarkes und der Nervenwurzeln," published his discovery that in the early stages of development the nervous system is made up of independent, closely packed cells without axons.
In 1887, Auguste **Forel** showed that certain degenerative effects remained limited to the cell body and its dendrites.
In 1887, Svante August **Arrhenius** announced the theory of electrolytic dissociation which says that in aqueous solution the molecules of all acids, bases, and salts are split into ions. This theory depends on **van't Hoff's** equilibrium principle.
In 1887, **Michelson** and Edward W. **Morley**, using an interferometer to investigate whether the speed of light depends on the direction the light beam moves, failed to detect the motion of the Earth with respect to the aether, thereby refuting the hypothesis that the aether exists.
In 1887, Heinrich Rudolf **Hertz** produced Maxwellian electromagnetic waves, the first radio waves. He demonstrated that they travel at the velocity of light and can be reflected, refracted, and polarized like light. They also led him to drop Helmholtz's action-at-a-distance point of view. The unit of

frequency was named in his honor.
In 1888, **Roux** removed from a frog's egg one of the two cells existing after the first cleavage and obtained a half embryo.
In 1888, Santiago **Ramón y Cajal**, employing **Golgi**'s staining technique, launched attacks on the 'nerve-net hypothesis' by demonstrating the anatomical independence of the axon from its target cell, i.e., that neurons are juxtaposed, not continuous. At the time it was not realized that nerve cells do not interact through cell bodies, but through their axons and dendrites. This permitted two hypotheses: that of the nerve-net or continuous network and that of the neuron or contiguous, but independent cells. This question was not settled until the increased resolving power of electron microscopy after 1950.
In 1888, George Henry Falkiner **Nuttall** showed the blood serum contained bactericidal substances, from which he concluded that phagocytes were merely accessory to the protection offered by serum.
In 1888, Heinrich Wilhelm Gottfried **Waldeyer** named **Roux**'s filaments 'chromosomes.'
In 1888, Theodore **Boveri** described the 'centriole' which in animals and most plants lies just outside a cell's nucleus.
Between 1888 and 1893, Marius Sophus **Lie** and Friedrich **Engel** published the six volumes of *Theorie der Transformationsgruppen* in which they showed that different sorts of symmetry form mathematical groups. Lie divided these groups into "deux grandes classes: les groups *intégrables* et les groupes *non intégrables*" (Cartan 1894:103).
In 1888, Nicola **Tesla** patented his invention of alternating electric current.
In the late 1880s, Louis **Lewin** and Arthur **Heffter** isolated the peyote alkaloid, *mezcal*.
In 1889, **Wallace** published his book on natural selection, which he called *Darwinism*.
In 1889, George Francis **FitzGerald**, in "The Ether and the Earth's Atmosphere," suggested that the null results of the **Michelson-Morley** experiment could be explained by the shrinkage of a body due to motion at speeds close to that of light, and that the only assumption necessary is that intermolecular forces obey the same laws as electromagnetic forces (FitzGerald 1889:390). In 1892, **Lorentz**, independently, reached the same conclusions about the contraction of a moving body.
In 1889, Giuseppe **Peano** postulated five properties of natural numbers in attempting to be as rigorous with numbers as **Euclid** had been with geometry.
In 1890, **Boveri** and Jean Louis **Guignand** established the numerical equality of paternal and maternal chromosomes at fertilization.
In 1890, Hans **Driesch** separated two cells of a fertized sea urchin egg by shaking with very different results than **Roux**: From a single cell arose an entire sea urchin. Roux's frog experiment was repeated and by merely turning the cell over it developed into a whole frog. Thus, a cell's competence to develop fully was established. Roux was not deterred by this result and continued to maintain, against **Weismann's** germ-line theory, that the mechanics of development were distributed throughout the cytoplasm and triggered by each prior stage.
In 1890, Richard **Altmann** reported the presence within cells of organisms which live as intracellular symbionts, and were later named mitochondria.
In 1890, Emil Adoph von **Behring** and Shibasaburo **Kitasato** showed that antitoxins, that is, antibodies, could be produced--without any knowledge of their chemical nature--which neutralized the soluble toxins, classically, diptheria, tetanus, and botulism.
In 1890, Theobold **Smith** demonstrated the transmission of disease by an 'arthropod vector,' a tick.
In 1890, William **James**, in *Principles of Psychology*, accepted the idea that all behavior derives from the nervous system. He also suggested that learning is accompanied by an increase in neuronal efficiency, and that primary memory, or short-term memory, is memory of the immediate past still in consciousness where it is the object of selective attention.
In 1890, Eugen **Bleuler** declared that 'dementia praecox' was curable.
In 1890, **Michaelson**, in "On the Application of Interference Methods to Astronomical Measurements," described the utility of interferometers "in measuring the angular size and the one-dimensional brightness distribution of sources that are too small to be resolved by a single telescope" (Lang and Gingerich 1979:2).
Before 1890, Herman **Hollerith** invented a punch card tabulator which was used in the United States Census of 1890. Hollerith's company eventually became **IBM**.
In the 1890s, William **Coley** observed that some of his cancer patients were able to eliminate their cancer after contracting severe bacterial infections and so causing him to use bacterial extracts to activate the immune system with some good results.
In 1891, Marie Eugene **Dubois** discovered 'Javaman,' now known as *Homo erectus*.
In 1891, **Waldeyer** named nerve cells 'neurons.'.

In 1891, George Redmayne **Murray** successfully treated hypothyroid patients with a preparation of sheep thyroid.
In 1892, **Poincaré** published the first of three volumes on celestial mechanics in which he made fundamental mathematical discoveries, such as his demonstration that dynamical systems are non-integrable, i.e., they are neither static nor deterministic. He also identified the reason for this, which is the existence of resonances between the degrees of freedom of, e.g., harmonic oscillators. His memoirs on 'analysis situs,' as it was then called, marked the beginning of modern topology.
In 1892, **Lorentz**, in "La théorie électromagnétique de **Maxwell** et son application aux corps mouvants," proposed a theory of 'charged particles,' in which a body carries a charge if it has an excess of positive or negative particles, an electric current in a conductor is a flow of particulate particles, and the particles create the electromagnetic field. "Because Lorentz completely separated ether [i.e., the field] and matter, he needed only one pair of directed magnitudes-one electric and one magnetic-to define the field at a point" (McCormmach 1976:494). He also derived **Fresnel**'s 'drag coefficient,' the measure of the motion that a moving transparent body communicates to light passing through it, and demonstrated that the drag was the result of the interference of light.
In 1893, Andreas Franz Wilhelm **Schimper** proposed the idea that the photosynthetic parts of plant cells came from cyanobacteria.
In 1893, **Freud** and **Breuer** published *Über den Psychischen Mechanismus Hysterischer*, marking the beginning of psychoanalysis. They claimed that "hysterics suffer mainly from reminescences" (Breuer and Freud 1893:7).
In 1893, **Michaelson** completed the measurement of the standard meter in terms of the wave length of the red line of the cadmium spectrum, providing an absolute and reproducible standard.
In 1893, Emile **Durkheim** published the first of a series of sociological books in which he explained how the ostensible explanations of theistic world-views, e.g., curiosity about the seasons or the rest of the natural environment, are actually "phrased so as to satisfy a dominant social concern, the problem of how to organize together in society" (Douglas 1966:91).
In 1894, William **Bateson**, in *Materials for the Study of Variation*, emphasized the importance of discontinuous variations and described and named homeotic mutations.
In 1894, H. J. H. **Fenton** discovered a reaction, to which he lent his name, now considered to be one of the most important mechanisms of oxidative damage in living cells.
In 1894, **Ramón y Cajal**, combining and extending the ideas of E. **Tanzi** and E. **Lugaro**, proposed the plastic, or functional, change hypothesis for neuronal growth, according to which synapses on 'associative pathways' are able to strengthen through use and to make new associations through learning.
In 1894, George **Oliver** and Eduard Albert **Sharpey-Schaeffer** demonstrated the effect of an extract of the adrenal gland, that is to say, a hormone, which contracted blood vessels and muscles and raised blood pressure.
In 1894, Emil **Fischer** suggested that a cell contains a chemically active substance whose geometrical configuration is complementary to that of another substance, fitting it like a key in a lock (Fischer 1894; de Duve 1991:22n8). These studies still form the basis of our notions of enzyme specificity.
[["From the time of [N.] **Carnot** on, when it was discovered that the new science of thermodynamics did not require any sort of picture or model to explain the nature of heat, there had been a widespread hostile attitude among Continental physicists [**Mach** is one example] to any form of hypothetical model in science. By [the time of **Boltzmann**, **Planck**, and **Hertz**], however, new developments in physics were requiring fresh patterns of explanation, and these warranted complex mechanical hypotheses" (Janik and Toulmin 1973:143)]].
In 1894, **Hertz**, in *Principien der Mechanik*, having earlier held that "**Maxwell**'s theory is in Maxwell's equations" (Hertz, quoted in McCormmach 1976:346), noted that mathematical formulas could confer a logical structure on physical reality, creating 'possible sequences' of observed events. Hertz opened *Principien* with the statement that "all physicists agree that the problem of physics consists in tracing the phenomena of nature back to the simple laws of mechanics" (*Ibid*.:348). He went on to trace the classic mechanical formulations of **Newton**, **Lagrange**, and **Hamilton**, but it was one of the last times anyone would make that statement.
In 1894, **Strutt** and William **Ramsay** discovered and isolated argon in the process of explaining the discrepancy between the weight of nitrogen obtained from the air and from ammonia.
In 1894, Élie Joseph **Cartan**, in "Sur la Structure des Groupe de Transformations Finis et Continus," laid out all possible variations of **Lie** groups and gave them names, e.g., U(1), or unitary group with one matrix row, or SU(2), or special unitary group with two matrix rows (Cartan 1894:133-287).
In 1894, Oliver Joseph **Lodge** invented the 'coherer,' a detector used in early radio receivers.

In 1895, Richard F. J. **Pfeiffer** presented the theory that bactericidal substances in the blood, or "Antikörper," were "highly active" and "were formed 'under the influence' of the body's cells and were consumed in the process of destroying bacteria" (Keating and Ousman 1991:248).
In 1895, **Smith** produced a blood deficiency disease in guinea pigs by depriving them of leafy vegetables.
In 1895, Johannes Eugenius Bülow **Warming**, in *Plantesamfund* (which was translated as *The Ecology of Plants* in 1909), plotted the distribution of plants against temperature and moisture.
In 1895, Wilhelm Conrad **Röntgen**, using a **Crookes**' tube, observed a new form of penetrating radiation, which he named X-rays.
In 1895, **Lorentz**, in *Versuch einer Theoris der electrischen und optischen Erscheinungen in bewegten Körpen*, spoke of 'ions,' instead of charged particles, and produced an equation connecting the continuous field with discrete electricity.
In 1895, Guglielmo **Marconi** sent longwave wireless telegraphic, or radio, signals over a distance of more than a mile.
In 1896, **Romanes** promulgated the notion that behavior is species-dependent and phyletic, or inherited. He also coined the term 'Neo-Darwinism' in order to differentiate pre- and post-Weismannian concepts of evolution.
In 1896, Conwy **Lloyd Morgan**, James Mark **Baldwin**, and Henry Fairfield **Osborn**, each independently, proposed a theory of how acquired characters could be inherited. Lloyd Morgan concluded that evolutionary changes in anatomy can give rise to new behavior patterns. Baldwin named his version 'Organic Selection' "since it required the direct cooperation of the organism itself." The idea behind this so-called 'Baldwin effect' is that learning creates habituation which, in turn, provides the adaptive occasion for selection, or "overproduction with survival of the fittest" (Baldwin 1896:546,548-549).
In 1896, Ferdinand Isidore **Widal** introduced serological diagnosis through his discovery that typhoid patients agglutinate typhoid bacilli.
In 1896, Eduard **Buchner** discovered a chemical in yeast, which he called *zymase*. He noted that the crushed yeast, that is, cell-free yeast, fermented sugar. This observation opened the era of modern biochemistry.
In 1896, **Freud** suggested analyzing childhood conflicts in the study of neuroses. He also devised a psychoanalytic technique called 'free association' which allows emotionally-charged, repressed material to be consciously recognized. Over the next few years, Freud expanded his interpretive repertoire to include "dreams..., slips of the tongue, bungled actions, the forgetting of names, and what he called 'screen memories' (vivid but essentially counterfeit recollections from childhood)" (Kerr 1993:76).
In 1896, Pieter **Zeeman** observed that a single spectral line splits into a group of closely spaced lines when the substance producing the line is subjected to a uniform magnetic field. This is known as the 'Zeeman effect,' and was explained by **Lorentz** on the basis of his electron theory.
In 1896, Antoine Henri **Becquerel** discovered radioactivity in uranium.
In 1896, **Boltzmann**, in *Vorlesunfer über Gastheorie*, provided what he felt was a reasonable basis for statistical mechanics: "We...obtain the correct average values if we consider...an infinite number of equivalent systems, which started from arbitrary initial conditions" (Boltzmann 1896:310). These mean values he called the '*Ergoden*,' or "the so-called 'quasi-ergotic hypothesis, [i.e.,] the trajectory of a [kinetic] system may pass *arbitrarily close* to every point on an energy surface" (Brush 1964:11).
In 1897, Paul **Ehrlich** , in *Die Wertbemessung des Diphtherieheilserums und deren theoretische Grundlagen*,determined that a toxin was toxic because it had a chemical, i.e., molecular receptor, structure complementary to the molecular structure of the susceptible cell. If there were no matching receptors, this meant there was no disease. If there were some matches, but the cell did not have enough receptors to deal with all the toxins, the cell would produce more and release them into the blood (Ehrlich 1897). This was the first selective theory of antibody formation. By 1900, he had revised this theory to mintain that antibodies were continuously formed under normal conditions.
In 1897, Charles **Sherrington** named the junction between the neurons, a 'synapse.'
In 1897, Christiaan **Eijkman** proved that in a rice diet only rice with hulls intact would prevent 'beriberi.'
In 1897, Gabriel **Bertrand** designated certain inorganic substances co-enzymes because they were necessary to activate certain enzymes.
In 1897, Felix **Hoffman** synthesized a form of acetysalicylic acid that enabled the mass production of aspirin two years later.
In 1897, Jean Henri **Fabre** observed a series of stereotypic sequences in insect behavior, later named 'fixed-action patterns' by Konrad **Lorenz**.

In 1897, Wilhelm **Fliess** suggested that all organisms were fundamentally bisexual, with the implication that adolescence is as much a time of sexual repression as of sexual flowering.
In 1897, Joseph John **Thomson**, using a **Crookes**' tube, demonstrated that cathode rays consisted of units of electrical current made up of negatively charged particles of subatomic size. Believing them to be integral to all matter, in "Cathode Rays," he hypothesized a model of atomic structure in which negatively charged particles, or electrons, were embedded in a sphere of positive electricity. (Thomson 1897)
In 1897, **Boltzmann**, responding to Ernst **Zermelo** on time irreversibility, preferred a "universe, which is in thermal equilibrium as a whole and therefore dead, [but has] here and there relatively small regions the size of our galaxy..., which during the relatively short time of aeons deviate significantly from thermal equilibrium," i.e., corresponding to the existence of life, to an entire universe of "unidirectional change...from a definite initial state to final state" (Boltzmann, quoted in Cercignani 1998:102). Earlier, to the same end, he had maintained that "the probability that such a small part of [the universe] as our world should be in its present state is no longer small" (Boltzmann 1895:415).
In 1897, Jacobus Cornelius **Kapteyn**, in a program of measuring the proper motions of stars, found two preferred directions of motion, roughly toward and away from the center of our Galaxy. This is known as 'star streaming.'
In 1897, **Peirce** attempted to publish a topographical system of symbolic logic which he belived could give geometric expression to any conceivable assertion or logical argument. "Once a formal structure had been adequately graphed, it could then be experimented upon in a manner similar to the way a scientist experiments with a structure in nature" (Gardner 1982:56).
In 1898, Henry Fairfield **Osborne** enunciated the evolutionary concept of 'adaptive radiation,' the descent from an ancestral form of related species occupying and exploiting different types of available habitats.
In 1898, Edward L. **Thorndike** devised the first reliable techniques for measuring learning in animals.
In 1898, **Golgi** described the 'Golgi apparatus.'
In 1898, **Stokes** suggested that X-rays were pulses of radiation emitted when electrons, ejected from a cathode, hit a target.
In 1898, Marie Sklodowska **Curie** and P. **Curie** discovered and isolated radium and polonium. and clarified that radiation was an atomic property. M. Curie coined the term 'radioactive.'
In 1898, J. **Thomson**, in "On the Charge of Electricity Carried by the Ions Produced by Röntgen-Rays," showed that neon gas consisted of two types of charged electrons, or ions, each with a different charge, or mass, or both. This raised the possibility that varieties of a single element might exist with the same atomic number but differ in mass.
In 1898, **Planck**, in "Über irreversible Strahlungsvorgänge. Vierte Mitteilung" and probably responding to **Boltzmann**'s criticism, adopted the kinetic theory and changed his program completely, saying that "all the radiation processes which do not exhibit the feature of irreversibility" must be excluded (Planck, quoted in Cercignani 1976:218).
In 1898, **Wien**, while studying streams of ionized gas, identified a positive particle equal in mass to the hydrogen atom, which later was named the 'proton.'
In 1898, **Poincaré**, in "De la mesure du temps," postulated the limiting and constant speed of light and formulated the principle of relativity non-mathematically.
In 1898, George Johnstone **Stoney** showed that the stability of the atmosphere of a given planet depends on its temperature and its mass. If the velocity of individual molecules, as determined by their temperature, exceed the planet's 'escape velocity,' as determined by its gravitational pull, the lighter molecules are more likely to escape.
In 1898, **Ramsey** and Morris **Travers** discovered neon, krypton, and xenon.
In 1898, James **Dewar** liquified hydrogen.
In 1899, Charles O. **Whitman** , working with pigeons, and Oskar **Heinroth**, working with ducks, independently discovered that the stereotypic responses of birds could be used as a taxonomic criteria for phylogenetic classification.
In 1899, the sixth edition of Emil **Kraepelin**'s textbook, *Psychiatrie*, codified a diagnostic distinction, based on outcome statistics, by adding dementia praecox, i.e., 'schizophrenia,' to 'manic-depression' and 'paranoia.'
In 1899, Ernest **Rutherford** characterized the radiation from radium as being quite complex, easily absorbed, and stopped by a few centimeters of air. These he named 'alpha rays.' He also characterized uranium radiation as far more penetrating. These he named 'beta rays.'
In 1899, **Becquerel** showed that radioactivity in uranium consists in charged particles that are deflected by a magnetic field.
In 1899, **Strutt**, in "On the Transmission of Light Through an Atmosphere Containing Small Particles

in Suspension, and On the Origin of the Blue of the Sky," explained 'elastic scattering of electromagnetic radiation,' called 'Rayleigh scattering,' as reflected photons, i.e., photons which bounce off atoms and molecules without any change of energy. Therefore, for example, the 'elastic scattering' of photons when they bounce off molecules and atoms in the Earth's atmosphere accounts for the color of the sky and red sunsets.
In 1899, J. **Thomson**, in "On the Masses of Ions in Gases at Low Pressure," pointed out that ions have "a very much smaller mass than ordinary atoms; so that in the convection of negative electricity...we have...something which involves the splitting up of the atom" (Thomson 1899:548).
In 1899, **Lorentz**, in "Théorie simplifiée des phénomènes électriques et optique dans des corps en mouvement," treated his contraction hypothesis mathematically in terms of electrons and, except for not determining the coefficient and not generalizing the subject to any mass, the resulting transformations for space and time coordinates are the same as those in his 1904 article.
In 1899, Thomas Chrowder **Chamberlain** raised the question of whether the "present knowledge relative to the behavior of matter under such extraordinary conditions as obtain in the interior of the sun [is] sufficiently exhaustive to warrent the assertion that no unrecognized sources of heat reside there? What the internal constitution of atoms may be is yet open to question. It is not improbable that they are complex organizations and seats of enormous energies" (Chamberlain 1899:12). Chamberlain was a geologist and "up to the end of the nineteenth century, the minimum estimates of geologists were far in excess of the maximum which physicists would allow for the age of the solar system on the basis of known sources of energy radiated by the sun. When the enormously greater energy from the conversion of mass became known, there was no difficulty in reconciling estimates" (Wright 1948:920).
In 1900, Julius **Bernstein** hypothesized that nerve cells have both a resting and a stimulated potential. During the resting potential, the cell is impermeable to the negatively charged ions. When the cell is stimulated, the ions can pass in both directions (Bernstein 1902)
In 1900, the significance of **Mendel's** work was realized when there were three independent accounts of it by Hugo Marie **de Vries**, Carl Erich **Correns**, and Erich von **Tschermak** von Seysegegg.
In 1900, Karl **Pearson** developed the chi-square, or χ^2, test, a statistical procedure that enables the determination of how closely an experimental set of values conforms to theoretical expectation.
In 1900, Mikhail Semenovich **Tsvet**, or sometimes Tswett, established that in leaves there are two green pigments, chlorophyll *a* and *b*, differing in color, fluorescence, and spectral absorption. Subsequently he discerned another green pigment, chlorophyll *c*.
In 1900, **Planck**, in "Zur Theorie des Gesetzes der Enieverteilung im Normalspektrum," introduced the 'quantum theory' to explain a formula, $E=hf$, where E is energy, f is frequency, and h is a new constant, 6.63 x 10^{-34} J-sec., which accounts for experimental data in black-body radiation. *Quantum* is a Latin word, widely used in German to mean 'portion.'. This theory holds that oscillating atoms absorb and emit energy, or light, only in discrete bundles, or 'quanta,' rather than continuously, as classical physics would have it. Each quanta has a value proportional to the frequency of the oscillation.
In 1900, Joseph **Larmor**, in *Aether and Matter*, showed that **Maxwell**'s theory of the electromagnetic field can be derived from a Lagrangian, which equals the square of the magnetic field strength H^2 minus the square of the electric field E^2.
In 1900, **Rutherford** identified a third type of radiation, which he called 'gamma radiation.' Rather than consisting of particles, like alpha and beta radiation, gamma rays are electromagnetic photons.
In 1901, **de Vries** devoted his book, in *Die Mutationstheorie*, promulgated the principle characters, or genes, and the speculation that that made possible, namely, evolution of species by discontinuities, or 'saltations,' rather than by imperceptible gradations. This led to **Darwin's** eclipse for some years, at least, for those biologists who believed with de Vries that mutation superceded selection as the cause of evolution.
In 1901, Richard **Bucke** proposed the possibility of man's evolution from self-consciousness to 'cosmic consciousness.'
In 1901, Josiah **Royce** contended that "the distinction between Self and the not-Self had a predominently *social origin*" (Royce 1901:245).
In 1901, **Planck** discovered the first indications of the granular structure of electromagnetic radiation while working on the spectrum of blackbody radiation.
In 1901, Oliver **Heaviside** and, independently, Arthur E. **Kennelly** predicted the existence of an atmospheric layer, later named the ionosphere, that would reflect radio waves. This encouraged **Marconi**, the following year, to make a successful attempt to send radio signals across the Atlantic ocean.
In 1901, **Ricci-Curbastro** and Tullio **Levi-Civita**, in *Méthodes de calcul différentiel absolu et leurs*

applications, developed a coordinate-free tensor calculus using **Christoffel**'s symbols.

In 1901, Willis H. **Carrier** invented the industrial air conditioner.

In 1902, W. **Bateson**, in *Mendel's Principles of Heredity: A Defense*, in which he demonstrated that **Mendel's** principles apply also to animals. In the same year, he coined 'allomorph,' and, before 1909, also 'genetics,' 'homozygote,' 'heterozygote,' and 'epistatic.'

By 1902, Karl **Landsteiner** found that human blood was one of four types, A, B, A-B, and O, thus making transfusions safe.

In 1902, E. **Overton** supported **Bernstein's** idea with evidence that exogamous sodium ions were responsible for the impulse (Overton 1902).

In 1902, **Fischer** proposed that proteins consist of chains of amino acids.

In 1902, Ivan **Pavlov** combined associative learning with reflex acts, postulating the existence of associated stimuli, or 'conditioned responses.' Later, he also described two non-associated behavioral modifications, 'habituation' and 'sensitization.'

In 1902, Lucien Claude **Cuénot** proposed that a gene plus two enzymes controlled hair color in mice; if both enzymes were present, it was grey, or if only one, it was black.

In 1902, J. W. **Gibbs**, in *Elementary Principles in Statistical Mechanics Developed With Special Reference to the Rational Foundation of Thermodynamics*, offered a more general approach to statistical mechanics than **Boltzmann** or **Maxwell**. What Boltzmann had called the *Ergoden*, Gibbs called the 'grand canonical ensemble,' and the process of achieving it is known as 'ensemble averaging.' The principle theme is the "analogy...between the average behavior of a canonical ensemble of systems and the behavior of a physical system obeying the laws of thermodynamics" (Klein 1976:392). This ensemble, or function, has a simple physical interpretation: the probability of finding at a certain time *t* a point in the small region of phase space around the point *q* at momentum **p**. That Gibbs' and Boltzmann's books did not become obsolete is due to the adequacy of classical theory in dealing with the relations between molecules, whereas quantum theory is necessary to deal with a molecule's internal structure.

In 1902, **Poincaré**, in *La science et l'hypotheése*, noted that it doesn't matter whether or not aether exists, that 'what is essential for us is that everything happens as if it existed.... [It] is only a convenient hypothsis, [and] some day, no doubt, the aether will be thrown aside as useless" (Poincaré 1902:211-212).

In 1902, Bertrand Arthur William **Russell** found the 'ultimate paradox:' If the set of all sets which do not contain themselves nonetheless contains itself, then it cannot belong to the set of all sets which *do not contain* themselves. If it does not contain itself, then it must belong to the set of all sets which do not contain themselves.

In 1903, the beginning of cytogenetics occurred when, in independent accounts, **Bovari** and Walter Stanborough **Sutton** pointed out that chromosomes permutated themselves in cell division, halved their complement in germ cell formation, and paired again in fertilization, in a "physical dance that kept perfect step with **Mendel's** abstract algebra" (Judson 1979:206).

In 1903, Willem **Einthoven** invented a string galvanometer which enabled him to produce the first electrocardiogram, or graphic record of the action of the heart.

In 1903, Richard **Kraus** distinquished natural, or normal, antibodies from acquired immune antibodies according to their 'avidity,' or strength. Both **Ehrlich** and **Landsteiner**, in contrast, were intent on reducing the difference to one of quantity.

In 1903, **Metchnikoff**, in *Études sur la nature humaine*, translated as *The Rhythm of Life*, argued that death from old age was only to be feared because of the accompanying pain and that, as science advanced and old age became less onerous, a natural wish to die would manifest itself.

In 1903, **Tsvet** made the principle of adsorption the basis of a new method which would permit the extraction from a solution of pigments in unchanged forms (Tsvet 1903), and subsequently developed and named it 'chromatography' (Tsvet 1906).

In 1903, Orville **Wright** and Wilbur **Wright** achieved flight in a manned, gasoline power-driven, heavier-than-air flying machine.

["The emergence of genetics coincided with the redefinition of the term *heredity* to refer exclusively to transmission: what had previously been seen as two aspects of a single subject (transmission and development) came to be regarded as distinct concerns. By the early decades of the twentieth century, the study of transmission had become the province of genetics, whereas that of development--now split off from genetics--continued as the province of embryology" (Keller 1995:4-5). At the same time as thinking about evolution turned from Haeckelian comparative anatomy and Weismannian speculation to the laboratory, embryologists shifted Haeckelian phylogenetic recapitulation and Weismannian concentration on heredity to a concern for experiment and developmental mechanics, specifically to **His**'s immediate causes of morphologies and **Roux**'s

Entwicklungsmechnik, or developmental mechanics. Unlike many cytologists, and later geneticists, who centered their investigations on the chromosomes, embryologists centered theirs on the cytoplasm of the egg. The geneticists were essentially reductionist; the embryologists integrative or holistic. Genetic methods looked for differences through interbreeding; embryological methods, for commonality.]
In 1904, **Nuttall**, using precipitin tests of blood serum proteins, inferred the close phylogenetic relationship between humans and apes.
In 1904, T. R. **Elliott** recognized that chemical agents, and specifically adrenaline, acted as neurotransmitters in peripheral nerves, helping the nerve signal across the synapse (Elliott 1904).
In 1904 and 1905, Arthur **Harden** discovered that the presence of phosphate was essential to the enzymes which ferment sugar.
In 1904, **Lorentz**, in "Electromagnetic Phenomena in a System Moving with Any Velocity Less than that of Light," formulated the so-called 'Lorentz transformation,' which describes the increase in mass, the shortening of length, and the time dilation of a body moving at speeds close to that of light, by which the space-time coordinates of a moving system can be correlated with those of any other system. "The quality of not changing under this or some other transformation is called invarience [which] is the mathematical expression of symmetry.... Both **Maxwell**'s electrodynamics and [Albert] **Einstein**'s special relativity are descriptions which are invariant under Lorentz transformation" (Park 1990:355-356).
In 1904, Hantaro **Nagaoka** proposed a 'Saturn model' of the atom with a nucleus and many electrons in a ring around it.
In 1904 or earlier, **Poincaré** gave the name the 'principle of relativity' to the proposition that, since the Universe contained no standard of absolute rest, anything is moving only in respect to something else.
In 1904, **Ramsey** discovered radon.
In 1904, L. P. **Teisserenc de Bort** published the results of 581 free balloon ascents in which instruments measured the temperatures and pressures in the atmosphere to a height of about 14 km.
In 1905, **Metchnikoff** introduced the theory that white blood cells are able to engulf and kill bacteria (Metchnikoff 1905).
In 1905, **Nuttall** demonstrated the importance of bacteria for digestion.
In 1905, John Newport **Langley** discovered acetycholine, but it was not recognized in the brain until F. **McIntosh** did so in 1941 (Langley 1905).
In 1905, F. **Knoop** deduced the beta-oxidation of fatty acids.
In 1905, Edmund Beecher **Wilson**, author of *Cell Biology in Development and Heredity* (published in 1896 and numerous later editions and others), discovered that the X chromosome is linked to the sex of the bearer.
In 1905, **Freud**, in *Drei Abhandlungen zur Sexualtheorie*, redrew the line between normality and mental illness: "Not some mysterious hereditary degeneration read back into infancy, but an otherwise normal childhood experience that would bear a resemblance to the adult behavior (or in the case of neurosis, to adult repressed fantasy)" (Kerr 1993:93). In the same year, in a postscript to another paper, Freud argued that patients sought to reexperience old erotic situations by transferring them to their physician.
In 1905, **Arrhenius** expressed concern about global warming as a result of burning fossil fuels.
In 1905, in the first of three articles in a single issue of *Annalen der Physik*, "Übereien die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtspunkt," **Einstein** sought an explanation of the photoelectric effect, the anomaly that electrons are emitted from the surface of a metal only if the incident light is sufficiently short wave length. Einstein determined that a massless quanta of light, which he called a 'photon,' in order to break the attractive forces holding the electrons in the metal, would have to impart the required energy according to **Planck**'s radiation law. "This elegantly quantified reversion to **Newton**'s corpuscular theory of light by Einstein was one of the milestones in the the development of quatum mechanics" (*Dictionary of Physics* 2000:387-3880.
In 1905, in the second article, "Über die von der molekularkinetischen Theorie der Wärme geforderte Bewegung von in rubenden Flüssigkeiten suspendierten Teilchen," **Einstein** studied some consequences of assuming that liguids and gases are composed of atoms. Even though too small to see, he conjectured that the presence of atoms could be confirmed if objects large enough to see were influenced by their fluctuations. This he demonstrated by showing that "a particle suspended in a liquid and observed with a microscope would be seen to dance around under the influence of the random fluctuations in pressure that are to be expected if the liquid consists of atoms in rapid motion" (Park 1990:309). This phenomena was well known to microscope users as Brownian movement. By inverting **Boltzmann**'s formula, Einstein described its mathematics, deriving the probability of a

macroscopic state for the distribution of gas molecules, in terms of the entropy associated with that state.
In 1905, in the third article, "Zur Electrodynamik bewegter Körper" ("On the Electrodynamics of Moving Bodies"), **Einstein** evolved the Special Theory of relativity by working out the consequences of two postulates: One, the laws of nature are the same for all frames of reference in uniform, i.e., not accelerating, relative motion, and, two, light is propagated at a constant velocity which, unlike things in ordinary experience, is independent of the movement of the emitting body and the observer. In other words, observers in motion with respect to one another will disagree about length and time in the other's system. This theory "led to the discovery that *time* is associated as a fourth coordinate on an equal footing with the other three coordinates of space, and that the scene of material events, the *world*, is therefore a *four-dimensional*, *metrical continuum*" (Weyl 1918a:201). The Special Theory was invented as "a way--the only way--to assure the complete validity and self-consistency of **Maxwell**'s equations" (Wheeler and Ford 1998:166). It also resulted in mathematical equations which confirmed the '**Lorentz** transformation' and contained the velocity of a moving body at the velocity of light relative to an observer, $V=(v_1+v_2)/(1+v_1v_2/c^2)$(Einstein 1905a:37-65). "The real (and great) merit of the Special Theory...was pedagogical. It arranged the old confusing material in a clear deductive pattern" (Everitt 1976:215).
Later in 1905, in a second paper of the Special Theory of relativity, "Ist die Trägheit einer Körpers von seinem Energiehalt abhängig?" ("Does the Inertia of a Body Depend upon Its Energy Content?"), **Einstein** wrote that "if a body gives off the energy *L* in the form of radiation, its mass diminishes by L/c^2.... The mass of a body is a measure of its energy content" (Einstein, quoted in Kantha 1996:46). This was published in *Annalen der Physik* in 1906 and put an end to speculation that the Sun's energy came from radiation (Einstein 1905b:69-71).
In 1905, **Poincaré**, in "Sur la dynamique de l'electron," obtained, independently of **Einstein**, many of the results of the Special Theory of relativity. However, he postulated nonelectric forces, or 'stresses,' to give stability to an electron; these were rendered irrelevant by quantum theory.
In 1905 and 1907, Ejnar **Hertzsprung** published papers relating colors and brightnesses of stars in a systematic way, and recognizing dwarf and giant stars.
In 1906, W. **Bateson** and Reginald Crundall **Punnett** reported less-than-independent assortment, or 'linkage,' in gene alleles on the same chromosome in sweet peas.
In 1906, **Sherrington** showed, in his book *The Integrative Action of the Nervous System*, that those cells which send their fibers and impulses directly to the limb muscles can be influenced to fire by excitation or not to fire by inhibition.
In 1906, Frederick Gowland **Hopkins** noticed that 'accessory food factors,' later called vitamins, were essential to the growth of rats.
In 1906, Andrei Andreyevich **Markov** described sequences of randomly linked probability variables in which the future variable is determined by the present variable, but is independent of the way in which the present variable arose from its predecessors. These 'Markov chains' launched the theory of stochastic processes.
In 1906, Walther Hermann **Nernst** stated a new tenet, often called the Third Law of Thermodynamics, according to which if a chemical change takes place between substances that are at absolute zero there is no change in entropy.
Beginning in 1906, Ferdinand de **Saussure** lectured on the structural principles of general linguistics, including the reciprocity of phonemes and the opposition of diachrony and synchrony (Saussure 1915).
In 1907, Ross Granville **Harrison** cultivated amphibian spinal cord, demonstrating that axons are extensions of single nerve cells. In so doing, he invented tissue culture (Harrison 1907).
In 1907, Alois **Alzheimer** characterized the senile degeneration , to which he loaned his name, by the 'senile plaques' and 'neurofibrillary tangles' which he found in an autopsied brain.
In 1907, **Arrhenius** published *Immunochemistry: The Application of the Principles of Physical Chemistry to the Study of Biological Antibodies*, thereby coining the term 'immunochemistry.'
In 1907, **Arrhenius** hypothesized that life on earth is descended from interstellar microorganisms, sucked in by gravity and pushed out by radiation. This hypothesis is usually called 'panspermia,' meaning 'life everywhere.' Since, at that time, it was assumed that, even though stars were born and died, the Universe was in essence eternal and unchanging, the question of its origin did not have to be addressed (Gribbin and Gribbin 2000:3-4).
In 1907, **Einstein**, in "Über die vom Relativitätsprinzip geforderte Trägheit der Energie," deduced the expression for the equivalence of mass and energy, $K_o=mV^2$, where K_o is energy, m is mass, and V^2 is the speed of light squared. ["$E=mc^2$" was the title of a *Science Illustrated* article which Einstein wrote in 1954 (Kantha 1996:46).] This relation says that "a sufficiently energetic packet of radiation (a

photon) can convert into matter with the appropriate mass, and vice-versa" (Gribbin 1998a:172).

In 1907, Luitzen Egbertus Jan **Brouwer** completed his doctoral dissertation on the logical foundations of mathematics which marked the beginning of the Intuitionist School.

In 1908, Archibald Edward **Garrod**, in *Inborn Errors of Metabolism*, recognized that gene products are proteins and showed that certain rare, inherited disorders were caused by the absence of specific enzymes. W. **Bateson**, in 1902, had suggested to him the probability that an inherited disorder was due to a recessive gene.

In 1908, Godfrey Harold **Hardy** worked out the equilibrium formula for a population heterogenous for a single pair of alleles: Assuming the truth of **Mendel**'s laws (and generalizing them), the resulting combinations will expand into the binomial distribution, or $p^2(AA) + 2pq(Aa) + q^2(aa)$, where p is the initial frequency of the dominant A in a population and q the initial frequency of the recessive a. This formula was derived independently by Wilhelm **Weinberg**, and is thus known as the Hardy-Weinberg equilibrium formula. It provided the first baseline for assessing the effects of mutation.

In 1908, William **McDougall**, in *An Introduction to Social Psychology*, postulated that human beings have as many as a dozen different basic instincts, e.g., curiosity, pugnacity, self-abasement, etc.

In 1908, Robert Andrews **Millikan** determined the probable minimum unit of an electrical charge, that is, of an electron. Later, he named 'cosmic rays.'

In 1908, **Planck**, attacking **Mach**'s position that physical theories were based solely on sense data, held that "the physicist creates the system of the physical world by *imposing* form upon it..., creat[ing] the mathematical structures which organize empirical facts" (Janik and Toulmin 1973:138).

In 1908, Hermann **Minkowski** took **Einstein**'s algebraic expression of the Special Theory of relativity and geometrized it, coupling space and time into a four-dimensional continuum, and providing a framework for all later mathematical work in relativity. "Henceforth, space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality" (Minkowski 1908:75).

In 1908, Frank W. **Very** suggested that the "atmospheres of the major planets would allow optically visible sunlight to pass through to the ground, which would heat up and reradiate at infrared wavelengths. Because the atmospheres are opaque to the infrared spectrum, this radiation would be trapped beneath the atmosphere where it could heat up the planetary surface" (Lang and Gingerich 1979:153).

In 1908, Henrietta Swan **Leavitt**, after years of analyzing the two Magellanic Clouds, reported finding 1,777 variable stars, and, having derived the periods of a few '*Delta Cepheid*-type' variables, also reported that the brighter among them tended to have longer pulsation cycles.

In 1908, George Ellery **Hale** completed building the 60-inch reflecting telescope on Mount Wilson in California.

In 1908, **Zermelo** founded axiomatic set theory.

In 1909, Charles D. **Walcott** discovered the Cambrian Burgess Shale fossils.

In 1909, Andrija **Mohorovicic** observed a discontinuity within the Earth that marks the junction between the crust and the mantle.

In 1909, reports by **Correns** and Erwin **Baur** described the non-Mendelian inheritance of a factor influencing chloroplast development, thus beginning the recognition of extra-nuclear or cytoplasmic genetics.

In 1909, F. **Meves** proposed that mitochondria originate from preexisting structures of the same kind and carry their own heredity.

In 1909, Wilhelm **Johannsen** published *Elemente der exakten Erblichkeitslehre* which was concerned with how to grow pure lines of beans in view of the fact that natural selection can influence change only if there is genetic variability. To this end he distinquished between 'genotype' and 'phenotype,' the one being variant due to heredity and the other being due to environment. Naming **Mendel**'s algebraic units 'genes,' Johannsen understood that to mean that each gene underlies a single trait.

In 1909, W. **Bateson**, in a much expanded new edition of *Mendel's Principles of Heredity*, echoed **Mivart's** idea that what was selected was born fit. Bateson believed that the variation giving rise to new species was saltational, but present from the beginning of life and waiting for disinhibition and expression. He coined the term 'genetics,' but abjured theorizing: Heredity, the Mendelian variations which he encountered in experiments, failed to explain big changes. By contrast, **Pearson** assumed that selection brought about stable varieties or species based on the small, incremental differences or gene frequencies in individuals belonging to groups of vast size.

In 1909, Kørbinian **Brodmann** , in *Vergleichende Lokaisationslehre der Groshirnrinde*, published a map of the cortex with 52 areas, each with a function. This map is still in use.

In 1909, Edward Tyson **Reichert** conceived the ambition to plot the evolutionary relationships among species by the divergences between their hemoglobin molecules. To this end he published six

hundred micrographs of hemoglobin crystals.
In 1909, Charles Jules Henri **Nicolle** showed that typhoid fever is transmitted by body lice.
In 1909, Fritz **Haber**, in order to synthesize ammonia from its elements, developed the first commercially important high-pressure chemical process.
In 1909, Hans **Geiger** and E. **Marsden**, under **Rutherford**'s direction, scattered alpha particles with thin films of heavy metals, providing evidence that atoms possessed a discrete nucleus.
In 1909, Vito **Volterra**, in "Sulle equazioni integro-differenziali della teoria dell'elasticità," writing on the hereditary phenomena, said that the delayed effects tend to zero when time tends to infinity.
In 1909, Karl **Bohlin** suggested that the center of the Milky Way lies within the large collection of globular clusters in the direction of *Sagittarius.*
In 1909, Vesto M. **Slipher** showed "photographic emulsions could record the infrared spectrum and...found that the major planets exhibited infrared absorption lines not present in sunlight. Subsequently, these bands were identified with amonia and methane" (Lang and Gingerich 1979:67).
In about 1909, David **Hilbert**'s work on integral equations established the basis for his subsequent work on infinite-dimensional space, which came to be called 'Hilbert space.'
In 1910, Francis Peyton **Rous** induced a tumor using a filtered extract of chicken tumor cells.
In 1910, Konstantin S. **Mereschovsky** published an essentially modern view of the bacterial origin of what later came to be called eukaryotic cells.
In 1910, Thomas Hunt **Morgan** discovered the white-eye sex linkage in *Drosophila*, relating it to **Mendel's** recessive traits, and thus initiating fruit fly genetics. His insistence that genes were not just logical constructs from Mendelian ratios developed into the general theory of linkage within a chromosome, according to which the strength of the linkage is inversely proportional to the likelihood that a 'crossover' will occur during meiosis. Later, he maintained that cytoplasm could be ignored in studying genetics [**Meiosis** consists in two divisions of the diploid nucleus of the fertilized cell accompanied by one division of its chromosomes. Initially, each chromosome replicates to produce two sister chromatids as in ordinary division, or mitosis. At this point the special features of meiosis become evident. Each chromosome must then somehow pair with its homologue. The pairing allows genetic recombination, or crossingover, to occur, whereby a random fragment of a maternal chromatid may be exchanged for a corresponding fragment of a homologous paternal chromatid (Alberts *et al*. 1994:1016). The duplicated homologues separate and "the chromosomes of each pair pass to opposite poles without separation of their chromatids [or half-chromosomes]. These chromatids then separate at the second division. Each of the four nuclei therefore has one of the four chromatids of each pair of chromosomes" (Darlington 1939:11). This is a haploid gamete and contains half the number of chromosomes of the egg. [**Meiosis** consists in two divisions of the diploid nucleus of the fertilized cell accompanied by one division of its chromosomes. Initially, each chromosome replicates to produce two sister chromatids as in ordinary division, or mitosis. At this point the special features of meiosis become evident. Each chromosome must then somehow pair with its homologue. The pairing allows genetic recombination, or crossingover, to occur, whereby a random fragment of a maternal chromatid may be exchanged for a corresponding fragment of a homologous paternal chromatid (Alberts *et al*. 1994:1016). The duplicated homologues separate and "the chromosomes of each pair pass to opposite poles without separation of their chromatids [or half-chromosomes]. These chromatids then separate at the second division. Each of the four nuclei therefore has one of the four chromatids of each pair of chromosomes" (Darlington 1939:11). This is a haploid gamete and contains half the number of chromosomes of the egg.
In 1910, P. **Boysen-Jensen** proved the existence of 'auxins' which are chemicals instrumental in the the growth of higher plants.
In 1910, Georges **Claude** discovered that electricity conducted through a tube of the rare inert gas, neon, gives a bright red glow and that other gases gave off other colors, e.g., argon gives blue, helium gives yellow and white, etc. Fluorescent light, introduced in 1935, is a variant containing argon and krypton.
In 1910, Alfred North **Whitehead** and **Russell**, in *Principia Mathematica*, put forth the theory that there is a discontinuity between a class and its members and attempted to overcome certain logical paradoxes by the formal device of branding them meaningless.
In 1911, Alfred Henry **Sturtevant**, an undergraduate student of **Morgan**'s, constructed the first rudimentary map of the fruit fly chromosome, establishing that genes are real. By 1917, the map was sufficiently continuous to be published.
In 1911, Casimir **Funk** isolated a crystal, which came to be known as B-complex, and coined the name 'vitamine.'
In 1911, **Tsvet**, having discovered many forms of xanthophyll and their chemical relation to carotene, proposed to call the general group 'carotenoids' (Tsvet 1911).

In 1911, **Bleuler** renamed dementia praecox 'schizophrenia.'
In 1911, Arnold Johannes Wilhelm **Sommerfeld** hypothesized that "the interaction between electrons and atoms was definitely and uniquely controlled by **Planck**'s quantum of action" (Cao 1997:126-127).
In 1911, **Rutherford**, in "The scattering of α and β particles by matter and the structure of the atom," thinking about the nature of the nuclei which could produce radiation, described the atom as a small, heavy nucleus, surrounded by electrons.
In 1911, Charles Thomson Rees **Wilson** developed the 'cloud chamber,' a device in which the paths of particles of ionizing radiation are made visible. The excess moisture in supersaturated vapor is deposited on the tracks of the ions.
In 1911, Heike Kamerlingh **Onmes** discovered 'superconductivity,' the ability of certain materials at low temperatures to carry electric current without resistance.
In 1911, **Einstein**, in "Einfluss der Schwerkraft auf die Ausbreitung des Lichtes" ("The Influence of Gravity upon the Propagation of Light"), said that if a "light beam is bent in an accelerating frame of reference, then if the theory is correct it must also be bent by gravity, and by the exactly equivalent amount" (Gribben 1998a:90; Einstein 1911:99-108).
In 1911, **Hertzsprung** published graphs plotting color or spectral class against the absolute magnitude of stars. In 1913, Henry Norris **Russell**, independently, presented similar graphs. These are now called Hertzsprung-Russell, or HR, diagrams and are the basis of the theory of stellar evolution. Russell also suggested that nuclear energy is generated inside stars when they reach a critical temperature.
In 1911, Jacob **Halm** argued that the masses of stars are correlated with spectral type and therefore with their luminosities.
In 1912, Alfred Lothar **Wegener** proposed a unified theory of continental drift, which opposed to the sinking of continents, based on fossil and glacial evidence.
In 1912, J. F. **Gudernatsch**, working with frogs, found that removing the thyroid gland prevents metamorphosis and that feeding thyroid extracts induces precocious metamorphosis.
In 1912, Ernest Everett **Just**, in "The Relation of the First Cleavage Plane to the Entrance Point of the Sperm," said that the former "passes either directly through the entrance-point of the sperm or a degree or so from it" (Just 1912).
In 1912, John Broadus **Watson** launched his polemic favoring the objective study of psychology as physicochemically-based behavior and reputiating introspection as unscientific. He denied the value of studying either consciousness or instinct, suggesting one could never be certain that a given behavior is free of learning.
In 1912, **Jung** conceptualized and named 'introvert' and 'extrovert,' and suggested the study of current conflicts for insights into the triggering of repressed, infantile contents.
In 1912, Max Theodor Felix von **Laue** obtained the first diffraction effects by letting X-rays fall on a crystal. Almost immediately, William Lawrence **Bragg** proposed a simple relationship between an X-ray diffraction pattern, or characteristic interference pattern, and the arrangement of atoms in a crystal that produced the pattern, thereby inventing X-ray crystallography.
In 1912, Louis Carl Heinrich **Paschen** and Ernest E. A. **Back** discovered that atomic line spectra have a splitting pattern in a very strong magnetic field.
In 1912, Victor **Hess**, in the course of a balloon flight, noted increasing radiation above 5000 feet and proposed an extra-terrestial source.
In 1912, **Slipher** obtained spectrograms of the *Andromeda* Nebulae, M31, which all showed clear evidence of a **Doppler** blueshift. By 1914, he had measured a dozen more Doppler shifts, all but one toward red.
In 1912, **Leavitt** concluded that those *Cepheid*-types in the smaller of the two Magellanic Clouds are so far away that they may be regarded as being roughly at the same distance and was thus able to work out the relationship between their luminosity, or energy output, and orbital period.
In 1913, Lawrence Joseph **Henderson** proposed that the concept of fitness, which in animals is the relative ability to transmit its genes to the next generation, be extended to the environment. This has ramifications for the origin of life.
In 1913, Shiro **Tashiro** discerned slight increases in carbon dioxide production by stimulated nerves.
In 1913, C. **Fabry** and M. **Buisson** reported the existence of ozone, a gas created by a photochemical reaction between sunlight and oxygen.
In 1913, Henry Gwyn-Jeffreys **Moseley** bombarded the atoms of various elements with X-rays and found that the wavelength decreased in proportion to the increase in the atomic weight of the element emitting the rays. From observing the wavelength, he discovered that the inner stucture responded in a characteristic group of lines, enabling the assignment of 'atomic numbers.' The periodic table

turned out to coincide with these numbers rather than, as had been supposed, the atomic weight.
In 1913, Niels **Bohr**,in "On the constitution of atoms and molecules," strongly influenced by **Sommerfeld**, applying the **Planck** quantum hypothesis to **Rutherford**'s atomic model and postulating stable states and single frequencies, calculated closely the frequencies of the spectrum of atomic hydrogen (which has a single electron). "Only certain photon energies are ever seen, identified by their corresponding frequencies or wavelengths, and this explains the appearance of the spectrum" (Park 1990:312). This supported his proposal that electrons moved around the nucleus in restricted orbits and his explanation of the manner in which the atom absorbs and emits energy by leaping from one orbital to another without traversing the space in between, and was the first theory of quantum mechanics.
In 1913, Frederick **Soddy** discovered that different forms of the same element were, in fact, groups of elements with the same chemical character, but varying in their masses, and that radioactive decay is accompanied by the transmutation of one element to another. To express this new found complexity of matter, the term isotopic element, or isotope, was used.
In 1913, **Einstein** and Marcel **Grossman**, in "Entwurf einer verallgemeinerten Relativitätstheorie und eine Theorie der Gravitation," investigated curved space and curved time as it related to a theory of gravity. Einstein contributed the physics and Grossman the mathematics.
In 1913, **Hertzsprung**, using statistical parallax, got an indication of the distance to a couple of *Cepheids* and was able to extrapolate a rough measure in numbers of the distance to the Small Magellanic Cloud, which was much farther away than had been imagined.
In 1913, **Cartan**, in "Les groupes projectifs qui ne kaissent invariante aucune multiplicité plane," announced his discovery of linear two-dimensional representations of the three-dimensional orthogonal matrix known as "a spinor..., a sort of 'directed' or 'polarized' isotropic vector; a rotation about an axis through which an angle 2π changes the polarization of this isotropic vector" (Cartan 1937:41). 'Spin' is quanticized rotation and always comes in multiples of a basic unit which is equal to one-half times **Planck**'s contant *h* divided by 2π. Cartan's concept was used by **Einstein** in the mathematics of the theory of General Relativity.
In 1913, Leo **Baekeland** invented a plastic laminate, known as Bakelite, and later as formica.
In 1914, Nicholas **Vaschide** published his hypothesis that sleep is not just the absence of being awake, but is a vital instinctual, i.e., biological, process.
In 1914, James **Franck** and Gustav **Hertz** confirmed experimentally **Bohr**'s theory of the stationary states of the energy levels in atoms by producing "jumps between them, supplying the excitation energy by collisions with accelerated electrons" (Segrè 1976:137).
In 1914, Arthur Stanley **Eddington** hypothesized that spiral nebula were actually distant galaxies.
In 1914, Harlow **Shapley** established that the *Cepheid* variables are pulsating stars, not binaries.
In 1915, Jacques **Loeb**, in *The Organism as a Whole*, maintained that a complicated organism was unimaginable without a prestructure in the egg which he characterized in colloidal chemistry terms. He also maintained that behavior consisted in stereotypic movements, directly elicited and controlled by sensory stimuli.
In 1915, **Morgan**, **Sturtevant**, Calvin Blackman **Bridges**, and Hermann Joseph **Muller** published *The Mechanism of Mendelian Inheritance*.
In 1915, **Bridges** discovered the first homeotic mutation in *Drosophila*, 'bithorax.'
In 1915, **Haber**, directing Germany's chemical warfare activities, initiated the use of poison gas releasing 150 tons of compressed chlorine on Allied positions around Ypres. **Nernst** also was a leader in the Germany's chemical warfare effort. In 1917, James Bryant **Conant** was put in charge of the United States' Chemical Warfare Service which was attempting to develop mustard gas (L. F. Haber 1986).
In 1915, in three lectures delivered to the Prussian Academy, and published the following year as *Grundlage der allgemeinen Relativitätatheorie* (*Foundation of General Relativity*), **Einstein** completed the mathematical generalization of the theory of relativity: Whereas spacetime in the Special Theory is geometrically flat, in the General Theory spacetime is curved and includes gravity as a determinant, i.e., "a ray will experience a curvature of its path when passing through a gravitational field, this curvature being similar to that experienced by the path of a body which is projected through a gravitational field" (Einstein 1916:127). Or, in other words, under the force of gravity, objects follow "a path of least resistance, the equivalent of a straight line, through a curved portion of space, or spacetime" (Gribbin 1998a:90-91). This is the first example of concepts from differential geometry being used to represent physical structures; thus, in order to get from a flat to a curved spacetime manifold, "one replaces in all tensorial (or spinorial) relations the flat metric η by the curved one, *g*, and one substitutes covariant derivatives with respect to the latter for those with respect to the former" (Ehlers 1981:536). In fact, in one these lectures, Einstein attributes "dem Zauber dieser Theorie," i.e.,

the magic of the theory, to the differential calculus methods of "**Gauss**, **Riemann**, **Christoffels**, **Ricci** und **Levi-Civita**" (Einstein, quoted in *Ibid.*:536).

Einstein's 1915 theory replaced the **Kepler**-**Newton** theory of planetary motion, which was based on the assumption of absolute space, with one which is able to account for the slow rotation, in the direction of motion, which the orbital ellipse of a planet undergoes. Einstein's value for the bending of light waves by the Sun is "almost precisely the same value" as **von Soldner**'s for light particles, which is to say that it is not space-bending but time-bending which differs from Newtonian calculations (Gribbin 1998a:53). Employing **Riemann**'s non-Euclidean geometry and equations which are highly non-linear, Einstein was able to predict radically new phenomena: The bending of light around the Sun and the precession of the perihelion of Mercury.

In 1916, Gilbert Newton **Lewis** said that the chemical bond consists of two electrons held jointly by two atoms.

In 1916, Karl **Schwarzschild** , in a paper which **Einstein** delivered to the Prussian Academy and which was based on the General Theory of Relativity, calculated that a star collapsing under its own gravitational force would cease to radiate energy beyond a certain parameter. This parameter is known as the 'Schwarzschild radius' and shrinking beyond it creates a 'black-hole.' Since inside a black-hole, according to Schwarzschild's solution, the curvature becomes infinite, and since this is a 'singularity,' i.e., not generally believable to physicists, it was not taken seriously for many years. In fact, when it *was* taken seriously, it was realized that there were *two* opposite solutions and that the singularity was an artefact of the coordinate system chosen by Schwarzschild to measure spacetime around a black-hole. The second solution is the origin of the notion of the existence of 'white-holes' and describes the expansion out of an initial singularity. Black-holes were not actually called that until, in 1968, John Archibald **Wheeler** used that name for what had been previously a 'Schwarzschild singularity,' a 'collapsed star,' or a 'frozen star' (Wheeler 1968:9).

In 1916, **Eddington**, in "On the Radiative Equilibrium of Stars," said that the pressure of radiation takes its place beside gas pressure and gravity as an equilibrating force.

In 1916, **Sommerfeld** modified **Bohr**'s atomic model by specifying elliptical orbits for the electrons.

In 1916, Irving **Langmuir** concluded that adsorption, the condensation of gas on a surface, is a single molecular layer thick and chemically bonded to the surface. It is not, as most thought, analogous to the physical attraction which holds the earth's atmosphere. He also noted that the length of hydrocarbon chains makes no difference to the shape of the surface energy curve provided that there are more than 14 carbons in the molecule (Langmuir 1917).

In 1917, J. **Schmidt** demonstrated that the differences between individuals in a population were genetic. Richard Benedict **Goldschmidt**, in 1920, and Francis Bertody **Sumner**, in 1924, demonstrated it in other populations. Their findings caused the downfall of the mutationalist and Lamarckian theories of **de Vries** and **Bateson** and "permitted a selectionist interpretation of slight differences among local populations that were obviously caused by differences in the environment" (Mayr 1959:4).

In 1917, D'Arcy **Thompson**, in *Growth and Form*, took basic body plans and changed the size and position of the parts relative to one another in geometric ways, showing how evolution might have proceeded. His thesis was that form "is determined by its rate of growth in various directions, hence rate of growth deserves to be studied as a necessary preliminary to the theoretical study of form" (Thompson 1917:51).

In 1917, **Landsteiner** and H. **Lampl** found that antibodies could be produced which reacted with synthetic haptens, that is to say, with incomplete antigens which are unable to induce antibody formation. This finding seemed for a long time to support a template model of antibody formation (Landsteiner and Lampl 1917).

In 1917, William D. **Harkins** noticed that terrestial elements "of low atomic weight are more abundant than those of high atomic weight and that, on average, the elements with even atomic numbers are about 10 times more abundant than those with odd atomic numbers of similar value, [and conjectured] that the relative abundances of the elements depend on nuclear rather than chemical properties and that heavy elements must have been synthesized from light ones" (Lang and Gingerich 1979:374).

In 1917, **Einstein**, in "Kosmologische Betrachtungen zur allgemeinen Relativitätstheorie" ("Cosmological Considerations on the General Theory of Relativity"), by adding a 'cosmical constant,' was able to describe a universe that conformed to what he and everyone else supposed: A closed and static sphere coextensive with the Milky Way (Einstein 1917:177-188). The same year, Willem **de Sitter** offered a different solution to the General Relativity equations, one which contained "negligibly small values for the mass density and pressure in ordinary matter" and thus permitted "exponential expansion" (Peebles 1993:77,393). In fact, these equations, without the addition of a cosmical contant and including matter, were solvable provided that the universe was not static but rather expanding or contracting. Moreover, mathematicians soon predicted a redshift as test-particles

moved away from each other.
In 1917, Heber D. **Curtis** pointed out that the nova he observed in spiral nebulae were 100 times farther away than nova in the the Milky Way. This supported the island universe theory of spiral nebulae.
In 1917, **Slipher**, using spectral analysis of spiral nebulae, recognized that they were generally receding from us at a high velocity.
In 1917, James Hopwood **Jeans** submitted an essay in which he described a general theory of the configuration of equilibrium of compressible and non-homogeneous masses of astronomical matter, enabling him to explain the behavior of certain nebulae and describe the evolution of gaseous stars.
In 1917, **Levi-Civita** recognized "the geometrical meaning of the **Christoffel** symbols as determining a natural parallel transport of vectors and tensors on Riemannian manifolds [which was important] in the subsequent development of differential geometry and field physics" (Ehlers 1981:527).
In 1918, Ronald Aylmer **Fisher** wrote the initial paper, "The correlation of relatives under the supposition of Mendelian inheritance," of what came to be known as population genetics, the joining of Mendelian experiments with a statistical approach to large populations.
As early as 1918, Paul **Portier** became convinced that mitochondria were direct descendents of bacteria.
In 1918, **Bridges**, working with *Drosophila*, suggested that gene duplications promote the evolution of organisms toward greater complexity.
In 1918, J. S. **Szymanski** demonstrated that animals are capable of maintaining approximately 24-hour activity patterns without external or temperature clues.
In 1918, Amelie Emmy **Noether**, in "Invarianten beliebiger Differentialausdrücke" and "Invariante Variationsprobleme," demonstrated the theorem that "wherever there is symmetry in nature, there is also a conservation law, and vice-versa. In other words, the symmetries of space and time are not only linked with conservation of energy, momentum, and angular momentum, but each *implies* the other" (Crease and Mann 1986:189).
In 1918, Hermann Klaus Hugo **Weyl**, in "Gravitation und Elektricitat" and two other papers, produced the first unified field theory in which the electromagnetic and gravitational fields appeared as a property of space-time (Weyl 1918a:201-216). To do so, he found it necessary to describe random changes in another aspect of a system as being precisely compensated by changes in another aspect. This he called 'measuring rod symmetry,' and later 'gauge invariance' (Weyl 1918b:176; 1928:100). A gauge transformation is simply a relabelling exercise, e.g., when the Earth rotates, the distance between New York and London remains the same. According to Weyl, "a state of equilibrium is likely to be symmetric.... The feature that needs explanation is, therefore, not the symmetry of [a] shape but deviations from this symmetry" (Weyl 1952:25-26).
In 1918, **Shapley**, using the Mount Wilson observatory, **Leavitt**'s period-luminosity law, and employing a statistical method of his own devising--i.e., he assumed the brightest stars in globular clusters had all the same intrinsic brightness, was able to show the dimensions of the Milky Way galaxy and the Earth's peripheral place in it.
In 1918, Ludwig **Wittgenstein**, in *Tractatus Logico-Philosophicus*, pointed out that "what can be said at all can be said clearly; and whereof one cannot speak thereof one must be silent" and "the sense of the world must lie outside the world" (Wittgenstein 1918:27,183).
In 1919, Harry **Steenbock** demonstrated the relationship between the plant pigment 'carotene' and vitamin A.
In 1919, Ernst **Spath** produced a synthetic version of peyote's psychoactive alkaloid, which he called 'mescaline.'
In 1919, Pierre **Janet** pointed out that the hypnotic condition must be learned by the subject: If the subject has never heard of hypnotism, it is unlikely that he can be hypnotized.
In 1919, E. **Rutherford** discovered the proton, which contains the positive charge within the nucleus of an atom, and published the first evidence of artificially-produced splitting of atomic nuclei; that is, he produced hydrogen through the bombardment of nitrogen with alpha radiation. His discovery made possible the description of the electrostatic force; namely, if each of two bodies have an excess of electrons or an excess of protons, repulsion occurs, but if the two bodies differ in their excesses, then attaction occurs.
In 1919, Francis William **Aston** designed the mass spectograph and discovered neon isotopes with it, enabling him to explain nonintegral atomic weights. This revealed that the helium atom was less massive than four hydrogen atoms, pointing to the transmutation of the first two elements. "Of the nearly 300 isotopes of elements, Aston isolated and measured the masses of more than 200" (Hoyle 1994:149).
In 1919, **Eddington** and Frank W. **Dyson** measured the bending of starlight by the gravitational pull

of the sun, thus confirming **Einstein's** general theory of relativity.
In 1920, Hermann **Staudinger** began to work on macromolecules, such as proteins, which had hitherto been thought by many to be aggragates. Others questioned the strength of the atomic forces.
In 1920, Otto **Loewi** showed that the terminal branches of nerve fibers release stimulating and inhibiting chemicals.
In 1920, Friedrich A. von **Hayak**, in *The Sensory Order*, postulated that *all* perception is a product of memory and an act of classification of the qualities of objects and events performed by maps of cortical cells. These interconnections are reinforced by the experience of prior contact. This essay was not published until 1952.
In 1920, **Jung**, in *Psychologische Typen*, first used the term 'anima,' a word borrowed from **Plato**, who used it to represent the soul of the individual. Jung used it to represent the archtype of the mediator between consciousness and the collective unconscious (for men; for women, he used 'animus'). Ignoring these mediators meant the failure to acknowledge all parts of a cognitive whole with the consequence that the hidden part would be dominant.
In 1920, E. **Rutherford** postulated the existence of the neutron, required in order to keep the positively-charged protons in the nucleus from repelling each other. Their existence explains why some atoms have identical chemical properties to one another but slightly different mass.
In 1920, **Eddington**, in "The Internal Constitution of the Stars," spelled out the implications of **Aston**'s discovery, namely: "Mass cannot be annihilated, and the deficit can only represent the mass of the electrical energy set free in the transmutation. We can therefore at once calculate the quantity of energy liberated when helium is made out of hydrogen. If 5 percent of a star's mass consists initially of hydrogen atoms, which are gradually being combined to form more complex elements, the total heat liberated will more than suffice for our demands, and we need look no further for the source of a star's energy" (Eddington 1920:19).
In 1920, Meghnad **Saha**, in "Ionization of the Solar Chromosphere," obtained an equation relating the degree of ionization of an atom, analogous to the dissociation of a molecule, to temperature and pressure, and thus accounting for the relative intensities of different spectral lines.
In 1920, **Michelson** and Francis G. **Pease**, using an optical interferometer, measured the first stellar diameters, *Betelgeuse* and five other supergiant stars.
In the early 1920s, it was ascertained that there were two sorts of nucleic acid, deoxyribonucleic acid and ribonucleic acid.
In the early 1920s, Victor **Jollos** hypothesized that the disappearance of environmentally-induced acquired traits even after hundreds of generations indicated that their acquisition should be assigned to the cytoplasm rather than the nucleus.
In 1921, Frederick Grant **Banting** and Charles Herbert **Best** isolated insulin while working on pancreatic secretions. Banting injected it into an apparently terminally ill patient who survived.
In 1921, Felix **d'Hérelle** discovered bacterial viruses which he named 'bacteriophage' (d'Herelle 1926).
In 1921, **Muller** raised the question of the relationship of genes to viruses, or 'naked genes' (Muller 1922).
In 1921, **Langley** described the autonomic nervous system and its functions.
In 1921, **Hopkins** isolated gluthione.
In 1921, Theodor **Kaluza** , in "Zum Unitätsproblem der Physik," wrote down **Einstein's** field equations in five dimensions. This reproduced the usual four-dimensional gravitational equations plus **Maxwell**'s equations for the electromagnetic field. In other words, according to this hypothesis, electromagnetism is not a separate force, but an aspect of gravity in a higher dimension.
In 1921, Otto **Stern** and Walter **Gerlach** demonstrated 'space quantization' "by sending a molecular beam, a tenuous stream of molecules or atoms, through a suitable magnetic field and observing their deflection.... The atoms orient themselves only in discontinuous positions" (Segrè 1976:138).
In 1922, Herbert Spencer **Gasser** and Joseph **Erlanger**, working together, and Edgar Douglas **Adrian** found that the electric pulses within neurons caused chemicals to be released and that their rate of conduction was proportional to the thickness of their sheaths.
In 1922, Walter **Garstang** , in "The Theory of Recapitulation: A Critical Re-statement of the Biogenetic Law," showed that phylogeny is not the cause but the product of different ontogenies (Garstang 1922).
In 1922, Elmer Verner **McCollum** led a team which showed that rickets is caused by a lack of a new food factor, vitamin D.
In 1922, Arthur Holly **Compton** demonstrated an increase in the wavelengths of X-rays and gamma rays when they collide with loosely bound electrons. This verified the quantum theory since the effect requires the rays be treated as particles, not waves (Compton 1923:483-502).

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In 1922, and 1924, Aleksandr **Friedman**, in "Über die Krümmung des Raumes," proposed several nonstatic, realistic models of an expanding (or contracting) decelerating universe which were consistent with **Einstein**'s General Theory of Relativity. These models assumed that the universe was of uniform curvature and uniform matter (idealized as dust exerting neglible pressure), that the expansion was not caused by galaxies moving apart, but by space itself stretching, and predicted that the beginning and the end of time would occur for dynamical reasons.

In 1922, Edwin Powell **Hubble** demonstrated the nebulae which failed to generate their own light were gaseous and located within the Milky Way galaxy.

In 1923, Oswald **Avery** demonstrated that different types of pneumococci had different and specific exterior capsules and that bacteria are of distinct, heritable varieties.

In 1923, **Bridges** discovered chromosomal translocation in *Drosophila*.

In 1923, Otto Heinrich **Warburg** reached the conclusion that "cancer cells differ from non-cancer cells, including growing embryonic cells, by their failure to suppress glycolysis in the presence of oxygen" (Krebs 1981:20). Today, it is realized that this only one of many ways cancer cells differ; it is a symptom and not the primary cause.

In 1923, Robert **Feulgen** discovered a selective staining technique for DNA localization, which is still in use.

In 1923, **Lloyd Morgan**, in his book *Emergent Evolution*, used the word 'emergent' to show that higher orders are not mere resultants of what went before, but were qualitatively new.

In 1923, Thorsten Ludvig **Thunberg** characterized photosynthesis as an oxidation-reduction reaction in which carbon dioxide is reduced and water is oxidized.

In 1923, Johannes Nicolaus **Brönsted** published his theory of the acid-base phenomena according to which any group of atoms that gives up a proton is called an acid, etc. In the same year, G. N. **Lewis** published his theory that neutralization accounts for the coordinate covalent bond between the acid and the base. His theory incorporated Brönsted's proton theory as a special case.

In 1923, Herbert M. **Evans** and K. Scott **Bishop** discovered vitamin E (Evans and Bishop 1923).

In 1923, Jean **Piaget**, in *Le Langage et la pensée chez l'enfant*, maintained that child development proceeds in the same sequence of genetically determined stages.

In 1923, **Eddington** published *The Mathematical Theory of Relativity*, considered by **Einstein** the finest presentation of the subject in any language.

In 1923, Werner **Heisenberg** and Max **Born**, using **Bohr**'s quantum mechanics, were finally able to calculate the wavelength of the two electron helium atom.

In 1923, Louis Victor **de Broglie** (rimes with *feuille*), in "Ondes et quanta," hypothesized that a moving electron particle has wave-like properties. "His central contribution was formula giving the relation between the momentum p of a particle and the wavelength λ of its associated wave, analogous to the earlier relation between energy and frequency, $\lambda = h/p = h/mv$, where for p is substituted the usual expression for the momentum of a moving object.... Assume a circular path, and assume that the wave makes a pattern that is closed on itself.... The circumference of the circle is a whole number of wavelengths: $2\pi r = n\lambda$, where n = 1,2,3,.... By de Broglie's hypothesis, this $2\pi r = nh/mv$, whence $mvr = nh/2\pi$, and this, as if by miracle, is the formula **Bohr** had had to guess in 1913 in order to derive his formula for the energy levels of hydrogen" (Park 1990:316).

In 1923, Electrolux produced the first electric **refrigerator**.

In 1923, Vladimir **Zworykin** invented the iconoscope television camera-tube.

In 1924, Aleksander Ivanovitch **Oparin** published his speculation that life, that is to say, metabolism + self-reproductivity (but not replication) + mutability, is preceded by the formation of mixed colloidal units, called coacervates, and is the inevitable result of chemical self-organization in a reducing environment (Oparin 1924). A reducing atmosphere is rich in hydrogen and hydrogen-containing gases, such as methane and ammonia, all of which "donate electrons to other substances and thereby produce energized molecules. These molecules are then able to take part in chemical reactions that can lead to the creation of more complex substances" (Darling 2001:17).

In 1924, E. **Gorter** and F. **Grendel** demonstrated that blood cells are surrounded be a membrane exactly two molecules thick (Gorter and Grendel 1925:439).

In 1924, John Burdon Sanderson **Haldane** began a series of papers in which gene frequency substitutions in a population were treated systematically.

In 1924, Alfred **Lotka**, in *Elements of Physical Biology*, compared the global eco-system to "a great world engine" in which "plants and animals act as coupled transformers of energy" in "the mill-wheel"

that is driven by "solar energy" (Lotka 1924:331-335). Lotka gave analytical substance to the vision intuitively adopted by field biologists. Population ecologists took the 'logistical equation' for population growth, which is in fact based on an analogy with autocatalytic chemical reactions, from his book.
In 1924, Satyendranath **Bose** derived **Planck**'s black box radiation law from photon statistics, that is, independent of classical electrodynamics. Instead of photons being statistically independent, he assigned them to cells and wrote of the cell's statistical independence.
In 1924, **Bohr**, Hendric Anton **Kramers**, and John C. **Slater** tried and failed to solve the apparent contradiction between waves and particles by the concept of the 'probability wave.' This probability is different from chance: "It meant a tendency for something. It was a version of the old concept of *potentia* in Aristotelian philosophy. It introduced...a strange kind of physical reality just in the middle between possibility and reality" (Heisenberg 1958:41; Bohr *et al.* 1924:785-812).
In 1924, **Bose**, in "Wärmegleichgewicht im Strahlungenfeld bei Anwesenheit von Materie," and **Einstein**, in an appendix to Bose's paper, predicted the existence of the statistical phenomena, now known as 'Bose-Einstein condensation,' whereby a significant fraction of particles at a sufficiently low temperature could occupy the same quantum state of lowest energy. In other words, in this state, the atoms--later recognized as particles of integer spin and still later called 'bosons,' in Bose's honor--would lose their individual properties and would act collectively as a single entity. Integer spin is either zero or an even number of multiples of the basic unit of spin.
In 1924, **Eddington**, in "On the Relation between the Masses and Luminosities of the Stars," correctly derived the various mass-luminosity relations of stars; e.g., for stars like the Sun, the absolute luminosity is proportional to the fourth power of the mass, but for more massive stars the absolute luminosity is proportional to the cube of the mass.
In 1924, Carl **Wirtz** suggested that the smaller a galaxy appeared the larger its change in color toward the red end of the spectrum. This is called 'cosmological redshift.' But Wirtz lacked the direct evidence to conclude that these smaller, redder galaxies were farther away.
In 1924, **Hubble**, using the 100-inch telescope on Mount Wilson and the same scale which **Shapley** had used to map the Milky Way, measured the distance to the nearer spiral galaxies, which was two million light years. So vast was this distance that "the whole Galaxy in which we live was suddenly shrunken, in the astronomical imagination, into a tiny mote floating in a vast, dark sea of emptiness" (Gribbin 1998a:65).
In 1925, Raymond Arthur **Dart** published his discovery of a skull of a new species, *Australopithecus africanus*, a missing link in the human fossil record. He speculated that "*Australopithecus* had been a bloodthirsty carnivore, [giving birth to] the killer ape myth..., including a connection between warfare and hunting and the concept that aggressiveness drives cultural progress" (de Waal 2001:45).
In 1925, Gilbert **Adair** published his determination of the correct size of the hemoglobin molecule and subsequently wrote the equation for hemoglobin's cooperativity.
In 1925, George Richard **Minot** and William Parry **Murphy** noticed that feeding raw liver aids in the treatment of 'pernicious anemia.' Their discovery led to the isolation of vitamin B12.
In 1925, Theodor **Svedberg** designed the ultracentrifuge.
In 1925, Samuel A. **Goudsmit** and George Eugene **Uhlenbeck** assigned angular momentum to electrons and established that they have the quantum mechanical property of spin.
In 1925, **Heisenberg**, in "Über quantentheoretische Umdeutung kinematischer und mechanischer Beziehungen," in order to avoid giving definite numbers to changing positions of quanta, changed the relationship between physical concepts and mathematical symbols through his use of symbols as imaginary quantities with arrays of numbers, called matrices. The rules for calculating these symbols often depends on the order they are written down. This became known as 'matrix mechanics.'
In 1925, Wolfgang **Pauli** perceived the principle that no two electrons in the atom can be in the same quantum state; in other words, two electrons must have opposite spin, thus cancelling each other, and there can be no more than two in the same orbital. This is known as the 'Pauli exclusion principle.'
In 1925, Enrico **Fermi** devised a statistical mechanics valid for particles subject to the exclusion principle, i.e., particles of half-integral spin, e.g., electrons, protons, neutrons, etc. Such particles came to be called 'fermions' in his honor. As Paul Adrien Maurice **Dirac**, independently, made the same calculation, these equations are now known as Fermi-Dirac statistics.
In 1925, Ernst **Ising** published a one-dimensional model of ferromagnetism in an attempt to explore the problem of atoms in a solid, each with a magnetic moment and a spin. This model demonstrated that the energy of the system is taken to be proportional to the amount of magnetism and that at any temperature above absolute zero there would be no spontaneous magnetism. One- and two-dimensional models have applications for phase transitions and interfaces in semiconductor technology.
In 1925, Gustaf **Ising** published a proposal for a 'linear accelerator.'

In 1925, Pierre **Auger** discovered that the ejection of an electron without the emission of a X- or gamma-ray photon is the result of the de-excitation of an excited electron within the atom.
In 1925, Walter **Noddack** and Ida Eva Tacke, who married **Noddack** the following year, discovered the element rhenium.
In 1925, Cecilia H. **Payne**, in *Stellar Atmospheres*, "assumed that the number of effective atoms required to make a spectral line barely visible in a stellar spectrum is the same for all lines of all elements and that the reciprocals of those fractional concentrations could be used to give the relative abundances of the elements. The results showed that the relative abundances [except for hydrogen] are similar to those in the Earth's crust" (Land and Gingerich 1979:244).
In 1925, Bertil **Lindblad** said that star streaming is evidence that the entire Galaxy is differentially rotating.
In 1925, George Y. **Rainich**, while re-expressing the content of the **Maxwell-Einstein** equations in a purely geometric form, established that, "under certain assumptions, the electromagnetic field is entirely determined by the curvature of space-time" (Rainich 1925:107).
In 1926, James Batcheller **Sumner** crystallized urease (Sumner 1926).
In 1926, **Sturtevant** found the first gene inversion in *Drosophila*.
In 1926, **Warburg** discovered a carbon monoxide-sensitive iron porphyrin enzyme which catalyses cell respiration.
In 1926, **Volterra** published his deduction of the nonlinear differential equation which describes the fluctuating balance of prey/predator populations: If prey increase, predators will also until prey decrease. As the predators starve, the prey increase. The two populations fluctuate out of phase with each other due to the length of the gestation period delaying the population peaks; i.e., the predator population is still growing after the prey population has begun to decline. This equation is similar to **Lotka**'s logistic growth equation, although based on classical mechanics and W. R. **Hamilton**'s principle of least growth. It is sometimes called the Lotka-Volterra equation.
In 1926, **Dirac** solved the derivation of **Planck**'s law and called **Heisenberg**'s quantity symbols *q*-numbers and ordinary numbers *c*-numbers (Dirac 1926:561-569).
In 1926, Erwin Rudolf Josef Alexander **Schrödinger** initiated the development of the final quantum theory by describing wave mechanics, which predicted the positions of the electrons, vibrating as **Bohr**'s standing waves. The mathematics itself is the deterministic 'classical' mathematics of classical waves. It in no way acknowledges the actual phenomena, a minute flash which propagates the wave, or indeterminism, which enters when the intensity of the mathematically the dual wave-particle nature of such things as electrons through their wave function, or *eigenfunction*, involving the coordinates of a particle in space, e.g., $\psi(x,y,z)$. This 'wave mechanics' predicted the positions of the electrons, vibrating as **Bohr**'s standing waves. It in no way acknowledges the actual phenomena, a minute flash which propagates the wave, or indeterminism, which enters when the intensity of the wave is related to the probable location of the flash. While the mathematics itself is the deterministic 'classical' mathematics of classical waves, the results show complete mathematical equivalence to matrix mechanics.
Later in 1926, **Born**, in "Quantenmechanik der Stossvorgînge," considering that the wave does not describe the exact behavior of any particle, interpreted the equation in terms of **Bohr-Kramers-Slater** probability. This added the arrow of time to **Schrödinger**'s classical, i.e., 'reversible,' mathematics, and 'quantum mechanics' was completed (Born 1926:52-55).
Still later in 1926, **Heisenberg**, in "Über die Spektra von Atomsystemen mit zwei Elektronen," using the unified quantum mechanics, quickly calculated the spectrum of several states of the helium atom.
In 1926, **de Broglie** attempted to obviate the quantum mechanical conundrum 'wave or particle' by maintaining instead that it is 'wave *and* particle,' reasoning that "quantum phenomena do *not* exclude a uniform description of the micro and macro worlds..., system and apparatus" (Bell 1987:175). Waves may have a corpuscular aspect and particles may have a wave aspect, depending on the properties of the model to be explained. For example, photon particles can be described as concentrated packets of waves, called 'wave packets,' with zero mass energy and electric charge and without well-defined edges.
In 1926, Oskar **Klein**, attempting to explain what happened to **Kaluza**'s fifth dimension, proposed that we do not notice it because it is "'rolled up' to a very small size [and that] what we normally think of as a point in three-dimensional space is in reality a tiny circle going round the fourth dimension" (Davies and Brown 1988:49). He also suggested that "the origin of **Planck**'s quantum may be sought just in this periodicity in the fifth dimension" (Klein 1926:516).
In 1926, **Klein** and, independently, Walter **Gordon** developed an equation in relativistic quantum mechanics for spin-zero particles.
In 1926, Gregor **Wentzel**, **Kramers**, and Leon **Brillouin**, each independently, invented the

'semiclassical, or WKB, approximation,' a technique in quantum mechanics, wherein "the wave function is written as an asymptomatic series with ascending powers of the **Planck** constant *h*, with the first term being purely classical" (*Dictionary of Physics* 2000:444).

In 1926, Robert Alexander **Watson-Watt** proposed the name 'ionosphere' for the conducting atmospheric layer.

In 1926, **Eddington**, in *The Internal Constitution of the Stars*, a summary of his work, said that all stars must maintain a temperature of at least forty million degrees in order to maintain their fuel supply.

In 1926, Ralph Howard **Fowler**, in "On Dense Stars," using the statistical description of atoms published the previous year by **Fermi**, showed the correct relation of energy and temperature in a white dwarf, leading to the conclusion that they "do not shine by thermonuclear reactions and that their light must come from the slow leakage of heat contained in the nondegenerate nuclei" (Lang and Gingerich 1979:573).

In 1926, Donald Howard **Menzel**, in "The Planetary Nebulae," raised the possibility that the Balmer emission lines, lines in the hydrogen spectrum created when electrons drop back to a lower energy level, are "the result of photoionization by ultraviolet star light, followed by recombination of free electrons and protons" (Lang and Gingerich 1979:573).

In 1926, Gregory **Breit** and Merle **Tuve** measured the distance to the ionosphere by measuring the time needed for a radio signal to bounce back.

In 1926, [?] **Busch** focused a beam of electrons with a magnetic lens, laying the foundations of electron optics.

In 1926, **Lorentz** modelled the damming of the Zuiderzee as the head of a Dutch government committee (Cercignani 1998:202).

In 1926, Jan-Christian **Smuts** coined 'holism in order to give a name to "the view that an intergrated or organic whole has a reality independent of and greater than the sum of its parts" (*Webster's* 1979:867).

In 1927, **Muller** demonstrated that the X-irradiation of sex cells in *Drosophila* causes an increased number of mutations, enabling mutations to be created experimentally.

In 1927, **Landsteiner** discovered the M and N blood groups.

In 1927, Martin **Heidegger** published *Sein und Zeit*, an original analysis of human existence. Unnoticed at the time in psychiatric circles, it later became the basis for 'existential analysis.'

In 1927, **Heisenberg**, in "Über den anschaulichen Inhalt der quantentheoretischen Kinematik und Mechanik," said electrons do not possess both a well-defined position *and* a well-defined momentum, simultaneously; i.e., "Even in principle we cannot know the present in all detail" (Heisenberg 1927:83). This uncertainty has nothing to do with the limitations of human observers; it is *intrinsic*, and converts absolute certainties into relative probabilities. Expressed as an inequality, one may say that the smaller the uncertainty about position, the greater the uncertainty about momentum, and vice-versa. "Quantum uncertainty makes it impossible to define *any* set of conditions precisely for the atoms" (Gribben 1998:19), and thus refutes, in principle, any possibility of, say, a gas in a box reversing itself to its original position over any amount of time, in the manner of **Poincaré**'s ideal 'cycle times.' Quantum uncertainty also provides the loophole to the law of the conservation of energy through which the forces embodied in photons make their brief appearances. **Born** and Pasqual **Jordan** collaborated with Heisenberg setting up the matrix algebra to describe this 'uncertainty principle.'

In 1927, **Bohr**, after discussions with **Heisenberg**, took the position, which came to be known as the Copenhagen interpretation, that the impossibility of simultaneously measuring a particle's position and its momentum, the 'complementarity principle' as he called it, is engendered by the measurement process in a specific experimental situation; i.e., measurement is inseparable from wave function reduction, or 'collapse.' "Wave-packet collapse...is the only irreversible feature of quantum mechanics and the one extraneous to the basic equations of this theory, which are perfectly time-reversible" (Cercignani 1998:118). Measurement is also a means of communication, and communication requires a common time. "Every atomic phenomena is closed in the sense that its observation is based on a recording...with irreversible functions" (Bohr, quoted in Prigogine 1996:156). The complementary principle itself implies closure: The microworld "part has no meaning except in relation to the [macroworld] whole, the total context.... What Bohr's philosophy suggests is that words like electron, photon, or atom should be regarded [like energy as a useful model that consolidates] in our imagination what is actually only a set of mathematical relations connecting observations" (Davies and Brown 1986:12,26).

In 1927, **Born** and Julius Robert **Oppenheimer** devised an adiabatic approximation in which "the motion of atomic nuclei is taken to be so much slower than the motion of the electrons that, when

calculating the motions of electrons, the nuclei can be taken to be fixed positions" (*Dictionary of Physics* 2000:47). An adiabatic approximation occurs when the time dependence of parameters are slowly varying.
In 1927, George Paget **Thomson** diffracted electrons by passing them in a vacuum through a thin foil, thus verifying **de Broglie**'s wave hypothesis.
In 1927, Clinton Joseph **Davisson** and Lester Halbert **Germer** measured the length of a **de Broglie** wave by observing the diffraction of electrons by single crystals of nickel.
In 1927, Paul **Ehrenfest** proved the theorem that "the motion of a wave packet is in accord with the motion of the corresponding classical particle, if the potential energy change across the dimensions of the packet is very small" (*Dictionary of Physics* 2000:529).
In 1927, Walter **Heitler** and Fritz **London** showed that chemical bonding, the force which holds atoms together, is electrical and a consequence of quantum mechanics.
In 1927, **Dirac** described a method of quantizing the electromagnetic field (Dirac 1927:243-265, 710-728).
In 1927, **Einstein** and Leo **Szilard** applied for a patent on a pump for liquid metals using a magnetic field to induce a ponderomotive force on a closed current loop in the fluid conductor. These pumps are used to circulate liquid sodium coolant in nuclear reactors.
In 1927, Georges **Lemaître** proposed, independently of **Friedman**, an expanding model of the universe from an initial singularity and consistent with **Einstein**'s General Theory. The main difference from Friedman was that Lemaître included both the redshift-distance relation and radiation pressure. This enabled him to show the importance of the early stages of the expansion: When the "primeval atom" exploded outwards, "the expansion [had] been set up by the radiation itself," and "the receding velocities of extragalactic nebulae are a cosmical effect of the expansion of the universe" (Lemaître 1931:490). One important implication is that the universe is not infinite, which incidently explains away **Olbers**' paradox.
In 1927, Jan H. **Oort**, confirming **Lindblad**'s hypothesis that the Milky Way is rotating, concluded the "stars closer to the galaxy's nucleus will generally revolve faster than the Sun, and hence those inner stars in the direction of the Sun's motion will be pulling away from the Sun, whereas those inner stars symmetrically opposite the direction to the nucleus will be catching up" (Lang and Gingerich 1979:555).
In 1927, **Menzel** obtained accurate measurements of the surface temperatures of Mars and Mercury.
In 1927, Vannevar **Bush** started construction on the 'Differential Analyzer,' an analog computer, which measured the rotation of various rods by mechanical means, in order to speed the solution of problems related to the electric power network.
In 1927, Richard Buckminster **Fuller** began the exploration of geodesics, "the most economical relationship between two events" (Fuller 1975:373), such as spherical great circles. This led to the development of geodesic domes, in the early 1940s, and the dymaxion map, patented in 1946.
In 1928, Albert **Szent-Györgi** showed that hexuronic acid was vitamin C and proposed the name L-ascorbic acid.
In 1928, Heinrich Otto **Wieland** and Adolf Otto Reinhold **Windaus** determined the structure of the cholesterol molecule.
In 1928, Lewis **Stadler** induced mutations in maize using ultraviolet light.
In 1928, Alexander **Fleming** discovered penicillin, a relatively innocuous antibiotic because it interfered with the synthesis of cells walls, a process specific to bacteria, rather than with metabolism.
In 1928, Frederick **Griffith** discovered that live pneumococci could acquire genetic traits from other, dead pneumococci (Griffith 1928).
In 1928, Linus Carl **Pauling**, in "The Shared Electron Chemical Bond," wrote that "in the case of two hydrogen atoms in the normal state brought near each other, the eigenfunction...corresponds to a potential [that] causes the two atoms to combine to form a molecule. This potential [involves] an interchange of position of the two electrons forming the bond, so that each electron is partially associated with one nucleus and partially with the other. [This] leads to the result that the number of shared bonds possible for an atom of the first row is not greater than four, and for hydrogen not greater than one" (Pauling 1928:359-360). An eigenfunction is a function of an operator which yields a state that when acted on by that operator yields the same state multiplied by a number.
In 1928, George **Gamow** explained the lifetimes of alpha radiation using the **Schrödinger** equation. Alpha decay is a 'tunnelling process.' The tunnelling effect involves the waviness of an alpha particle, or any electron, which makes it finitely probable it will tunnel through what would have been an insurmountable obstacle if it were a classical particle. Having tunnelled, the alpha particle is no longer held by the 'strong nuclear force' and is repelled or radiated away. Gamow also pointed out that the edges of wave packets can interact over distances at which particles would be repelled, making

nuclear fusion possible at temperatures that exist inside the Sun and other stars.
In 1928, **Gamow** devised the 'liquid drop model' of the atomic nucleus, implying that it is held together by something like surface tension. "The success of the model has been associated with the fact that the binding forces in both the nucleus and the liquid drop are essentially short-ranged" (Issacs 2000:271).
In 1928, Rolf **Wideröe** and, independently, **Szilard** invented linear accelerators of a more advanced design than the one G. **Ising** had proposed. In his patent application, Szilard said, "The electric field can be conceived of as a combination of an electric field in accelerated motion from left to right and an electric field of decelerated motion from right to left. The device is operated in such a way that the velocity of the accelerated ion equals, at each point, the local velocity of the field moving from left to right" (Szilard, quoted in Telegdi 2000:26).
In 1928, Chandrasekhara **Raman** observed weak, inelastic scattering of light from liquids. This effect, known as 'Raman scattering,' arises from vibrating molecules.
In 1928, Albrecht **Unsöld**, using a spectroscope, investigated light from the Sun and "interpreted the strength of the hydrogen lines an implying that there are roughly a million times as many hydrogen atoms as anything else" (Gribbin and Gribbin 2000:94).
In 1928, **Weyl**, in *Gruppentheorie und Quantenmechanik*, created a matrix theory of continuous groups and discovered many of the regularities of quantum phenomena could best be understood by means of group theory (Weyl 1928).
In 1928, John **von Neumann** conceived 'game theory.'
In 1928, **London** revived **Weyl**'s work on symmetry but showed that local gauge symmetry applies not to space but to the electromagnetic field which enforces the conservation of electric charge between local areas.
In the late 1920s, it was found that deoxyribonucleic acid (DNA) was located exclusively in the chromosomes, whereas ribonucleic acid (RNA) was located mainly outside the nucleus.
In 1929, **Haldane** showed that the development of organic compounds took place before the first living things. He also pointed out that ultraviolet radiation could have been the spark which animated the "hot, dilute soup" (Haldane 1933:149).
As early as 1929, Frank MacFarland **Burnet** came to believe that "resistant [to viruses] bacterial variants are produced by mutation in the culture prior to the addition of virus [and that] the virus merely brings the variants into prominence by eliminating all sensitive bacteria" (Luria and Delbrück 1943:491-492). "Where the mutational change to resistence is correlated to a change of phase, from smooth to rough or vice-versa, the change of the [antigenic make-up of the cellular] surface must be a direct result of the mutation" (Luria and Delbrück 1943:510; Burnet 1930).
In 1929, **Fisher**, in *The Genetical Theory of Natural Selection*, provided a mathematical analysis of how the distribution of genes in a population will change as a result of natural selection, and maintained that once a species' fitness is at a maximum, any mutation will lower it.
In 1929, David **Keilin**, having discovered 'cytochromes,' proteins that function as electron-carriers, four years earlier, formulated the "fundamental idea of aerobic energy systems: the concept of the respiratory chain" (Mitchell 1978; Keilin 1929).
In 1929, K. **Lohmann**, Cyrus Hartwell **Fiske**, and Y. **Subbarow**, in muscle extracts, isolated 'adenosine triphosphate' (ATP), the phosphate bonds of which, when hydrolysed, release energy, and 'phosphocreatine,' from which some of the phosphorus in ATP in obtained.
In 1929, Adolf Friedrich Johann **Butenandt** and, independently, Edward Adelbert **Doisy** isolated 'estrone,' a sex hormone, from urine.
In 1929, **Jung**, in a commentary on *Das Geheimnis der goldenen Blüte*, translated as *The Secret of the Golden Flower*, began an exploration of the significance of alchemical symbolism in depth psychology for the resolution of conflicts of opposites. Over the following 25 years, he expanded the study of mandorlas, noticing analogies between quadripartite schemes, e.g., father-son-spirit-mother, black-green-red-gold, etc., and taking them to be archetypal ideas.
In 1929, Robert Jemison **van de Graaf** developed an electrostatic particle accelerator.
In 1929, **Szilard**, in "Über die Entropieverminderung in einem thermodynamischen System bei Eingriffen intelligenter Wesen, "disputed **Maxwell**, showing that 'inspection,' or information, is inevitably associated with a decrease in entropy; that is, the energy gained by the discriminations of the Demon will be wholly offset by the energy spent in acquiring the information on which the discriminations are based (Szilard 1929:539-541).
In 1929, **Dirac** published his 'relativistic wave equation' which describes the electron's spin and led to the prediction of the electron's antiparticle, the 'positron.'. This more or less completed quantum field theory which combined quantum mechanics with **Einstein**'s special relativity: "Just as photons were particles--the quanta--associated with the electromagnetic field, so the electron was associated with

an electron field and the proton with a proton field. Every kind of particle was intimately intertwined with a field, and every kind of field with a particle. Since there were gravitational fields, [the prediction was made that] there must be particles called gravitons.... In the picture provided by quantum field theory, the particles influence each other by bouncing photons back and forth" (Johnson 1999:61-62).
In 1929, Nevill F. **Mott**, in "The Wave Mechanics of α-Ray Tracks," analyzed the "wave functions [of the tracks] in the multispace formed by the co-ordinates both of the α-particle and of every atom" on a photographic plate in a cloud chamber..., [with the nuclei] considered effectively at rest" (Mott 1929:79-80), that is, stationary. The equation he used is similar to **Born**'s first probability equation which is time-independent.
In 1929, **Hubble**, in "A Relation between Distance and Radial Velocity among Extra-Galactic Nebulae," observed that all galaxies are moving away from each other. Correlating the distance of a particular galaxy and the speed with which it is receding by an analysis of the light spectra, he noted a persistent cosmological redshift, and explained this in terms of the **Doppler** effect: The light is receding and the farther away the larger the 'gravitational redshift.' It is the product of the stretching of the color wavelength by gravity; i.e., when an object has a very strong gravitational pull, what starts out relatively short wave (blue) will become relatively long wave (red).
In 1929, Robert d'Escourt **Atkinson** and Franz **Houtermans**, inspired by **Gamow**'s work, published calculations of how the tunnel effect might operate in stars and showed that even with the tunnel effect only the fastest-moving particles with the smallest positive charge, i.e., protons from hydrogen nuclei, could penetrate the barriers. Their conclusion, and **Unsöld**'s and **Menzel**'s, regarding the preponderance of hydrogen on the Sun was ignored by most astronomers who preferred to believe that heavy elements prepondered, as on the Earth.
In 1929, Frank **Whittle**, combining the concepts of rocket propulsion and gas turbines, invented jet propulsion. Independently, Hans **von Ohain** put together the same combination in 1933.
In 1930, Friedrich **Breinl** and Felix **Haurowitz** published a proposal for a template theory of antibody production (Breinl and Haurowitz 1930).
In 1930, Gavin **de Beer** formalized the morphological modes in which ontogenetic acceleration and retardation could produce evolution.
In 1930, **Fisher** discussed stable, or equilibrium, states of the sex ratio in terms which later came to be called game theory. Taking random fluctuation of allelic populations into account and treating the processes of gene frequency as stochastic processes, he concluded that chance effects were negligible.
By 1930, Phoebus Aaron **Levene** had "elucidated the structure of mononucleotides and [shown them to be] the building blocks of nucleic acids. He also isolated the carbohydrate portion of nucleic acids and distinquished deoxyribose from ribose" (German Life Science Information Service 1993:14; Levene and Bass 1931).
In 1930, Léon **Rosenfeld**, in "Zur Quantelung der Wellenfelder," applied quantum field theory to the gravitational field and was able to compute the gravitational self-energy of a photon, but obtained a quadratically divergent result.
In 1930, **Dirac**, in the first edition of his textbook *The Principles of Quantum Mechanics*, defined the 'superposition' of states by saying that a "*state A may be formed by the superposition of states B and C when, if any observation is made on the system in state A leading to any result, there is a finite probability for the same result being obtained when the same observation is made on the system in one (at least) of the two states B and C.* The Principle of Superposition says that when any two states *B* and *C* may be superposed in accordance with this definition to form a state *A* and indeed an infinite number of different states *A* may be formed by superposing *B* and *C* in different ways" (Dirac 1930:15-16). Dirac went on to say that this principle forms the foundation of quantum mechanics, and is completely opposed to classical mechanics since this principle requires indeterminacy in the results of observations. On the other hand, superposition is thought to only occur at the unobservable microscopic level; it theoretically could but "does not happen in the world we know," the macroscopic world (Park 1990:426).
In 1930, Ernest Orlando **Lawrence** published the principle of the cyclotron which is using a magnetic field to curl up the particle trajectory of a linear accelerator into into a spiral. This permitted acceleration of atoms to high speeds and the creation of nuclear reactions.
In 1930, Subrahmanyan **Chandrasekhar** calculated that "white dwarfs more massive than 1.4 suns would collapse under their own weight, paving the way for the theoretical prediction of neutron stars and black-holes" (Begelman and Rees 1996:30).
In 1930, **Menzel**, using **Stoney**'s argument, inferred the presence of hydrogen on the giant planets.
In the early 1930s, the Theoretical Biology Club, at Cambridge University, adopted the process philosophy of **Whitehead**, in which the metaphysics of static substances is replaced by an ontology in

which 'things' are actually emerging processes (Depew and Weber 1995:416). John Desmond **Bernal**, Joseph **Needham**, and Conrad Hal **Waddington** were members.
Beginning in the 1930s, K. **Lorenz**, Nikos **Tinbergen**, and Irenäus **Eibl-Eibesfeldt** investigated natural, as opposed to contrived, animal behavior, and were able, by using comparative analysis of closely related species, to discern stereotyped natural behavior structures or episodes (thus making the notion of 'instinct' respectable). This study of innate and learned responses and the interaction between them is called ethology.
In the 1930s, Rupert **Wildt**, building on **Very**'s suggestion that Venus's atmosphere is mainly carbon dioxide, proposed that since that is highly opaque to surface radiation a considerable greenhouse effect would be produced.
In 1931, Harriet B. **Creighton** and Barbara **McClintock**, working with maize, and Curt **Stern**, working with *Drosophila*, provided the first visual confirmation of genetic 'crossing-over.' (Creighton and McClintock 1931).
In 1931, Sewall **Wright** concluded that 'random drift,' or chance fluctuation of allelic populations, was a significant factor in evolution. This opposed **Fisher**'s opinion. (It should be noted that at this period the assumptions necessary in order to quantify genes resulted in much over-simplification).
In 1931, Ulf Svante von **Euler** isolated the peptide 'substance P.'
In 1931, **Pauling** published *The Nature of the Chemical Bond and the Structure of Molecules and Crystals*, detailing the rules of covalent bonding.
IIn 1931, John Howard **Northrop** and Moses **Kunitz**, applying the phase rule solubility test for the homogeneity of dissolved solids, corroborated J. B. **Sumner**'s belief that enzymes are proteins.
In 1931, Ernst August Friedrich **Ruska** and colleagues invented the prototype of the transmission electron microscope.
In 1931, Hans Albrecht **Bethe** provided a solution to the one-dimensional **Ising** model on which most subsequent solutions to the two-dimensional model depend.
In 1931, **Pauli**, in order to solve the question of where the energy went in beta decay, predicted the existence of a 'little neutral thing,' the 'neutrino.'
In 1931, Kurt **Gödel** published his proof that the axiomatic method has inherent limitations, namely, because the consistency of a set of axioms cannot be derived from itself, it is incomplete, thus showing that the aims of **Frege** , **Hilbert**, and B. **Russell** could never have been achieved.
In 1931, Herbert **Butterfield** characterized the 'Whig interpretation of history' as "the tendency in many historians to write on the side of the Protestants and Whigs, to praise revolutions provided they have been successful, to emphasize certain principles of progress in the past and to produce a story which is the ratification if not the glorification of the the present" (Butterfield 1931:v).
In 1931, **Atkinson** suggested that "the abundance of elements [in stars] might be explained by the synthesis of heavy nuclei from hydrogen and helium by successive proton captures, [which protons] would be absorbed by nuclei until they become unstable and ejected alpha particles" (Lang and Gingerich 1979:303).
In 1931, Bernhard V. **Schmidt** invented a new type of telescopic optical system which made possible sharp photographs of wide areas of the sky.
In 1932, **Haldane** introduced the term 'altruist.'
In 1932, A. **Bethe** conceptualized 'pheromones,' chemicals secreted by animals and insects for communication.
In 1932, Hans Adolf **Krebs** and Kurt **Henseleit** discovered the 'urea cycle,' a circular pathway in liver cells in which excess ammonia, produced by the breakdown of amino acids, and carbon dioxide react together creating urea, which is filtered by the kidneys and excreted.
In 1932, Axel Hugo Teodor **Theorell** isolated myoglobin and therefore was able to show its oxygen absorption and carrying capacities.
In 1932, Franz **Moewus** initiated studies on sexuality in a flagellated protozoa, the green algae *Chlamydomonas*, and subsequently demonstrated that unicellular organisms possessed genes that behave in the classical Mendelian way.
In 1932, Walter **Cannon**, in *The Wisdom of the Body*, maintained that the body's steady state is regulated by negative feedback mediated by the autonomic nervous system through the sympathetic and parasympathetic divisions of the hypothalamus.
In 1932, Frits **Zernike** invented the phase-contrast telescope (Zernike 1934). By 1935, he was applying the same principles to microscopes, but was unable to get them produced commercially until 1941. This development allowed unstained living cells to to be seen in detail for the first time.
Early in 1932, Irène **Curie** and Frédéric **Joliot** bombarded nonradioactive beryllium with alpha particles, transmuting it briefly into a radioactive element.
In 1932, James **Chadwick** described the helium alpha particles which created the **Curie-Joliet** effect

as consisting of two protons and two neutrons, thus isolating the neutron, the first particle discovered with zero electrical charge. It has almost the same mass as a proton. Atoms with identical chemical properties but different numbers of neutrons, and thus different masses, are called isotopes.
In 1932, Harold Clayton **Urey** along with his teacher G. N. **Lewis** and colleagues demonstrated the existence of deuterium, or heavy hydrogen, spectroscopically. Subsequently, he isolated isotopes of heavy oxygen, nitrogen, carbon, and sulphur.
In 1932, **Fermi** succeeded in intensifying the **Curie-Joliet** effect by using the newly discovered and very massive neutrons in beta rays instead of alpha rays.
In 1932, Carl David **Anderson**, using a cloud chamber in the study of cosmic rays, discovered the positron, or positive electron, fulfilling Dirac's prediction.
In 1932, **Heisenberg** proposed a model of the atom in which protons and neutrons exchange electrons to achieve stability.
In 1932, John Douglas **Cockcroft** and Ernest T. S. **Walton** built the first linear accelerator with which they bombarded lithium with protons, producing helium and achieving the first artificial nuclear reaction.
In 1932, Peter Joseph Wilhelm **Debye** and others independently observed the diffraction of light by ultrasonic waves.
In 1932, **von Neumann**, in *Mathematische Grundlagen der Quanten Mechanik*, dealt with the dualistic paradox by emphasizing the role of the observer, saying that it is we, and our consciousness, who produce the collapse of the wave function, not 'hidden variables.'
[The dualistic paradox may be thought of on analogy to the field anthropologist's problem: After meeting the anthropologist, 'primitive' people are changed by the encounter; or, as **Bohr** thought, analogous to the partition between subject and object, the movability of which enables us to talk about ourselves (Petersen 1968:3-4). However, in practice the distinction between wave and particle, between classical and quantum, makes very little difference to the experimenter. The distinction is made for a particular application depending on how much accuracy or completeness is desired. "It is the toleration of such an ambiguity, not merely provisionally but permanently, and at the most fundamental level, that is the real break with the classical ideal.... Indeed good taste and discretion, born of experience, allow us largely to forget, in most calculations, the instruments of observation" (Bell 1987:188-189)].
In 1932, **Einstein** and **de Sitter** put forth a revised cosmological model, which was a solution to the **Friedman** equations, took account of **Hubble**'s proof of the expansion of the Universe, and tentatively implied an initial singularity.
In 1932, **Shapley** published the first edition of the Shapley-Ames Catalogue of galaxies.
In 1932, Edward H. **Land** invented polarizing film.
In 1932, George Kingsley **Zipf** published the scaling relationships which are now known as Zipf's law, namely, that ordered quantities are apt to be inversely proportional to their rank, that is, proportional to 1, $^1/_2$, $^1/_3$, $^1/_4$, etc.
In 1933, **Goldschmidt** concluded that evolution was the result of sudden changes by successful mutations that act on early embryological processes (Goldschmidt 1933) .
In 1933, John Howard **Northrop** isolated and crystallized the protein-splitting enzymes pepsin, trypsin, and chymotrypsin (Northrop 1935).
In 1933, M. **Goldblatt** and von **Euler** discovered 'prostaglandins.'
In 1933, **Theorell** isolated the 'yellow enzyme,' separated it into a catalytic coenzyme and apoenzyme, and found the main ingredient to be albumin. This led to Theorell's discovery of the chemical chain reaction known as 'cellular respiration' in which food is translated into energy.
In 1933, I. **Curie** and **Joliet**, using polonium plus beryllium in a cloud chamber, proved that "hard gamma rays...produce electron-positron pairs by materialization.... They also noted single positrons in addition to pairs" (Segrè 1976:193).
In 1933, **Fermi** developed a theory of decay and weak interactions in which a neutron changed into a proton, emitting a neutron and a neutrino. The following year, **Heisenberg** and others extended it in terms of the strong nuclear force.
In 1933, Karl **Jansky**, in the course of investigating atmospheric static which was interfering with radio communications, established that the radio source he had been hearing since the previous year came from outside the solar system.
In 1933, Fritz **Zwicky** discerned that a "considerable fraction of the mass had been missed" in measuring the velocities of certain galaxies (Peebles 1993:419). What was first known as 'missing mass' became known as 'dark matter,' and today is discerned mainly through its gravitational effects. "The nature of this dark matter is unknown.... Exotic [i.e., undetected] particles such as axions, massive neutrinos or other weakly interacting massive particles (collectively known as WIMPs) have

been proposed.... A less exotic alternative is normal matter in the form of bodies with masses ranging from that of a large planet to a few solar masses. Such objects, known collectively as massive compact halo objects (MACHOs), might be brown dwarfs...(bodies too small to produce their own energy through fusion), neutron stars, old white dwarfs or black holes" (Alcock et al. 1993:621).
In 1934, **Bernal** and Dorethy **Crowfoot** began the structural analysis of proteins (Bernal and Crowfoot 1934) and, later, William Thomas **Astbury** established that the orderliness of cells was a structural, or crystalline, orderliness. This conception was revolutionary, marking the disappearance of the 'colloidal' conception of vital organization, itself a sophisticated variant of the older doctrine of 'protoplasm.'
In 1934, **Warburg** discovered the coenzyme nicotinamide and, the following year, that it is a constituent of cells.
In 1934, **Butenandt** and colleagues isolated the hormone progesterone.
In 1934, U.v. **Euler** discovered a fatty acid which he called 'prostaglandin,' in the mistaken belief that it was produced by the prostate gland.
In 1934, Henrik **Dam** , working with baby chickens, isolated and identified a hemorrhagic factor which he called *Koagulations Vitamine*, or vitamin K. Two years later, **Doisy** synthesized it.
In 1934, **de Beer** and Julian Sorell **Huxley** published *The Elements of Experimental Embryology* in which the central concept is that of a dominant region in relation to which other regions are specified.
In 1934, Pavel Alekseyevich **Cherenkov** discovered that when high-energy charged gamma ray particles pass through a transparent medium at a speed greater than the speed of light *in that medium* they emit light at certain angles. This is known as Cherenkov (sometimes Cerenkov) radiation.
In 1934, **Szilard** filed the first patent application for the idea of a neutron chain reaction. The following year, in order to keep the patent a secret, he assigned it to the British Admiralty.
In 1934, I. **Curie** and **Joliot** announced the discovery of "artificial radiation obtained by bombarding certain nuclei with alpha particles" (Segrè 1976:198).
In 1934, **Fermi**, Edoardo **Amaldi**, Bruno **Pontecorvo**, Franco **Racetti**, and Emilio **Segrè**, while improving on the **Curie-Joliet** artificial radiation technique by using neutrons to bombard uranium, established that "slow neutrons [having passed through paraffin] were much more efficient than fast ones in producing certain nuclear reactions" (Segrè 1976:205; Fermi *et al* 1934). In other words, they showed how nuclear reactions could be controlled.
In 1934, I. **Noddack** expressed scepticism at **Fermi**'s transuranic elements, insisting that "it was necessary to compare the chemistry with the chemistry of all the known elements because it would be conceivable that the nucleus could break into several large fragments" (Malley 2000:947). In other words, she questioned whether the transformed uranium was not heavier, as Fermi supposed, but in fact *lighter*. At the time nobody else realized that this was possible and Noddack did not do the experiment which would have proved that her conjecture was correct.
In the five years subsequent to 1934, Glenn **Seaborg** and Jack **Livingood** discovered or characterized the radioisotopes iodine-131, cobalt-60, and several others.
In 1934, **Wheeler** and **Breit** calculated the probability that two colliding photons would create an elctron-positron pair. This prediction was confirmed in 1997 at the Stanford Linear Accelerator Center.
In 1934, **Hubble** and Milton **Humason**, in the course of adding more galaxy spectra, determined photographically that there were at least as many galaxies in the Universe as there are stars in the Milky Way. Hubble also reformulated his law $\log(V)=0.2m+B$, where V is radial velocity, m is the apparent magnitude of the object and B is a constant which depends on Hubble's constant, or parameter, H, which is at present considered to be 50 to 100 kilometers per second per Megaparsec, the speed of an object's recession to its distance, plus the absolute magnitude of the object. It doesn't matter that the value of H is still controversial because the relative distances stay the same. A plot of this equation is known as a Hubble diagram and the slope 0.2 obtains the expected results for the laws of **Einstein**'s General Theory of Relativity. It's also consistent with **Friedman**'s model.
In 1934, **Zwicky** and Wilhelm Henrich Walter **Baade** advanced the idea that "a super-nova represents the transition of an ordinary star into a *neutron star*, consisting mainly of neutrons. Such a star may possess a very small radius and an extremely high density.... A neutron star would therefore represent the most stable configuration of matter as such" (Zwicky and Baade 1934:263).
Beginning in 1934, Konrad **Zuse** built a series of computers, Z1 through Z4, utilizing binary arithmetic and stored programs. "Along the way..., he invented the first programming language--the 'Plan Calculus,' or *Plankalcül*--and began to analyze methods by which a computer could play chess" (Waldrop 2001:40n).
In 1934, Gaston **Bachelard**, in *Le Nouvel Esprit Scientifique*, declared that "one may *imagine* the spin of an isolated electron, for example, but one does not *think* it. Thinking...depends on mathematical

relations.... Objects have a reality only in their relations" (Bachelard 1934:132). All else is imagination.

In 1934, Karl R. **Popper**, in *Logik der Forschung*, advanced the theory that the test of an empirical system, the demarcation of the limit of scientific knowledge, is its 'falsifiability' and not its 'verifiability,' his aim being "to select the one which is by comparison the fittest, by exposing them all to the fiercest struggle for survival" (Popper 1934:42). To be falsifiable systems of statements must be logically precise and unambiguous, i.e., capable of being "subjected to tests which *might* result in their refutation" (*ibid.*:314).

In 1935, Boris **Ephrussi** and George Wells **Beadle**, by transplanting Drosophila parts, invented a general method of developmental genetics (Ephrussi and Beadle 1935).

In 1935, Wendell **Stanley** and **Northrop** crystallized the tobacco-mosaic virus (Stanley 1935).

In 1935, N. **Timoféeff-Ressovsky**, K. G. **Zimmer**, and Max **Delbrück** wrote a paper entitled "On the nature of gene mutation and gene structure" (Timoféeff-Ressovsky 1935). In his theoretical contribution to this paper (which **Schrödinger** popularized ten years later), Delbrück pointed out that "whereas in physics all measurements must in principle be traced back to measurements of place and time, there is hardly a case in which the fundamental concept of genetics, the character difference, can be expressed meaningfully in terms of absolute units.... [And] the stability of [the well-defined union of atoms] must be especially great vis-à-vis the chemical reactions that normally proceed in the living cell; the genes can participate in general metabolism only catalytically" (quoted in Stent 1982:353-354).

By 1935, John Tileston **Edsall** and A. von **Muralt** isolated 'myosin' from muscle.

In 1935, William Cumming **Rose** recognized the essential amino acid 'threonine.'

In 1935, **Szent-Györgi** demonstrated the catalytic effect of dicarboxylic acids on respiration.

In 1935, Hugh **Davson** and James Frederick **Danielli** proposed a 'protein-lipid sandwich' model for the structure of cell membranes (Danielli 1935; Davson and Danielli 1943).

In 1935, [?] **Knoll** demonstrated the feasibility of a scanning electron microscope.

In 1935, Gerhard **Domagk** discovered the efficacy of prontosil, the forerunner of sulfa drugs, in the course of treating streptococcal infections.

In 1935, Hideki **Yukawa** attempted to model the fundamental 'strong' nuclear force by analogy with quantum electrodynamics. This led to the prediction of the existence of the 'pion,' or 'pi-meson.'

In 1935, **Einstein**, Boris **Podolsky**, and Nathan **Rosen**, in "Can quantum-mechanical description of physical reality be considered complete?," proposed "a *Gedanken-Experiment* designed to show that the physical system had simultaneous properties that quantum theory could not determine, thereby demonstrating that the theory was 'incomplete,'" which allowed Einstein, *et. al.*, to continue to adhere to the classical framework (Folse 1985:143). The implication of being incomplete is the need for additional, or hidden, variables. The goal is to have 'objective reality' "localized on each particle[:] If *A* and *B* have flown a very long way apart then..., at the very least, *A* cannot be directly affected instantaneously [by any disturbance of *B*], because...no physical signal or influence can travel faster than light" (Davies and Brown 1986:15,14; Einstein *et al.* 1935:138-141).

In 1935, **Watson-Watt** designed the first workable 'radio direction finding,' or RDF, device for locating moving objects by bouncing radio waves off them and calculating the range by transmitted pulses. Independently, Rudolph **Kühnold** was working on a similar system, but only realized that pulse transmission was necessary some months later. It began to be called 'radar,' for 'radio detection and ranging,' after 1940.

In 1935, Albert W.**Stevens** and Orvil J. **Anderson** carried photographic plates on a balloon into the stratisphere, setting a record for manned flights. The developed plates showed the tracks of cosmic rays.

In 1935, **IBM** introduced a punch card machine with an arithmetic unit based on relays which could do multiplication.

In 1936, **Pauling** and Charles **Coryell** reported that hemoglobin undergoes a profound structural change when it combines with oxygen (Pauling and Coryell 1936).

In 1936, André **Lwoff** and Marquerite **Lwoff**, having discovered that bacterium required nutritional factors much like higher organisms and in the course of producing chemically defined media for their growth, discovered that growth factors, or vitamins, act as coenzymes, i.e., small molecules which assist enzymes in the performance of catalysis.

In 1936, Carl Ferdinand **Cori** and Gerti Theresa Radnitz **Cori** discovered and isolated a new phosphorylated intermediate, glucose-1-phosphate, in carbohydrate metabolism (Cori and Cori 1936).

In 1936, Edward Calvin **Kendall** and Phillip Showalter **Hench** discovered 'cortisone.'

In 1936, Egas **Moniz** designed the first prefrontal leucotomy to treat anxiety and agitation accompanying psychiatric conditions in humans.

In 1936, Gregory **Bateson**, in *Naven*, coined the term 'schismogenesis' to refer to escalating cycles in living systems that oscillate uncontrollably: "a process of differentiation in the norms of individual behavior resulting from cumulative interaction between individuals" (Bateson 1936:175).
Beginning in 1936, Fritz **Zwicky**, using a **Schmidt** telescope, discovered twenty supernovas and identified the two main types. Supernovas are violent events, and only at this time did the peaceful, harmonius, Aristotelian view of the stars begin to change.
In 1936, **Hubble**, in *The Realm of the Nebulae*, described the Universe as extending out about 500 million light years. Subsequently, this distance has been revised upward several times, such that if our galaxy were represented by an aspirin the entire Universe would be a kilometer across (Gribbin 1998a:68).
In 1936, Felix **Wankel** designed a motor which revolved around a central shaft.
In 1936, Alan M. **Turing** published "On Computable Numbers," in which he developed the Turing machine, the abstact precursor of the computer. A Turing machine consists of a finite set of logical and mathematical rules and a tape of infinite length.
In 1936, Alonzo **Church** proved the thesis that any mental process, such as the brain or a computer, which divides numbers into two sorts can be described by some general recursive function. It is sometimes called the Church-**Turing** thesis.
In 1936, or earlier, Moritz **Schlick**, in *Die Philosophie der Natur*, noted that "one may not, for example, say that...the momentary state of actual present wanders along the time-axis through the four-dimensional world. For a wandering of this kind would have to take place in time; and time is already represented within the model and cannot be introduced again from the outside" (Schlick 1936:43).
In 1937, Edouard **Chatton** pointed out the cytological differences between organisms such as bacteria and blue-green algae, which he named 'prokaryotes,' and all other organisms, which he called 'eukaryotes.'
In 1937, Neil Kensington **Adam** showed that elastic surface films are ubiquitous at the air-water interface (Adam 1937).
In 1937, **Krebs** discovered the citrus acid cycle, also known as the tricarboxylic acid cycle and the Krebs cycle. The citric acid cycle , that is, the breakdown of the carbohydrate pyruvic acid which citric acid catalyzes, accounts for about two-thirds of the total oxidation of carbon compounds in most cells. The process is cyclical because citric acid is regenerated and replenished. Its end products are CO_2 and high-energy electrons, which pass via NADH and $FADH_2$ to the respiratory chain (Krebs and Johnson 1937)
In 1937, James **Papez** proposed that the group of neurons that made up the anatomical substrate of the emotions was located in the limbic system (Papez 1937).
In 1937, **Landsteiner** put forth the view that when a foreign substance entered the body it was taken up by phagocytic cells where it served as a template against which globulin molecules could be synthesized. This theory was later falsified, i.e., disproved, but was appealing at the time because it explained away the paradox that a finite number of genes could generate a comparably vast diversity of antibodies.
In 1937, Tracy Morton **Sonneborn** worked out how to mate different strands of *Paramecium*, a ciliated protozoa, and detailed the interaction of the cytoplasm and the nucleus. By this time, hybridization techniques made the study of microorganisms accessible. Since they reproduced rapidly and did not undergo the complexity of tissue differentiation, they were superior subjects for the study of the chemistry of the organism.
In 1937, **Haldane**, influenced by **Landsteiner**'s ABO blood groups, developed the 'one-gene, one-antigen' hypothesis, which entailed that distinctions between antigens could be traced to the encoding by specific genes of different alleles (Haldane 1937).
In 1937, Arne Wilhelm Kaurin **Tiselius** invented an electrophoresis apparatus which permitted the obtaining of much higher resolutions and the separation of charged molecules (Tiselius 1937a). The first experiments, carried out with horse serum, allowed the globulins to separate into three parts, *alpha*, *beta*, and *gamma* and further investigation showed they were different chemically and that the antibodies, or immunoglobulins, were found in the *gamma* globulin or between the *beta* and *gamma* globulins (Tiselius 1937b).
In 1937, Theodosius **Dobzhansky**'s book, *Genetics and the Origin of Species*, detailed **Wright**'s position on genetic drift, and echoed Sergei **Chetverikov**'s position, from the 1920s, that nature uses heterozygotes to 'soak up' and preserve variation. Dobzhansky held that the unit of evolution was the population and that this fact greatly reduced the time required to respond to environmental changes.
In 1937, **Warburg** demonstrated how the formation of ATP is coupled with the removal of hydrogen atoms from glyceraldehyde 3-phosphate.
In 1937, Eugen **Werle** and colleagues discovered 'cytokinin,' a plant hormone which promotes cell

division.
In 1937, P. A. **Gorer** discovered the first 'histocompatibility' antigens in lab mice (Gorer 1937).
In 1937, George William Marshall **Findley** and F. O. **MacCullum** discovered 'interferon,' a glycoprotein produced by cells in response to viral attack.
In 1937, V. M. **Goldschmidt**, in "Geochemische Verteilungsgesetze der Elemente," provided data on the relative abundance of chemical elements in meteors and stellar spectra.
In 1937, **Zwicky** calculated that "extragalactic nebulae offer a much better chance than stars for the observation of the gravitational lens effects" (Zwicky 1937:290). A gravitational lens is an intervening space-warping mass which acts as a virtual telescope as it amplifies the light from the more distant target.
In 1937, investigations into the properties of petrochemical polyamides by Wallace Hume **Carothers** resulted in the production of nylon fibers. His employer, DuPont, allied with the pulp wood industry, orchestrated a campaign to suppress competition from hemp fibers in the United States, under the guise of suppressing *Cannabis sativa*, and succeeded in making it illegal to grow that same year.
In 1937, Ivan Matveevich **Vinogradov**, in "Some theorems concerning the theory of prime numbers," proved that every sufficiently large integer can be expressed as the sum of three odd primes.
In 1937, Claude **Shannon**, in his Master's thesis, showed that relay circuits, being switches, resemble the operations of symbolic logic: two relays in series are *and*, two relays in parallel are *or*, and a circuit which can embody *not* and *or* can embody *if/then.* This last meant that a relay circuit could *decide*. Since switches are either on or off, binary mathematics was therefore possible (Shannon 1938).
In 1937, George **Stibitz** , working with the telephone companies electromechanical relays, demonstrated a one-bit binary adding machine.
In 1938, Herbert F. **Copeland** added a fourth domain, bacteria, to the taxonomy of the living world (Copeland 1938).
In 1938, **McClintock** described the bridge-breakage-fusion-bridge cycle in maize and predicted special structures on the ends of broken chromosomes, called 'telomeres' (McClintock 1938).
In 1938, the **Coris** described the catalytic process by which the body converts surplus sugar into storable glucogen by demonstrating the existence of a new enzyme, phosphorylase, that catalyzes the cleavage and synthesis of the glycosidic bonds of polysaccharides. Eventually, they were able to synthesize glycogen in a test tube.
In 1938, Jean Louis **Brachet** demonstrated that ribonucleic acids are accumulated in regions of high morphogenetic development.
In 1938, a **coelacanth**, *latimeria chalumnae*, a primitive bony fish, known from Devonian fossils, was caught off Southeast Africa.
In 1938, Hans **Spemann** proposed the concept of cloning and insisted that cell differentiation was the outcome of an orderly sequence of specific stimuli, namely, chemical inductive agents, which were predominantly cyto-plasmic in operation (Spemann 1938).
In 1938, Warren **Weaver** coined the term 'molecular biology' (Weaver 1938).
In 1938, Otto **Hahn** and Lise **Meitner**, with their colleague Fritz **Strassman**, bombarded uranium nuclei with slow speed neutrons. Meitner, after fleeing the Nazis and working with Otto **Frisch**, interpreted the Hahn-Strassman results to be 'nuclear fission,' the term fission being borrowed from biology. They explained what happened in the nucleus by reference to the liquid drop model: "As the nucleus gets bigger, with more and more protons, the protons are farther apart, and the repulsive strength grows in comparison with the strong nuclear force, [and eventually] just enough to tip the balance in favor of the repulsive forces and split the nucleus" (Seaborg 2001:58-59). They also calculated that vast amounts of energy would be released by a sustained chain reaction.
In 1938, Carl F. **von Weizsächer** and, independently, H. **Bethe** proposed the existence of two chains of reaction by which the celestial conversion of hydrogen to helium is effected. These are the proton-proton cycle in less massive and luminous stars, and the carbon-nitrogen-oxygen cycle, in the most brilliant stars, where a minute amount of carbon acts as a catalyst, producing the nitrogen which is essential for life, i.e., the very same nitrogen nuclei which are now in your body (Gribbin and Gribbin 2000:108). After either of these processes has converted most of the star's hydrogen to helium, 'helium-burning' is initiated, and by the addition of helium the heavier elements are built up (through iron-56 and ultimately beyond that through bismuth-209 and the radioactive elements).
In 1938, **Einstein**, Leopold **Infeld**, and B. **Hoffman**, in their theory of the interaction of point masses with gravity, showed that the laws of motion of such particles follow from gravitational field equations.
In 1938, Pyotr **Kapitsa** and John F. **Allen** discovered that helium, when cooled within 2.2 kelvins of absolute zero, becomes a 'superfluid,' able to flow without friction. This effect occurs because up to about 10 percent of the helium atoms undergo **Bose-Einstein** condensation.
In 1938, **Compton** demonstrated that cosmic radiation consists of charged particles.

In 1939, J. **Huxley** introduced the notion to evolutionary studies of gradual change in a character, say size or color, over a geographic or ecological area. He termed this a 'cline.'
In 1939, **Theorell** isolated 'cytochrome c,' an enzyme responsible for energy reactions in mitochondria.
In 1939, **Siemens** began production of commercial transmission electron microscopes.
In 1939, **Just**, in *The Biology of the Cell Surface*, emphasized the changes in the ectoplasm during and after fertilization (Just 1939).
In 1939, C. **Anderson** discovered the 'mu-meson,' or 'muon,' one of a class of elementary particles, known as 'leptons.'
In 1939, Isadore Isaac **Rabi** and collaborators J. M. B. **Kellogg**, N. F. **Ramsay**, and J. R. **Zacharias** developed the "molecular-beam magnetic resonance method for measuring nuclear magnetic moments" (Kellogg *et al*. 1939:728). This forms part of the basis for lasers, atomic clocks, and the measurement of the **Lamb** shift.
In 1939, **Szilard** and Eugene Paul **Wigner** visited **Einstein** to discuss methods of averting a German atomic bomb. This led to Einstein's letter to the President of the United States.
In 1939, **Szilard** proposed stacking alternate layers of graphite and uranium in a lattice, the geometry of which would define neutron scattering and subsequent fission events.
In 1939, Grote **Reber**, with a 31 foot parabolic reflector in his back yard, confirmed **Jansky**'s discovery of cosmic static.
In 1939, **Oppenheimer** and George **Volkoff**, in "On Massive Neutron Cores," concluded that stable neutron stars could only exist if they had masses in a range from 10 to 70 percent of the Sun. For masses, greater than this limit, "the star will continue to contract indefinitely, never reaching equilibrium" (Oppenheimer and Volkoff 1939:381).
In 1939, **Gamow**, using a **Hertzsprung-Russell** diagram, suggested that stars evolve upward along the diagram as they slowly deplete their hydrogen fuel.
In 1939, **Oppenheimer** and Hartland **Snyder**, in "On Continued Gravitational Contraction," using **Schwarzschild**'s solution to **Einstein**'s equation, described the formation of black-holes: "When all the thermonuclear sources of energy are exhausted a sufficiently heavy star will collapse.... The radius of the star approaches [its Schwarzschild] radius [and] light from the star is progressively reddened" (Oppenheimer and Snyder 1939:455). They also pointed out that there were two incompatible views, inside and outside, of black-hole formation: For an observer outside the black-hole the collapse takes almost forever, while inside a co-mover perceives the collapse as "finite, and...of the order of a day" (*ibid*.:455).
In 1939, **Bush** proposed an associative information retrieval system which he called 'Memex' and which is ancestor to 'hypertext' and the 'World Wide Web.' He foresaw this operating on an electric analog computer, which was completed in 1942.
In 1939, **Stibitz** and Samuel B. **Williams** designed and built the binary 'Complex Computer,' actually more of a desktop calculator, "equiped with 450 relays and three modified Teletype machines for entering problems and printing out the answers" (Waldrop 2001:35).
In 1939, John Vincent **Atanasoff** and Clifford Edward **Berry** began to build a protp-type 16-bit adding machine which used vacuum tubes and had a circuit that could store binary numbers until needed.
In 1939, Nikolai Sergei **Trubetzkoy**'s *Grundzüge der Phonologie*, which contains his theory of distinctive phonemic oppositions, was published posthumously (Trubetzkoy 1939).
In 1940, **Pauling** suggested, in support of the immunochemical template theory, that the specificity of an antibody is the result of complementariness between its structure and a portion of the surface of the homologous antigen. In other words, this complementariness is induced by the antigen into the variable folding patterns and noncovalent bonds of the antibody *after* protein systhesis has already taken place (Pauling 1940).
In 1940, Herman Moritz **Kalckar** and Vladimir Aleksandrovitch **Belitser** discovered 'oxidative phosphorylation,' a coupled electron-transfer reaction by which ATP is regenerated (de Duvé 1991:13-14).
In 1940, Ernst Boris **Chain** and Howard Walter **Florey** extracted and purified penicillin and demonstrated its therapeutic utility.
From the work of Torbjörn **Caspersson**, published in 1940 and 1941, and **Brachet**, published in 1942, the association of RNA with cell growth was established (Judson 1979:641n236; Caspersson 1946; Brachet 1946).
In 1940, **Landsteiner** and colleagues found the Rhesus factor, a variant on the surface of red blood cells of most human beings, i.e., those that are *Rh+ (Landsteiner and Weiner 1940).*
In 1940, **de Beer** wrote *Embryos and Ancestors*, a refutation of **Haeckel**'s biogenetic law.
In 1940, Edwin M. **McMillan** and Phillip H. **Abelson** discovered the first transuranium element

'neptunium,' a byproduct of uranium decay.
In 1940, Georgii **Flerov** and Konstantin **Petrzhak** discovered the spontaneous fission of uranium.
In 1940, **Urey** became director of the United States government program to separate uranium isotopes. In the course of this, he developed statistical methods of isotope separation which permitted large scale production of $uranium^{235}$.
In 1940, Norbert **Wiener** proposed building vacuum-tube electronic computers which would make totally preprogrammed digital calculations using binary mathematics on magnetic tape (Wiener 1940).
In 1940, Igor **Sikorsky** invented the heliocopter.
Beginning about 1940 [?], Roman **Jakobson** propounded the theory that the sounds of all human languages are composed of atomic units, which he called 'features,' that all human beings innately possess the biological bases of these features, and individual languages are subsets of them. Language acquisition involves the "activation of the particular features that a given language uses; as people mature, they lose the unused ones" (Lieberman 1991:37).
In the 1940s, Wilhelm **Reich** proposed that cancer results from repressed emotions, especially those related to sexual desires.
In 1941, **Haldane** speculated that the self-reproduction of the gene could be demonstrated by labelling the gene and then seeing if the copy gene contained the label while the original did not (Haldane 1941:44).
In 1941, Fritz Albert **Lipmann**, using a bacterium that clots milk, proposed that adenosine triphosphate takes energy out of the metabolic flow and conducts it to reactions where needed. This was a radical sharpening of the idea of specificity (Lipmann 1941).
In 1941, **Astbury** established the DNA has a crystalline structure.
In 1941, George Wells **Beadle** and Edward Lawrie **Tatum**, using the bread mold *Neurospora crassa*, published the assertion that genes control cells by controlling the specificity of enzymes, i.e., one gene controls one enzyme so a mutation in a gene will change the enzymes available, causing the blockage of a metabolic step. A major advantage of *Neurospora* over *Paramecium* is that the former can be grown on defined, preferably, synthetic medium, e.g., manufactured vitamins and amino acids, whereas the latter must have bacteria (Beadle and Tatum 1941).
In 1941, **Burnet**, reviving ideas of **Metchnikoff**, focused on two experimental facts incompatible with the template hypothesis: "the continued production of antibody in the absence of antigen, and the presence of the secondary response, in which a second inoculation with an antigen elicits a host response qualitatively more rapid than that which followed the first inoculation" (Podolsky and Tauber 1997:27).
In 1941, **Northrop** produced a crystalline antibody to diphtheria.
In 1941, **Bush** became director of the United States Office of Scientific Research and Development where he directed such programs as the mass production of sulfa drugs and penicillin, the development of the atomic bomb, and the perfection of radar. As part of the latter effort, Karl **Lark-Horowitz**, Seymour **Benzer**, and others developed germanium crystal rectifiers, the semiconducter later used in transistors. Atomic bomb development was known as the Manhattan Project with Oppenheimer in overall charge of the scientists involved.
In 1941, **Seaborg**, **McMillan**, Joe **Kennedy**, and Arthur **Wahl** deduced from secondary evidence the existence of a trace amount of 'plutonium,' transuranium element 94, which they made from uranium-238. "That increased the potential material available for a bomb by a hundredfold" (Seaborg 2001:78). Moreover, its fission rate was greater than U-235 and a fissionable isotope employed in the bomb dropped on Nagasaki.
Beginning in 1941, Lev Davidovic **Landau** constructed a complete theory of the quantum liquids at very low temperatures.
In 1942, **Waddington** described 'canalization,' the capacity to respond to an external stimulus by some developmental reaction, such as the formation of an ostrich's calloses, which are under genetic control. "Once a developmental response to an environmental stimulus has become canalized, it should not be too difficult to switch development into that track...by the internal mechanism of a genetic factor...; the same considerations which render the canalization advantageous will favor the supercession of the environmental stimulus by a genetic one. By such a series of steps, then, it is possible that an adaptive response can be fixed without waiting for the occurrence of a mutation which...mimics the response well enough to enjoy a selective advantage" (Waddington 1942:565).
In 1942, J. **Huxley** wrote *Evolution, The Modern Synthesis*, which lent its name to the 'modern synthesis' of evolutionary studies created by **Fisher**, **Haldane**, and **Wright**. It received its name because it "gathered under one theory--with population genetics at its core--the events in many sub-fields that had previously been explained by special theories unique to that discipline. Such an occurrence marks scientific 'progress' in its truest sense--the replacement of special explanations

carrying little power in prediction or extension with general theories, rich in implications and capable of unifying a diverse set of phenomena that had seemed unrelated" (Eldredge and Gould 1971:108).
In 1942, Ernst **Mayr**, in writing *Systematics and the Origin of Species* against the 'typological' species concept, did for systematics what **Dobzhansky** had done for genetics. Later, he came to deny the likelihood of any gene remaining selectively neutral, i.e., available for random drift, for any length of time.
In 1942, **Szent-Györgi** and colleagues showed that myosin was not the sole structural protein in muscle, but shared that role with 'actin,' the complex of the two being named actomyosin. They also showed that threads of actomyosin, in the presence of magnesium and potassium ions, contracted with the addition of adenosine triphosphate (ATP).
In 1942, J. **Weiss** discovered ionic 'charge transfer.'
In 1942, **Fermi**, pursuant to scaling-up the creation of plutonium 239, created the first controlled, self-sustaining nuclear chain reaction from 'piles,' **Szilard**'s lattice, of uranium and graphite. The term pile has been superseded by 'reactor.' This was accomplished as part of the Manhattan Project, of which **Compton** was in charge of the Metallurgical Laboratory and under him Fermi commanded the physicists and **Seaborg** the chemists.
In 1942, Rudolph **Minkowski**, in "The Crab Nebulae," pointed out that "sufficient mass is blown off from the stellar envelope during the supernova explosion to allow the remnant star to stop its collapse at the white dwarf stage" (Lang and Gingerich 1979:482).
In 1942, **Wiener**, Julian **Bigelow**, and Arturo **Rosenblueth** explained that all voluntary action involved feedback, that "the processes of communication and control are based on the much more fundamental notion of *message*, [that] the nervous system [is an] array of feedback loops in active communication with the environment, [and that] through feedback...a mechanism could embody *purpose*" (Waldrop 2001:56). In other words, the mind, purposeful spirit, is inextricably bound up with the body, with matter.
In 1943, bacterial genetics was born with the publication of the paper by Eduardo Salvatore **Luria** and **Delbrück**, the core of the so-called 'phage group,' reporting evidence that mutation, not adaption, was how bacteria acquired resistance to phage and that mutation was revealed through its selection: "When a pure bacterial culture is attacked by a bacterial virus, the culture will clear after a few hours due to destruction of the sensitive cells by the virus. However, after further incubation for a few hours, or sometimes days, the culture will often become turbid again, due to the growth of a bacterial variant which is resistent to the action of the virus" (Luria and Delbrück 1943:491). Nine months later Jacques Lucien **Monod** and Alice **Audureau** demonstrated similar results which were published at the end of the war(Monod and Audreau 1946). Many people believed the resistance of bacteria to antibiotics was the result of some sort of adaption induced by the antibiotic, which implied that acquired characteristics could be inherited (Monod et Audureau 1946).
In 1943, **Sonneborn** discovered the cytoplasmic factor *Kappa*, which he was able to control through effecting the environment (Sonneborn 1943).
In 1943, Thomas **Francis** and Jonas Edward **Salk** developed a formalin-killed-virus vaccine against type A and B influenzas.
In 1943, Albert **Hofmann** ingested the ergotomine molecule, lysergic acid 25 (LSD-25), which he had synthesized in 1938.
In 1943, Kenneth **Craik**, in *The Nature of Explanation*, said "the brain functions like a simulator [which] gives to thought its power to predict events and to anticipate their sequence in time" (Changeux 1983:134).
In 1943, Warren S. **McCulloch** and Walter H. **Pitts** published "A Logical Calculus of the Ideas Immanent in Nervous Activity," where they claimed that the brain could be modelled as a network of logical operators on a **Turing** machine. This initiated discussions which led to the use of computational metaphors and Boolean functions in the study of cognition.
[In the early, mid-1940s, there were two distinct approaches to understanding the nature of life, functional and structural. The proponents of a functional description were biochemists--**Avery** and Erwin **Chargaff**--and geneticists--**Luria**, **Delbrück**, Alfred **Hershey**, and **Monod**. The chief proponents of the structural approach, that is, characterizing the chemical sequences of the large, long-chain protein molecules and, stereochemically, reconstructing their three-dimensional architecture, were **Bragg**, **Pauling**, **Astbury**, and **Bernal**].
In 1944, through the experiments of Oswald T. **Avery**, Colin **MacLeod**, and Maclyn **McCarty**, it was established that the material of heredity, specifically in **Griffith**'s dead pneumococci, was deoxyribonucleic acid. In other words, even though they were dead, the cells could transfer their genes as long as their DNA remained intact. Up to this time, most biologists thought genes were probably protein and nucleic acid was some sort of skeletal material for the chromosomes (Avery *et*

al. 1944).
In 1944, Peter B. **Medawar** proved the immunological nature of graft-rejection (Medawar 1944).
In 1944, Selman **Waksman** discovered streptomycin.
In 1944, George Gaylord **Simpson**, in *Tempo and Mode in Evolution*, argued that no observations in the fossil record required 'inherent forces,' or orthogenesis, toward 'desired ends,' e.g., large size.
In 1944, Robert Burns **Woodward** and William E. **Doering** announced the 'total synthesis' of quinine. Total synthesis occurs when a molecule is built up from the smallest, most common compounds. Over the next eighteen years, Woodward synthesized, in 1951, cholesterol and cortisone, in 1954, strychnine and lysergic acid, in 1956, reserpine, in 1960, chlorophyll, and, in 1962, a tetracycline antibiotic.
In 1944, Archer John Porter **Martin** and Richard **Synge** devised, 'paper partition chromatography,' in which solutions move in columns on sheets of paper instead of in tubes packed with absorbent materials.
In 1944, **Seaborg** proposed a second 'lanthanide group' as an addition to the periodic table of the elements. Lanthanum is element 57 and the lanthanide group consists of elements 58 through 71. Actinium, immediately below lanthanum in the periodic table, is element 89 and Seaborg proposed the existence of a similar series, 90 through 103, or 'actinide group.' This led, in the course of the next twenty years, to the isolation of elements 95 through 106 and about 150 isotopes, in each case with the participation or under the leadership of Albert **Ghiorso**.
In 1944, L. **Onsager** published a complete solution for the two-dimensional **Ising** model.
In 1944, **Szilard** proposed the term 'breeder' to describe a reactor able to generate more fuel than it consumed.
In about 1944, Stanislaw Marcin **Ulam** and Edward **Teller**, both working on the Manhattan Project, suggested a two-stage radiation implosion design, employing both fusion and fission, permitting the detonation of thermonuclear weapons.
In 1944, **Reber** found discrete sources of radio emission in the direction of *Cynus* and *Cassiopeia*.
In 1944, Hendrick **van de Hulst** and Jan H. **Oort** pointed out that radio telescopes can sample more distant regions of the Universe than optical telescopes. Radio telescopes usually have a parabolic reflector, which works in a manner similar to the main mirror of an optical telescope.
In 1944, Howard W. **Aiken** and a team of engineers from **IBM** displayed a huge programmable calculator, the 'Automatic Sequence Controlled Calculator,' later known as the 'Mark I.'
In 1944, **von Neumann** and Oskar **Morgenstern**, using zero-sum parlor games like poker and chess, published their formulation of game theory in reference to human economic behavior. The central assumptions are that the players are able to foresee the consequences of their actions and will behave rationally, and according to some criterion of their self-interest. About the same time, von Neumann applied game theory to United States nuclear strategy, which led to his being characterized, along with **Teller**, as Dr. Strangelove in Stanley Kubrick's movie.
In 1944, **Hayek**, in *The Road to Serfdom*, argued that no central economic planner could possibly command the countless bits of localized and individual information necessary and that only the unorganized price system in a free market enables order to arise from the myriad of individual plans.
In 1945, **Schrödinger**, in *What is Life?*, asked questions about replication, structure, aperiodicity, coding, and metabolism which set biology's agenda for 30 years.
In 1945, Ray **Owen** demonstrated that identical cattle twins, i.e., who had shared an *in utero* circulatory system, were unable, in adulthood, to mount an immune response to antigens produced by the twin. This was the first demonstration of immune tolerance.
In 1945, Michael James Denham **White**, in *Animal Cytology and Evolution*, the first monograph on cytogenetics, gathered together prior research on chromosomes and the various sorts of mitotic and meiotic mechanism. New editions kept this synthesis together through 1971 (White 1973).
In 1945, **Wright** devised the 'Coefficient of Relationship', which represents in numerical form the genetic probabilities for related members of a population to carry replica genes. There are just three possible conditions of this in an individual, namely, that both, one only, and neither of his genes, at a given locus, are identical by descent, or $c_2+c_1+c_0=1$. The relationship is completely specified by any two of them, e.g., $2c_2+c_1$. One-half of this number, $c_2+{}^1/_2c_1$, may therefore be called the expected fraction of genes identical by descent in a relative.
In 1945, Maurice **Merleau-Ponty**, in the *Phénoménologie de la Perception*, asserted that the foundations of science entail the primacy of perception as against the older 'retinal image + judgement = perception as hypothesis.'
In 1945, **van de Hulst**, in "Heromst der radiogolven uit het wereldruim," discussed the possibility of discrete lines in the spectrum of cold, neutral, interstellar hydrogen and correctly predicted its appearance at 21 cm.

In 1946, Joshua **Lederberg** and **Tatum** discovered that the bacteria *Escherichia coli* sometimes exchange genes (Lederberg and Tatum 1946).
In 1946, L. **Michaelis** proposed that free radicals were obligate intermediaries in metabolic pathways in living cells.
In 1946, U.v. **Euler** deteched a neurotransmitter, 'noradrenaline,' in the sympathetic nervous system.
In 1946, **Landau** postulated an attenuation, or 'damping,' of wave motion when the velocity of a wave is comparable to the velocity of electrons in 'plasmas.' A plasma forms when electrons are separated from their nuclei by heat.
In 1946, Willard Frank **Libby** developed radioactive carbon-14 dating, employing the known rate of decay, measured by its half-life, and relative proportion of its decay products.
In 1946, Martin **Ryle** and Derek D. **Vonberg** were "the first in radio astronomy to employ an antenna configuration analogous to **Michelson**'s optical interferometer. They soon demonstrated how source sizes in radio astronomy may be estimated by measuring the fringe amplitudes associated with various spacings of the receiving elements" (Sullivan 1982:182), or, in other words, "two aerial systems were used [to observe the sun] with a horizontal separation of several wave-lengths, and their combined output was fed into the receiving equipment" (Ryle and Vonberg 1946:339). "The maximum resolution of the array is...determined not by the size of the individual elements, but by their maximum separation. Interferometers are [used] also in infared and optical astronomy [where] the incoming beam is split and then recombined with itself to form an interference pattern" (*Dictionary of Astronomy* 1997:238).
In 1946, Robert H. **Dicke**, in order to reduce the noise from a radio telescopic receiver, described an alternating on-off switch which produces "greatly improved accuracy and effective sensitivity" (Sullivan 1982:105).
In 1946, James S. **Hey**, S. J. **Parsons**, and J. W. **Phillips**, in "Fluctuations in Cosmic Radiation at Radio Frequencies," announced their discovery of a discrete radio source from the direction of the constellation *Cygnus A*.
In 1946, **Gamow** suggested that the relative abundances of the elements were determined by nonequilibrium nucleosynthesis during the early stages of the Universe's expansion.
In 1946, Fred **Hoyle** suggested that collapsing stars will continue until, reaching **Chandrasekhar**'s limit, they become rotationally unstable and throw off the heavy elements which they have built up and that "the observed intensity of cosmic rays can be explained by means of such an association" (Hoyle 1946:384).
In 1946, John **Mauchly** and John Presper **Eckert**, trying to more quickly ascertain artillery shell trajectories for the United States War Department, demonstrated ENIAC, or Electronic Numerical Integrator and Computer. Its components were entirely electronic.
In 1946, **von Neumann**, Arthur W. **Burks**, and Herman **Goldstine**, in "Preliminary Discussion of the Logical Design of an Electronic Computing Instrument," going out of their way to use biological metaphors, defined the concept of a software program and showed how a computer could execute such a program by , stored in a binary-code random-access memory unit, by obeying instructions of a central control unit. This ' von Neumann architecture,' drawing its circuit designs using **McCulloch-Pitts** neural-net notation with its sharp distinction between software and hardware, is the basis for almost all computers today.
In 1947, **Bernal**, in a speech on "The Physical Basis of Life," proposed that the lagoons and pools at the edge of the oceans served to concentrate the chemical building blocks and raised the possibility of these chemicals being further concentrated by being absorbed on particles of clay (Bernal 1947).
In 1947, Paul **Weiss** published his concept of 'molecular ecology,' which involves the functional role of the cell surface and 'fields' of chemical and physical conditions: "Let the number of [molecules] keep on increasing..., and all of a sudden a critical stage arises at which some of the [molecules] find themselves...cut off completely from contact with their former vital environment by an outer layer of their fellows.... Thus would ensue a train of sequelae of ever-mounting, self-ordering complexity.... The fate of a given unit would be determined by its response to the specific conditions..., [which vary] locally as functions of the total configuration of the system--its 'field pattern,' for short" (Weiss 1967:819-820).
In 1947, John Tyler **Bonner** published a study of chemotaxis in slime mold, demonstrating that the interaction of chemical messages and receptors produces their aggregation in a complex organization.
In 1947, Ilya **Prigogine**, in *Étude thermodynamique des phénomènes irrèversibles*, dealt with the constructive role of time, i.e., irreversibility, and self-organization in open thermodynamic systems.
In 1947, Louis **Werner** and Israel **Perlman** isolated element 96, curium.
In 1947, John **Bardeen**, Walter H. **Brattain**, and William **Schockley** invented the point-contact

transistor amplifier, a voltage and current amplifier, which, in contrast to the vacuum tube it replaced, is an arrangement of semiconductor materials sharing common physical boundaries. A semiconductor is a solid material, e.g., silicon, in which certain induced impurities enhance its conductive properties.
In 1947, Willis Eugene **Lamb** and R. C. **Retherford** found a slight difference of energy between the state of zero angular momentum and the first excited state of hydrogen. Known as the 'Lamb shift,' it results from the quantum interaction between an electron and atomic radiation.
Later in 1947, H. **Bethe** noticed that calculations of mass and energy, for example, for the **Lamb** shift, in the theory of quantum electrodynamics (QED), **Dirac**'s equation of 1929, conformed more closely to their experimental values the closer to zero distance the calculation of the 'coupling points' is carried.
In 1947, George **Rochester** and C. C. **Butler** discovered a cosmic particle which they named ' V.'
In 1947, Dennis **Gabor** invented 'holography,' a method of displaying a three-dimensional image of an object by splitting a coherent light beam so that some of it falls on a photographic plate and the rest on the object which reflects back onto the photographic plate. The two beams form an interference pattern on the plate with alternating light and dark. "The light is where the two images both relect light back and reinforce each other, while the dark is where the images do not match" (van Dulkin 2000:112). The plate is then developed, creating a 'hologram,' Greek for 'completely written.'
In 1947, **Langmuir** proposed that non-linearities in weather phenomena made them unstable when subjected to small changes in their energy cycles.
In 1948, **Burnet** and Frank **Fenner** hypothesized that the immune system discriminated between 'self' and 'nonself' (Burnet and Fenner 1949).
In 1948, George David **Snell** and Peter **Gorer**, transplanting tissues between mice, discovered a genetic factor, which they called H-2, for 'histocompatibility two.'
In 1948, William Howard **Stein** and Stanford **Moore** isolated amino acids by passing a solution through through a chromatographic column filled with potato starch.
In 1948, Sin-itiro **Tomonaga**, Victor **Weisskopf**, Julian Seymour **Schwinger**, and Richard **Feynman**, each independently, invented different methods of making precise the renormalization calculations of the QED. These methods invoved various ways of smothering the unwanted infinities in calculating the **Lamb** shift. "The essence of renormalization is to make the transition from one level of description to the next.... It is when you solve the field equations that you see the emergence of particles. But the properties--the mass and the charge--that you ascribe to a particle are not those inherent in the original equation" (Schwinger, quoted in Gleick 1992:262). Continuing into 1949, Feynmann published numerous papers in which he completed the mathematics of QED with 'Feynman diagrams,' applicable, for example, in the chemistry "to those problems in which the heavy nuclei can be approximated as fixed point particlescarrying an electric charge" (Gell-Mann 1994:110). In the late 1960s, Feynman diagrams proved essential in quanticizing gauge theories (Feynman 1985:127-128).
In 1948, Marya **Goeppert-Meyer** and, independently, Hans **Jensen** proposed the 'shell' structure of the nucleus in which the nucleons are assumed to move in shells analogous to atomic electron shells, or levels.
In 1948, **Gamow** and Ralph A. **Alpher**, in "The Origin of Chemical Elements," predicted that an adiabatic thermodynamic radiation event would have produced a background of microwave radiation with a temperature of five degrees K and would have provided the non-equilibrium conditions necessary for the successive captures of neutrons by protons which formed the elements. Gamow assumed the cosmic *ylem*, the primordial matter, consisted of neutrons with a temperature of ten billion degrees (Alpher *et al.* 1948:803-804). Later that year, the theory was further developed by Alpher and Robert C. **Herman**. Also, the same year, in opposition to this theory, Herman **Bondi**, Thomas **Gold**, and, independently, **Hoyle** promulgated a 'Steady-State' theory of the Universe, i.e., there is no beginning and matter is continuously created to fill in the gaps left between the old galaxies. The standard form of **de Sitter**'s 1917 solution reappears as the line element in this theory. In other words, they rationalized **Hubble**'s redshift as a local phenomena (Bondi and Gold 1948:258, 262; Hoyle 1948:379-380). However, they did not account for the possibility of background radiation temperature.
In 1948, **von Neumann** observed that replication and metabolism are logically separable, and, in fact, are analogous processes to software (nucleic acid) and hardware (protein).
In 1948, **Shannon**, in *A Mathematical Theory of Communication*, proposed a linear schematic model of communications, defining the fundamental problem of communication as the task of reproducing at one point in space a message created at another point. He worked out how such a message could be reliably sent, the theoretical limit of the amount of information it could contain, and contributed the notion of negentropy as a measure of information, thereby creating 'information theory.' The word 'bit,'

short for binary digit, and credited to John **Tukey**, was used in print for the first time.
In 1948, **Wiener**, in *Cybernetics*, *or Control and Communication in the Animal and Machine*, which dealt with general communications problems, said that living organisms are metastable **Maxwell** demons whose "stable state is to be dead" (Weiner 1948:72). Weiner coined 'cybernetics,' in honor of **Maxwell**'s paper "On Governors," from the Greek for 'steersman,' from which the word 'governor' is descended.
In 1949, Victor **Negus** and Arthur **Keith** reconstructed the supralaryngeal airways of a Neanderthal fossil and concluded that its tongue was closer to that of a chimpanzee than a human and that it lacked a pharynx, or soft palate.
In 1949, Ivan Ivanovich **Schmalhausen**'s *Factors of Evolution: The Theory of Stabilizing Selection* was translated into English by **Dobzhansky** and so associated with the 'modern synthesis.' He offered two versions of stabilizing selection. The first, which the modern synthesis adopted, built up "the mean or average form by selecting against the extremes at both ends of the distribution" (Gottlieb 1992:133). The second saw evolution as a process where, in the course of severe environmental pruning and breeding among the survivors, the traits which enabled survival, the 'adaptibilities,' might be assimilated genetically. This is similar to the **Baldwin** effect and **Waddington**'s 'genetic assimilation.'
In 1949, Sven **Furberg** ,in his dissertation for Birbeck College, London,drew a model of DNA, setting sugar at right angles to base, with the correct three-dimensional configuration of the individual nucleotide.
In 1949, Frederick **Sanger** made the claim that proteins are uniquely specified, the implication being that, as there is no general law for their assembly, a code was necessary.
In 1949, **Szent-Györgyi** showed the isolated myofibrils from muscle cells contract upon the addition of ATP.
In 1949, **Pauling** discovered the molecular nature of sickle-cell anaemia (Pauling *et al*. 1949).
In 1949, Donald **Hebb** suggested in *Organization of Behavior* that selective reinforcement of neural connecions accounts for learning and memory. Moreover, this reinforcement causes the brain to organize itself into 'cell assemblages,' the building blocks of information. Since any given neuron would belong to several such assemblages, the activation of one assemblage would activate others, creating larger concepts and more complex behaviors.
In 1949, Jerzy **Konorski** suggested that memory is the result of functional transformations, or plastic changes, in neurons.
In 1949, George A. **Miller** and Frederick **Frick**, writing on the uses of information theory in psychology, noted that "what a person expects to hear is critical to what he *does* hear" (Miller, quoted in Waldrop 2001:97).
In 1949, **Brillouin** proposed an information theoretical refutation of **Maxwell**.
In 1949, Freeman **Dyson**, in several papers, unified **Feynman**'s and **Schwinger**'s radiation theories, emphasizing the so-called 'scattering matrix,' which contained the different routes from the initial state to a given end-point.
In 1949, Francis **Bacon** invented a fuel cell employing only hydrogen and water.
In 1949, John G. **Bolton**, Gordon J. **Stanley**, and O. B. **Slee** identified three discrete radio sources: *Taurus A* in the *Crab Nebulae, Virgo A*, and *Centaurus A*.
In 1949, another **Hale** telescope, the 200-inch mirror on Mount Palomar, was completed.
In 1949, **Gödel**, in "A Remark about the Relationship between Relativity Theory and Idealistic Philosophy," reported his discovery of solutions for the field equations of General Relativity that described worlds, which he calls 'rotating universes,' in which it is possible to travel into the past "exactly as it is possible in other worlds to travel to distant parts of space" (Gödel 1949:560).
In 1949, Gilbert **Ryle**, in *Concept of Mind*, held that the mind is part of the body's activity, not a separate and theoretically equivalent counterpart to the body, not "a ghost in a machine" (Ryle 1949:15).
In 1950, **Chargaff** showed that the tetranucleotide theory was wrong, in other words, that DNA did not consist of a monotonous succession of nucleotides (in a fixed order in sets of four), and that the molecule to molecule "ratio of total purines to total pyrimidines, and also of adenine to thymine and of quanine to cytosine, were not far from 1" (Chargaff 1950:13). The collapse of the tetranucleotide theory made it highly likely that nucleic acids were also sequentially specific.
In 1950, Cyril **Hinshelwood** published his derivation of the biological activity of a three-dimensional protein strictly from its one-dimensional sequence (Caldwell and Hinshelwood 1950).
In papers of 1950 and 1951, **McClintock**, working in the genetics of maize, reported finding control elements, providing the first evidence that genetic regulation might be universal. She found evidence that some genes move from place to place and often affect nearby genes. In the mid-1970s, these

genes were isolated and named transposons (McClintock 1950; McClintock 1951).
In 1950, George Ledyard **Stebbins** wrote *Variation and Evolution in Plants.*
In 1950, **Lwoff** , Louis **Siminovitch**, and Niels **Kjeldgaard**, succeeded in 'inducing' *Bacillus megaterium*, a lysogenic bacteria, to produce virions, or bacteriophage, by irradiation. This established that viruses have a dormant or noninfective stage, which they called 'prophage,' reproducing along with each cycle, and are thus intimately associated with the genetic material of their hosts (Lwoff *et al*. 1950; Lwoff 1992). Lwoff speculated that animal-cell viruses function in the same way.
About 1950, Boris **Belousov** discovered serendipitously a non-living chemical oscillator which came to be known as the Belousov-Zhabotinsky reaction.
In 1950, Karl von **Frisch** discerned the code which is conveyed by the dance of bees (Frisch 1951; Frisch 1965).
In 1950, Ernst L. **Wynder** and Evarts A. **Graham** published, in the *Journal of the American Medical Association*, a survey indicating a strong correlation between contracting lung cancer and smoking tobacco.
In 1950, Leo **Rainwater** combined the liquid drop and shell models of the atomic nucleus.
In 1950, Chushiro **Hayashi** showed that neutrons will interact with thermally excited positrons to form protons and antineutrinos and "determined the value of the proton-neutron ratio resulting from spontaneous and induced *beta* processes" (Alpher *et al.* 1953:1348).
In 1950, Fred L. **Whipple**, in "A Comet Model. I: The Acceleration of Comet *Encke*," hypothesized a great difference between comets and meteors: "A model comet nucleus...consists of a matrix of meteoric material with little structural strength, mixed together with frozen gases, a true conglomerate.... We know very little about the meteoric material except the pieces seem to be small [and] physically the meteoric material is strong enough to withstand some shock in the atmosphere.... As our model comet nucleus approaches perihelion, the solar radiation will vaporize the ices near the surface [and] meteoric material below some limiting size will be blown away" (Whipple 1950:376-377).
In 1950, Karl Otto **Kiepenheuer** and, independently, Hannes **Alfvén** and Nicolai **Herlofson** hypothesized that cosmic radio emissions come from discrete electromagetic sources with magnetic fields moving at extremely high speeds, close to that of light. Such radiation is known as 'synchrotron radiation.' Until this time, most assumed that radio interference was only a type of decelerating thermal radiation, known as '*bremsstrahlung*,' which is German for 'breaking radiation.'
In 1950, **Fermi** and A. **Turkevich**, having examined all the thermonuclear reactions that might have led to element formation, concluded that no element heavier than helium could have been produced in a nonequilibrium primal fireball.
In 1950, **Oort** proposed that comets originate in a cloud of particles, perhaps, a light-year from the Sun and that upon occasion are deflected into the Solar System after being gravitationally perturbed by a passing star.
In 1950, **Hoyle** claims to have coined 'big-bang' for the primal fireball, disparaging the notion that such ever occurred (Hoyle 1994:255).
In 1950, John Forbes **Nash**, in "Non-cooperative Games," introduced "the concept of the non-cooperative game and develope[d] methods for the mathematical analysis of such games" (Nash, quoted in Kuhn *et al* 1995:5). Generalizing the minimax solution introduced by **von Neumann** in 1928 for the two-person zero-sum game, Nash proved that "every non-cooperative game has at least one equilibrium point..., such that no player can improve his payoff by changing his mixed stategy unilaterally" (*Ibid.*:5). In other words, the basic requirement for constituting an equilibrium is the stabilization of the frequencies with which the various stategies are played.
In 1950, David **Huffman** devised an algorithm by which any set of symbols can be compressed in everything from compact discs to interplanetary spacecraft (Waldrop 2001:94n).
In the 1950s, John **Robinson** distinquished between gracile and robust *Australopithecus* in functional terms, which he suggested are somewhat analogous to the differences between chimpanzees and gorillas, and suggested that the gracile type was ancestral to hominids.
In 1951, **Pauling** discovered by crystallography that an alpha helix, a twisted polypeptide chain, is the basic structure of many proteins. Successive turns of the helix are linked by hydrogen bonds (Pauling *et al*. 1951).
In 1951, **Lederberg** and Norton **Zinder** announced that in order to become lysogenic bacteria need not wait for a mutation to arise if they can pick up a gene for resistence from another strain, a phenomena they called 'transduction' (Zinder and J. Lederberg 1952). In the same year, Esther **Lederberg** proved that lysogeny could be transmitted in bacterial crosses like any other genes (E. Lederberg 1951).
Later in 1951, **Monod**, Germaine **Cohen-Bazire**, and Melvin **Cohn**, with an array of artificial b-

galactosides, learned to decouple the production of the enzyme from its natural stimulus and from the natural substrate, lactose, and called the process 'induced enzyme synthesis,' or just 'induction.' Subsequent work established that enzyme induction consists in the actual synthesis from amino acids of the entire enzyme molecule, and that this protein is stable, not 'dynamic,' as many thought(Monod et al. 1951).
In 1951, Carl **Djerassi** synthesized 19-nor-17a-ethynyltesterone, or norethindrone, an inhibitor of ovulation when taken orally.
In 1951, Erwin **Mueller** invented the field-ionization microscope.
In 1951, Otto **Struve** suggested the transit method of planet detection: In stars with a fortuitous alignment with the Earth, when a planet transits, or eclipses, the star, it will dim slightly.
In 1951, **Ryle** described a phase-switched, or **Dicke**-switched, radio interferometer which "enables the radiation from a weak 'point' source such as a radio star to be recorded independently of the radiation of much greater intensity from an extended source.... It also has important applications to the measurement of the angular diameter and polarization of a weak source of radiation" (Ryle 1952:351).
In 1951, George H. **Herbig** and, independently, Guillermo **Haro** reported finding faint gas clouds within the constellation *Orion*. These are known now as Herbig-Haro objects.
In 1951, Ernst **Öpik** and, independently, the following year, Edwin E. **Salpeter** presented arguments for the synthesis of carbon and other heavy elements by helium burning in the interiors of stars: Under suitable temperatures, beryllium 8 is "formed momentarily by the collision of two [helium] alpha particles [that] can capture a third one before breaking up [back] into two alpha particles, and thus carbon 12 can be synthesized" (Lang and Gingerich 1979:375).
In 1951, Francis **Graham Smith**, using the Cambridge interferometer, was able to communicate highly accurate positions for discrete radio sources to **Baade** and **Minkowsky** who, using the Mount Palomar optical telescope and a spectroscope, unambiguously confirmed the identity of the two strongest radio sources in the sky, *Cassiopeia A* and *Cygnus A*.
In 1951, Ludwig F. **Biermann** suggested that the ion tails of comets, which always stream away from the Sun, "are accelerated by a moving plasma of solar origin and proposed that the Sun emits a continuous flow of solar corpuscles of the same type as those causing geomagnetic storms" (Lang and Gingerich 1979:147).
In 1951, Jay **Forrester** and Robert **Everett**, working for the United States Navy, completed the construction of ' Whirlwind,' a 'real-time computer,' taking twice the space of ENIAC, which could constantly monitor its inputs, making it suitable for simulations. In the course of its development, Forrester devised 'magnetic-core memory.' Whirlwind's success caused the U. S. Air Force to fund Project Lincoln, which used Whirlwind as the test bed for the air defense system. This system required analog-digital tele-communication and its engineers built a device called a modulator-demodulator, or 'modem.'
In 1951, Willard Van Orman **Quine**, in "Two Dogmas of Empiricism," said the distinction between 'analytic' and 'synthetic,' roughly that between ideas and fact, and 'reductionism,' which holds that logical constructs are meaningful if they refer to immediate experience, are each ill-founded dogmas. The real "unit of empirical significance is the whole of science" (Quine 1953:42).
In 1952, Alan Lloyd **Hodgkin** and Andrew Fielding **Huxley**, using microelectrodes applied to the gigantic axon of a squid, demonstrated the ionic workings of nerve impulses and described them in a series of mathematical formulas (Hodgkin and Huxley 1952).
In 1952, Alexander R. **Stokes** worked out the mathematics of helical diffraction, important in interpreting X-ray crystallographs.
In 1952, **Lederbergs** and Luca **Cavelli-Sforza** and William **Hayes**, working independently, announced that bacteria differentiated into genetic donors and recipients. Hayes said further that when the doner passed a copy of its genes to the recipient, it could also pass the genetic ability to be a donor (J. Lederberg *et al*. 1952; Hayes 1952).
In 1952, Alexander L **Dounce** said that the order of amino acids in each specific protein derives from the order of nucleotides in the corresponding RNA molecules which were templated by the DNA molecules (Dounce 1952).
In 1952, Guido **Pontocorvo** assembled evidence that the gene as the minimum unit of heritable physiological function had considerable length along the chromosome. The gene as the minimum unit in which mutations can be induced is much smaller. Therefore, mutations could occur at different points along a single physiological gene (Pontecorvo 1952).
In 1952, **Hershey** and Martha **Chase** showed that when a phage particle infects its bacterial host cell, only the DNA from the phage enters the cell and the protein of the phage remains outside. Combining **Chargaff**'s result with that of the Hershey-Chase experiment meant that the repeating elements of

Schrödinger's codescript could be identified as the nucleotides carrying adenine, quanine, thymine, or cytosine (Hershey and Chase 1952).

By 1952, **Turing** had noticed that patterns are formed by the rates at which interacting chemicals diffuse and react. This "theory can, in principle, account for the specification of most (possibly of all) biological patterns, although the mathematical obstacles are often formidable" (Harold 1990:415). The mathematics involves "the [non-linear] bifurcation properties of the solutions of differential equations. Applied mathematicians had been aware for many years that when a parameter of a system passes through a certain critical value there can be a qualitative change in behavior as a previously stable state becomes unstable. The archetypal example, first studied by **Euler** more than two centuries earlier, is the sudden buckling of a beam when it is overloaded" (Saunders 1992:xiv). This theory accounts for certain organizational features in plants (e.g., the frequency of five petals and the scarcity of seven petals), but it is also compatible with physiological genetics (Turing 1952).

In 1952, Humphrey **Osmond** and John **Smythies** theorized that schizophrenia was the result of a chemical chain reaction, the cycle of which could only be broken by a retreat from 'reality.' Osmond later coined the term 'psychodelic.'

In 1952, Jay **Haley** and G. **Bateson** recognized that the symptoms of schizophrenia are suggestive of an inability to discriminate logical types and described it in terms of a double-bind hypothesis (Bateson 1954).

In 1952, R. S. **Mulliken** worked out and systemized the quantum mechanics of 'charge transfer.'

In 1952, David **Bohm** , in "A suggested interpretation of the quantum theory in terms of hidden variables, I and II," extended and completed **de Broglie**'s ideas concerning a unified description of quantum mechanics; that is to say, by making certain assumptions, e.g., that the field was objectively real, and, by hiding certain variables, he gave a plausible account of how to eliminate the indeterminism of having more than one point of view (Bohm 1952:369-396).

In 1952, Gian Carlo **Wick**, Arthur S. **Wightman**, and **Wigner** suggested several 'superselection rules' governing unobservable quantum mechanical states (Wick *et al.* 1952:103; Wightman 1995:754).

In 1952, Donald Arthur **Glaser** invented the 'bubble chamber,' a device for detecting ionizing radiation, wherein a liquid gas is kept slightly above its boiling point under sufficient pressure to prevent its boiling. Just before the ionizing particles are released, the pressure is lowered and the particles become the centers of bubbles.

In 1952, **Urey**, in *The Planets: Their Origin and Development*, argued that the cold, original atmosphere of the Earth must have been composed of the stable molecules of methane, ammonia, water, and hydrogen.

In 1952, **Baade** showed that the *Cepheid* period-luminosity relation was in error, thereby increasing the **Hubble** expansion time constant by a factor of two.

In 1952, Michael George Francis **Ventris** deciphered so-called 'Linear B,' an extremely archaic form of Greek>, probably written by the South Achaeans in the late second millenium bce.

In 1953, G. **Mueller** reported finding amino acids in a carbonaceous chondrite, a meteorite, but his finding was discounted because of the possibility of contamination.

In 1953, William Maurice **Ewing** published evidence to support his theory that the sea floors are spreading from central ridges and that the continents consist of plates in motion with respect to each other. This led to the acceptance of **Wegener**'s continental drift hypothesis. With Bruce **Heezen**, Ewing invented the seismograph which is now standard.

In 1953, **Sanger**, using dinitrophenol which binds to one end of an amino acid, determined the sequence of the glycyl chain of the amino acid bases in bovine insulin, the first protein to be so analyzed (Sanger and Thompson 1953). The other chain was sequenced by 1955 and revealed that there was a sequence unique to bovine insulin, that it was not a repetitive series, and, in hind site, confirmed that a code would be required for protein synthesis.

In 1953, George E. **Palade**, Keith Roberts **Porter**, and Albert **Claude** developed methods of fixation and thin sectioning that enabled many intracellular structures, which they named 'endoplasmic reticulum,' to be seen in electron microscopes (Porter 1953).

In 1953, **Lwoff** postulated that the protein coats on viruses are carcinogenic when activated by outside factors such as ultraviolet light (Lwoff 1953; Judson 1978:375).

In 1953, James Dewey **Watson** and Francis Harry Compton **Crick** built a model of DNA showing that the structure was two paired, complementary strands, helical and anti-parallel, associated by secondary, noncovalent bonds. This discovery made apparent the mechanism of replication. Their effort brought together the functional and the structural approaches to the study of life: Watson's background was with the phage group and Crick was a physicist learning X-ray crystallography (Watson and Crick 1953). The two approaches combined to become, as Crick called it in 1947, "the chemical physics of biology" (quoted in Judson 1979:110) and, finally, molecular biology. Maurice H.

F. **Wilkens**' and Rosalind **Franklin**'s X-ray crystallographs of DNA supported the discovery of the structure (Wilkens *et al*. 1953; Franklin and Gosling 1953).
[In 1953, in working out the structure of the double helix, **Watson** and **Crick** had "for the first time introduced genetic reasoning into structural determination by demanding that the evidently highly regular structure of DNA must be able to accomodate the informational element" (Stent 1980:xvii). In other words, "the basis of heredity switched from one based on *location* to one based on *information* encoded in the structure of macromolecules" (Sapp 1987:193). Watson and Crick employed 'information,' the recently popularized cybernetic term, differently than cyberneticists: Genetic information is functional whereas cybernetic information is defined as the mathematical converse of entropy].
In 1953, **Szilard** and Aaron **Novick** proposed that a cell's synthesis of some enzymes was not stimulated by the presence of an inducer, but by the absence of the enzyme's end product, a classic example of feedback control (Novick and Szilard 1954).
In 1953, **Gamow** began the attempts to explain the coding problem, that is, how the sequential structure of DNA could directly, physically order the sequential structure of proteins. In Gamow's scheme, several different base sequences could code for one amino acid (Gamow 1954).
In 1953, Konrad Emil **Bloch** and, independently, Feodor **Lynen** discovered the mechanics and regulation of cholesterol and fatty acid metabolism: Acetic acid, or acetyl coenzyme A, is converted to mevalonic acid, which is converted to isoprene, a hydrocarbon, which converts into a symmetrical C30 hydrocarbon, squalene. This is converted into lanosterol, and finally into cholesterol (Bloch and Langdon 1957).
In 1953, G. C. **Willis** noticed that atherosclerotic plaques keep forming in the same places on the ground substance of the arterial intima and, subsequently, did studies which implicated mechanical stresses, such as high blood pressure and heart beats. That the lesions of scurvy occur in the intimal ground led to Willis's hypothesis that ascorbic acid is a treatment for atherosclerosis (Willis 1953:17-22).
In 1953, Stanley L. **Miller**, in **Urey**'s lab, bombarded a mixture of ammonia, water vapor, hydrogen, and methane with an electrical discharge to simulate lightening and produced the amino acids alanine and glycine (S. Miller 1953:528-529). "Not since Friedrich **Wöhler** synthesized urea in 1828 had a chemical experiment been hailed as a comparable milestone" (de Duvé 1991:109-110). Since that time, a number of experiments have been performed in which these molecules are converted to greater complexity by ultraviolet light and ionizing radiation.
In 1953, **Medawar**, Leslie **Brent**, and Rupert E. **Billingham** established in principle that immunological tolerance could be acquired by injecting hemopoietic cells from a genetically different donor into rodents in utero or at birth. Not having evolved the immunolgical equipment to reject them, the engrafted cells perpetuated themselves, and endowed the recipient with the donor immune system (Billingham *et al*. 1953).
In 1953 and 1954, Vincent **du Vigneaud** synthesized the peptide hormones oxytocin and vasopressin.
In 1953, Eugene **Aserinsky** and Nathaniel **Kleitman** noticed regularly occurring periods of rapid eye movement (REM) during sleep and correlated this with when dreams are particularly vivid and emotionally charged. This opened a new era of research in the relation of brain to mind.
In 1953, Andrei **Sakharov** invented a fusion and fission detonator which was the basis for the first thermonuclear bomb built by the Soviet Union. His work was independent of that of **Ulam** and **Teller**.
In 1953, Ernst Carl Gerlach **Stueckelberg** and André **Petermann**, in "La Normalization des Constantes," reported their discovery of the 'renormalization group,' a group of transformations exploiting the finite arbitrariness arising in scattering-matrix elements after the removal of certain divergences. This theory was first used in quantum electrodynamics: When there occurs an infinite number of parameters, some must be removed, usually by taking the observed mass and charges of the electron as 'renormalized' parameters. Good agreement is obtained with experimental results, despite the apparent impossibility of making the procedure mathematically sound.
In 1953, Iosif S. **Shkovskii**, arguing that both optical and radio emissions in the *Crab Nebulae* come from synchrotron radiation, hypothesized that high energy electrons radiate optically visible light whereas lower energy electons radiate at radio wave lengths in the same magnetic field. Because the high energy electrons lose their energy faster, this accounts for the much more intense radio emissions.
In 1953, An **Wang** invented the magnetic core computer memory.
In 1953, **Wittgenstein** published his *Philosophical Investigations* in which he held, among other things, that the mind categorizes on the basis of 'family resemblances:' "How is the concept of a game bounded? What still counts as a game and what no longer does?... We do not know the boundaries

because none have been drawn" (Wittgenstein 1953:I, 68-69).
In 1954, Marthe **Vogt** recognized that noradrenaline was present in the hypothalmus.
In 1954, Rita **Levi-Montalcini** and associates showed that nerve growth factor stimulated the growth of axons in tissue culture.
In 1954, Paul **Zamecnik**, working with rat liver, developed and refined the cell-free system, a biochemical cocktail, for protein synthesis. The basic constituents are molecules of RNA containing amino acids, enzymes, ATP, and microsomal particles, or ribozymes.
In 1954, **Benzer**, working with mutant *rII* viruses in bacteria, proved that mutations occurred within genes and devised a technique by which one could locate mutations at the scale of a single nucleotide. This enabled him to sequence, or map, the parts of the gene, the amino acids, that is to say, the 200,000 letters of the phage virus genetic code (Benzer 1955).
In 1954, Hugh E. **Huxley** and Jean **Hanson** and, independently, A. **Huxley** and R. **Niedergerke** observed in X-ray crystallographs that, when muscles contract, the areas built exclusively of actin filaments are comparatively narrow. To explain this, they hypothesized that bridges occur between the actin, or thin, filaments and the thick, or myosin, filaments and that these bridges pull thin filaments past the thick filaments in a racheting action. It is known as the 'sliding filament, moving cross-bridge model.'
In 1954, Anthony C. **Allison** provided evidence that individuals heterozygous for the sickle-cell gene are protected against malaria.
In 1954, Jean **Dausset** observed that some recipients of blood transfusions formed antibodies. These antibodies defined the first 'human leukocyte antigens' (HLA) and led to the definition of the 'major histocompatibility complex' (MHC). H-2, an antigen similar to HLA, had been discovered earlier by **Snell**. HLA can be typed and thus blood tests can determine the compatibility of transplant tissue. MHC is a genetically controlled system by which the body distinquishes material it deems harmful.
In 1954, **Salk** developed an injectable killed-virus vaccine against poliomyelytis, the incidence of which began to decline after mass immunization began the following year.
In 1954, Andrei N. **Kolmogorov** outlined a theorem, subsequently proved by Vladimir Igorevich **Arnold** and Jürgen Kurt **Moser**, and known as KAM theory, which dealt with the influence of **Poincaré** resonances on trajectories, showed their frequencies to depend on the values of dynamic variables, and provided the starting point for understanding the appearance of chaos in Hamiltonian systems.
In 1954, Chen Ning (Frank) **Yang** and Richard **Mills** and others proposed that if there were as many as eight different electromagnetic fields which interacted with each other and with electrons proposed to be of three types of charge, then the charges would be able to change in different places and times. This introduced the idea of non-Abelian gauge fields. A gauge field is a symmetry group. An Abelian group is a symmetry group which commutes, e.g., *ab = ba* or the aspects of a round ball, whereas non-Abelian groups depend on the direction of rotation for their symmetry, e.g., a book, and are therefore non-communitive.
In 1954, Charles Hard **Townes** , J. P. **Gordon**, and H. J. **Zieger**, in "Molecular microwave oscillator and new hyperfine structures in the microwave spectrum of NH_3," developed the theory of the maser, or 'microwave amplification by stimulated emission of radiation.' The maser is an oscillator in which the basic frequency control arises from atomic resonance rather than a resonant electric circuit. The waves are coherent; that is, they're all the same frequency, in the same direction, and the same phase relationship. The following year, Nikolai Gennediyevitch **Basov**, independently, also developed a maser.
Between 1954 and 1957, Robert **Hofstadter** used the Mark III Stanford Linear Accelerator and the electron-scattering method, i.e., he bounced electrons off protons or neutrons and measured the recoil angle, to find the size, charge and magnetic moment distribution, and surface thickness parameters of atomic nuclei.
In 1954, Robert **Hanbury Brown** and Richard Q. **Twiss**, using a total-intensity interferometer at Jodrell Bank, developed a mathematical theory supporting the idea that basis information from radio telescopes could be gained from correlation *after* detection.
In 1954, at the time of his death, **von Neumann** was writing *Theory of Self-Reproducing Automata*, where he proved, in theory, that a 'cellular automaton' could reproduce itself provided it exceeds a certain threshold of complexity. This formalism was suggested to him by **Ulam**: Each cell in a lattice would be occupied by an automaton in one of a finite number of states. At each tick of a cosmic clock, the automaton would change to a new state, determined by its current state and the states of its neighbors. Automata theory is known as recursion theory among logicians. The book, edited by **Burks**, was published in 1966.
In 1954, **Needham** published the seven volumes of *Science and Civilization in China*.

In 1955, **Gold** proposed that the Earth's axis sometimes changed by 90 degrees, triggered by movements of its mass.
In 1955, Walter Sampson **Vincent** announced experiments which suggested that a small fractional portion of RNA transfers nuclear information to the cytoplasm. This fraction was later given the name transfer RNA, or tRNA. Later that year, **Crick** hypothesized the existence of an intermediate nuclear product which he called an 'adaptor,' and ultimately came to be recognized as tRNA.
In 1955, Neils Kaj **Jerne** suggested a natural selection theory of immunity in which cells, while still in the embryo, produce a wide variety of antibodies. Any antibodies which made contact with the embryo's own antigens would be permanently lost. "The early removal of a specific fraction of molecules [would] lead to the permanent disappearance of this type of specificity.... The absent specificities would include, beside auto-antibodies, natural antibody against antigens implanted in the animal during embryonic life" (Jerne 1955:853-854). Later, foreign antigens would select the best fit among the remaining antibodies, bind to them, and be delivered up for dissociation and elimination. The formation of this complex also stimulated the production, i.e., cloning, of more of the selected antibody, which is then capable of a more rapid secondary response.
In 1955, Élie Leo **Wollman** and François **Jacob** found that, by agitating a bacterial culture, mating could be stopped when only part of the genes had been piped across, permitting the manipulation of a few genes at a time (Wollman and Jacob 1955).
In 1955, Arthur **Pardee** and Rose **Littman** reported that 5-bromouracil, an analogue of the base thymine, causes a high proportion of mutants in phage (Littman and Pardee 1956).
In 1955, Severo **Ochoa** and Marianne **Grunberg-Manago** isolated the first enzyme involved in the synthesis of a nucleic acid, an RNA-like molecule in a cell-free system (Grunberg-Manago and Ochoa 1955).
In 1955, Christian René **de Duvé** and colleagues, using a centrifuge, isolated a new subcellular particle, which they named lysosome to emphasize the hydrolytic, or water-releasing, properties of its enzymes.Lysosomes play a pivotal role in cellular and metabolic processes (de Duvé 1963). Subsequently de Duvé discovered another organelle which he called a peroxisome. Peroxisomes use oxygen to digest or neutralize certain types of molecules (de Duvé 1969).
In 1955, after Oliver **Smithies** used starch gels to separate the alleles of inherited protein variations by electrophoresis. Only then were extensive studies of wild species possible.
In 1955, Leo **Hurvich** and Dorethea **Jameson** formulated the opponent-process color theory: There are three color 'channels' in the visual system, one channel is achromatic and signals differences in brightness; the other two are chromatic and signal differences in hue. Also, in the retina there are three mosaics of cone cells, the so-called long-wave (L), the middle-wave (M), and the short-wave (S) receptors. The difference between the the signals from the L and M receptors generates the red-green channel, and the difference between the sum of the signals from the L and M receptors and the signals from the S receptors generates the blue-yellow channel (Jameson and Hurvich 1955).
In 1955, Kazuhiko **Nishijima** and, independently, Murray **Gell-Mann** identified V particles as an additive quantum number, isospin +1, which Gell-Mann called 'strangeness.'
In 1955, Nicolai Nicolaevich **Bogoliubov** and Dmitrij V. **Shirkov**, "using the group properties of finite **Dyson** transformations for coupling constants and field functions,...obtained group functional equations for QED propagators and vertices in the general (i.e., massive) case," and introduced the term 'renormalization group' (Shirkov 1997:255).
In 1955, **Segrè** discovered 'anti-protons.'
In 1955, **Wheeler** described a hypothetical object, a 'geon,' constructed out of electromagnetic radiation varying in size from the smallest field to an entire universe, but "most easily visualized as a standing electromagnetic wave, or beam of light, bent into a closed toroid," and so massive that it will hold itself together by its own gravity (Wheeler 1955:133). "Such an object, viewed from a distance, produces the same gravitational attraction as any 'real' mass, moves in an orbit of its own, and manifests inertia. However, examined in detail..., it proves to contain nothing but empty space" (Wheeler 1962a:57); i.e., a geon "provides a completely geometric model for mass" (Wheeler 1962b:xii).
In 1956, **Waddington** in *Principles of Embryology*, defined epigenetics in the broadest possible sense as those interactions of genes with their environment that bring the phenotype into being and demonstrated with *Drosophila* that selection for the *ability* to acquire a trait that appears in response to an environmental stimulus may, if it is selectively advantageous, become genetically assimilated after a certain number of generations (Waddington 1957) .
In 1956, Heinz **Fraenkel-Conrat** and Gerhard **Schramm**, independently, demonstrated that tobacco-mosaic virus RNA is self-replicating and alone gives the disease.
In 1956, **Wollman** and F. **Jacob** published a first, rudimentary genetic map of the *E. coli*

chromosome, and established that when the donor's chromosome entered the recipient, the recipient became endowed with two sets of genes for several hours until resuming cell division.
In 1956, Vernon M. **Ingram**, using electrophoresis and chromatography, showed that human normal and sickle-cell hemoglobins have different 'fingerprints,' i.e., their amino acids differed due to a mutated gene (Ingram 1958). .
In 1956, Paul **Berg** noticed that the enzyme specific to an amino acid required something more to permit the enzyme to recycle and determined it was (Berg 1956). At about the same time, **Zamecnik**, Mahlon **Hoagland**, Robert William **Holley**, and others made the same determination (Hoagland *et al*. 1957; Holley 1957). Berg led the way to the enumeration of separate enzymes and species of tRNA for all twenty amino acids (Berg and Ofengand 1958). Zamecnik's lab discovered that tRNA carried, at one end, the three nucleotide sequence cytosine-cytosine-adenine where the amino acid hooked on (Hecht *et al*. 1958)
IIn 1956, Arthur **Kornberg** discovered DNA polymerase, the first of a group of three enzymes responsible for DNA synthesis, that is, the attachment of nucleotides onto the unzipped DNA molecule during DNA replication, and, of the three, the one which repairs damaged DNA. It is the enzyme now used to make DNA probes (Kornberg 1956).
In 1956, Elliot **Volkin** and Lazarus **Astrachan** published data which suggested that cells possess a high-turnover RNA, which later proved to be messenger RNA (mRNA)(Volkin and Astrachan 1956).
In 1956, Christian Boehmer **Anfinsen** , by breaking the various bonds connecting a whole protein, concluded that its three-dimensional conformation is dictated by its amino acid sequence.
In 1956, Jo Hin **Tjio** and Albert **Levan** determined that the human genome has 23 chromosomes.
In 1956, Al **Hubbard** developed the rule in the therapeutic use of LSD-25 that it was contingent on the mind*set* of the person taking the drug and the *setting* in which the experience occurred.
In 1956, Steven **Szara** synthesized dimethyltryptamine, or DMT, which is closely related to serotonin and best known for its psychotropic properties.
In 1956, Tsung Dao **Lee** and **Yang** published the suggestion that the law of parity conservation, or space-reflection symmetry, is violated by the 'weak' force, one of the four fundamental forces. Chien-Shiung **Wu** and a team led by Ernest **Ambler** then performed an experiment which showed that parity is not conserved in beta decay, and thus there can be physically lawful asymmetry, or preferred handedness. A team led by Leon Max **Lederman** and Richard **Garvin** confirmed this result. A team led by Valentine **Telegdi**, on the basis of the Lee-Yang paper and without knowledge of the Wu-Ambler results, also showed that parity is not conserved in beta decay (Crease and Mann 1986:208-209).
In 1956, Clyde **Cowan** and Frederick **Reines** confirmed the existence of the neutrino.
In 1956, Leon **Cooper** showed that in superconductivity the current is carried in bound pairs of electrons, or 'Cooper pairs.'
In 1956, Hans E. **Suess** and **Urey** provided detailed data on the abundance of elements and isotopes.(Suess and Urey 1956:53-74)
In 1956, Beno **Gutenberg** and Charles **Richter** pointed out that earthquake tremors follow a power law: In any given area in a year, the number of earthquakes that release a certain amount of energy is inversely proportional to that energy.
In 1956, G. **Miller**, dealing with conscious perception and short-term memory in the context of information theory, published "The Magical Number Seven, plus or minus Two: Some Limits on Our Capacity for Processing Information." In it, he measured the 'amount of information' by equating it with ' variance:' "Anything that increases the variance also increases the amount of information" (G. Miller 1956:81).
In 1956, Herbert A. **Simon**, Allen **Newell**,and J. Clifford **Shaw** demonstrated 'Logic Theorist,' their complex information, i.e., not standard algorithmic, but rather 'heuristic procedure,' at a conference on 'artificial intelligence,' or 'AI,' a term invented by John **McCarthy** (Waldrop 2001:133-139).
In 1956, Wesley **Clark**, Ken **Olsen**, and Harlan **Anderson** finished a transistor-driven interactive computer, the TX-0, the ancestor of the Digital Equipment Corporation's, or **DEC**'s, TX-2.
In 1956, Nathaniel **Rochester** and John H. **Holland** published computer programs which simulated neural networks.
In 1957, Matthew **Meselson** and Franklin **Stahl** developed density-gradient centrifugation for separating nucleic acids in order to confirm that DNA reproduces itself in the manner predicted by the **Watson-Crick** model (Meselson *et al*. 1958).
In 1957, Melvin **Calvin**, in *The Path of Carbon in Photosynthesis*, reported his observation of unpaired electron spins, i.e., free radicals, induced by light in photosynthetic systems. The carbon cycle is also known as the Calvin cycle and was determined by using a tracer isotope of carbon-14 in combination with paper chromatography.

In Earl Wilbur **Sutherland** isolated cyclic adenosine 5'-monophosphate, or cAMP and explained how it is released through the binding of a hormone to the outside of a cell membrane and goes on to perform many roles in the cell's metabolism (Sutherland 1966)
In 1957, David W. **Talmadge** modified Jerne's hypothesis, giving it a cellular orientation, so that lymphocytes, that is, receptor-carrying cells, rather than serum, served as the source of immunological memory and selection (Talmadge 1957). Independently, **Burnet** seems to have arrived at the same revision. The essence of this theory is fourfold: Each clone is produced somatically by genetic hypermutation; each clone produces antibodies which have the ability to react immunologically with a very small number of chemical configurations on the surface of an antigen; the immune system is able to distinguish self from non-self; and self-tolerance is set up early in life by the elimination of self-reactive lymphocytes (Burnet 1957). [revised 02/01/03]
In 1957, **Feynman** and Murray **Gell-Mann** proposed a law tying together the weak interactions at work in strange-particle decay and in beta decay which were permitted by the previous year's **Lee-Yang-Wu** proof. When a particle decays by a weak interaction, e.g., neutron into proton or pion into muon, one sort of wave is transformed into another sort. The possible transformations include scalar, vector, axial vector, pseudoscalar, and tensor, or S, V, A, P, and T; Feynman and Gell-Mann identified V and A as the wave transformations produced by weak interactions. Robert **Marshak** and E. C. George **Sudarshan** drew similar conclusions at about the same time (Gleick 1992:335-338; Johnson 1999:151-153).
In 1957, **Bardeen**, **Cooper**, and John **Schreiffer** formulated the 'BCS theory' of superconductivity according to which a pair of negatively-charged electrons moving through a positively-charged elastic crystal lattice as a result of **Coulomb** forces.
In 1957, Herbert **Kroemer** showed theoretically that heterostructural transistors, made by laying down thin layers of semiconductors such as gallium arsenide, should be superior to conventional transitors built from specially modified pieces of a single material such as silicon.
In 1957, Charles W. **Misner**, while evaluating **Feyman**'s quantization of General Relativity, proved that "*the Hamiltonian operator is zero*" (Misner 1957:497).
In 1957, **Misner** and **Wheeler** proposed that gravity is not a force but rather a manifestation of geometry, i.e., that the entities of geometry are a kind of physical reality. According to quantum 'geometrodynamics,' space is multiply connected by 'wormholes' at the smallest **Planck**-length distances and therefore has a foamlike structure (Misner and Wheeler 1957:225-307).
In 1957, Hugh **Everett**, III, proposed a "pure wave mechanics" formulation of quantum mechanics in which the "unique relative-state" of the universe, a closed system, should be taken as coinciding with reality (Everett 1957:454). Reality is taken to be a composite system in which the state vector has many branches and "*all* possible [measurements] are realized every time, each in a different edition of the universe, which is therefore continually multiplying.... There is no association of the particular present with any particular past (Bell 1981:133). Each automaton, i.e., apparatus *cum* memory sequence, in each superposed 'branch' sees the world obey the familiar quantum laws, while this 'branching' corresponds to the collapse of the wave function. Memories and records are in fact *present* phenomena" (*ibid.*:135-136). If this "theory were correct..., we could safely assume that *all* possible arrangements of matter and energy are represented somewhere among the infinite ensemble of universes. Only in a minute proportion of the total would things be arranged so precisely that living organisms, hence observers, arise.... In short, our universe is remarkable because we have selected it by our own existence" (Davies and Brown 1986:38). Everett considered his theory a *metatheory* to quantum mechanics. John Stuart **Bell** considered "the really novel element" to be Everett's repudiation of the 'past,' on a par with **Einstein**'s repudiation of absolute simultaneity (*ibid*.:118). This has come to be known as the 'many worlds interpretation,' where each instant is a different world.
In 1957, Rudolf L. **Mössbauer** discovered that when the emitting nucleus of a gamma-ray photon is "held by strong forces in the lattice of a solid, the recoil energy is shared by all the nuclei in the lattice [and] typically...the recoil will be negligible" (*Dictionary of Physics* 2000:309).
In 1957, E. Margaret **Burbidge**, Geoffrey R. **Burbidge**, William A. **Fowler**, and **Hoyle**, in "Synthesis of Elements in Stars," or "B^2FH," said that "in order to explain all the features of the [element] abundance curve, at least eight different types of synthesizing processes are demanded" (Burbidge *et al.* 1957:551): Hydrogen burning, responsible for most energy production; helium burning, responsible for carbon synthesis and other syntheses with the capture of additional alpha particles; alpha process, where various elements are synthesized by the addition of alpha particles to Ne^{20}; *e*, or equilibrium, process, where under very high temperature and density the elements comprising the iron peak are synthesized; *s*, or slow, process, where neutron capture with the emission of gamma radiation takes place on a long-time scale; *r*, or rapid, process, where neutron captures occur quickly compared to beta decay; *p* process, where proton capture is responsible for the synthesis of proton-rich isotopes;

and *x* process, or various processes, responsible for the synthesis of deuterium, lithium, beryllium, and boron, all unstable at the temperatures of stellar interiors. At the same time, Alastair G. W. **Cameron**, independently, discussed many of the same topics and argued that many of these elements are formed during fast reactions of supernova explosions.
About 1957, Martin **Kruskal** developed "a coordinate system in which the structure of a black-hole could be described in one smooth set of equations, joining the flat spacetime far outside the hole on to the highly curved spacetime inside without even a hint of a singularity at the **Schwarzschild** horizon" (Gribbin 1995:129). Wormholes, which topologists call 'handles,' are continuous lines of force that exit and re-enter the observer's world.
In 1957, Kees **Boeke**, in *Cosmic View: The Universe in Forty Jumps*, a book intended for children, illustrated what one would see by adding a zero, or power, to the scale of a square picture of two people on a picnic blanket, moving in and out twenty times.
In 1957, the United States government formed the Advanced Research Agency, or **ARPA**, in response to the Soviet Union's Sputnik, the first artificial satellite.
In 1957, John **Backus** led the team which created 'Fortran,' the Formula Translation language for the **IBM** 704 computer.
In 1957, Noam **Chomsky**, in *Syntactic Structures*, attacked behaviorism and proved that linquistic grammars are analogous to **Turing** machines and that both are hierarchical: word strings below phrase structures below transformations between sentence structures.
In 1958, R. J. **Goldacre**, in "Surface films, their collapse on compression, the shapes and sizes of cells and the origin of life," proposed the possibility that amphipathic lipo-protein films at the air-water interface of the 'primal soup' under the stress of waves formed membrane tubes and then collapsed forming permeable bags "bearing many resemblances to the properties of the membranes of living cells" (Goldacre 1958:287-288).
By 1958, David L. **Nanney**, working with ciliated protozoa, *Tetrahymena*, recognized the existence of two systems: genes and epigenetic mechanisms which regulate 'gene expression,'.
In 1958, Albert H. **Coons** , coupling antibodies to fluorescent dyes, showed experimentally that one cell made only one antibody (Coons 1958). Later that year, Gustave J. V. **Nossal** and **Lederberg**, working together in **Burnet**'s lab, verified the clonal selection theory's requirement that there could only be one antibody type produced by any given lymphocyte; this came to be known as 'allelic exclusion' (Nossal and Lederberg 1958). The same year, Lederberg recognized that, in the context of random drift, it was necessary to postulate the continuation throughout life of the diversification of antibody-producing cells. Lederberg also postulated that two signals initiated by a single interaction but separated in time were necessary to distinguish between inactivation of self and activation of nonself. Further, he introduced the rhetorical dichotomy between the terms *selective* and *instructive*, representing respectively the clonal and template models (Lederberg 1959). Until Jerne's theory, all immunologists were agreed that the antigen impressed its mark on, or instructed, the antibody producing cells.
In 1958, **Crick** enunciated the legendary 'Central Dogma': "Once information has passes into protein *it cannot get out again*. In more detail, the transfer of information from nucleic acid to nucleic acid, or from nucleic acid to protein may be possible, but transfer from protein to protein, or from protein to nucleic acid is impossible" (Crick 1958:153).
In 1958, **Stein** and **Moore** invented the automatic fraction collector and contibuted to the development of the automated amino acid analyzer.
In 1958, F. **Jacob** and **Wollman** named and described 'episomes,' which are "circular, extrachromosomal sequences of DNA that possess the capacity to integrate into, as well as dissociate from, the chromosome of a cell. They can replicate either autonomously or while inserted within the chromosome" (Podolsky and Tauber 1997:392n24; Jacob and Wollman 1958).
In 1958, **Hofman** isolated the active ingredient of the mushroom *Psilocybe* and synthesized psilocybin, which he noted had a marked similarity to serotonin.
In 1958, Phillip W. **Anderson** showed that the effect in a metal of strong 'disorder,' or irregularity, perhaps arising from a high concentration of atomic impurities, would localize all the electron wave functions; i.e., each quantum state would be confined to a certain region, falling off exponentially with the distance outside that region.
In 1958, **Townes** and Arthur L. **Schawlow** published their idea for an optical mazur, or 'laser.' Gordon **Gould**, independently, developed a similar idea.
In 1958, Jack St. Clair **Kilby** built the first integrated circuit.
In 1958, **Ryle** and colleagues found the first real evidence that the Universe is evolving. By counting the numbers of galaxies of different apparent intensities, "the number of [weak] sources was found to be about twice that expected from counts of intense sources [and thus] there appears to be a real

discrepancy between the observations and the predictions of the steady-state model" (Ryle 1958:306). "This [is] compatible with an evolving Universe if galaxies were more prone to undergo violent outbursts in the remote past, when they were young" (Rees 1995:5-6).
In 1958, Cornell H. **Mayer** and colleagues reported the surface of Venus is around 600 degrees K.
In 1958, Eugene N. **Parker** proposed the 'solar wind' theory: There is a flow of atomic particles from the Sun's corona, following from hydrodynamic equations of a million degree corona, which carries with it magnetic field lines that form into a spiral pattern as the Sun rotates.
In 1958, Michael **Polanyi**, in *Personal Knowledge*, asserted that there is an interpretative ingredient in scientific knowledge.
In 1958, **Heisenberg**, in *Physics and Philosophy*, wrote: "If actually all our knowledge is derived from perception, there is no meaning in the statement that the things 'really exist;' because if we have perceptions of things it cannot possibly make any difference whether the things exist or do not exist. Therefore, to be perceived is identical with to be existing" (Heisenberg 1958:84).
In 1958, Herbert **Gelernter** devised 'Geometry Theorem Prover' in Fortran List Processing Language.
In 1958, a joint United States and European committee, including among its members, **Backus**, Alan **Perlis**, and **McCarthy**, was formed to create a universal programming language, 'Algorithmic Language,' or 'Algol.' In the course of creating Algol, Backus and Peter **Naur** invented 'Backus-Naur notation' for giving the formal definition of a programming language. Although little used after its completion in 1960, Algol was the precursor of 'Pascal.'
In 1959, R. H. **Whittaker** added a fifth domain, fungi, to the taxonomy of living things (Whittaker 1959).
In 1959, Noel L. **Warner** and Aleksander **Szenberg** performed the experiments which led to the concept of T (for thymus) cells and B (for bursa in birds, but produced in the bone marrow of adult mammals) cells (Szenberg and Warner 1962).
In 1959, **Pardee**, F. **Jacob**, and **Monod** published an experiment establishing a generalized model of the synthesis of enzymes. That this occurs in the absence of genetically determined repressors is due to exogamous induction; that is, the immunity of lysogenic cells corresponds exactly to inductibility and, if regulation occurs at the gene and not later in the process, then regulation is completed at the level of the ribosome (Pardee *et al*. 1959).
In 1959, Edmond H. **Fischer** and Edwin Gerhard **Krebs** isolated and purified the first protein kinase and described 'reversible protein phosphorylation.' Protein kinase takes phosphate from adenosine triphosphate and adds it to phosphorylase, turning it on. Another enzyme, protein phosphatase, reverses this process, deactivating the phosphorylase (E. G. Krebs *et al*. 1959).
In 1959, **Porter** showed that the antibody molecule could be cut into three pieces by utilizing an enzyme which cuts bonds within the peptide chain. Of the three pieces, two would still combine with antigen. These he named antigen-binding fragment, or Fab, and the third piece, crystallizable fragment, or Fc. The Fc region corresponds to different types of effector function. Also, he showed that the whole antibody could be divided into different functional classes, i.e., IgA, IgD, etc (Porter 1959).
In 1959, Gerald M. **Edelman** demonstrated, by using reducing agents to split sulphide bonds between the peptide chains, that the immunoglobulin gamma G, or IgG, molecule, the most prevalent class in mammals, was a multi-chain structure. This showed that the chains were a reasonable size for determination of their amino acid sequence. Edelman also showed that antibodies are constructed in a modular fashion from domains, with the light chain composed of a variable and a constant domain and the heavy chain composed of four domains, three variable and one constant. Furthermore, he showed that the variable domains share homologous regions as do the constant domains (Edelman 1959).
By 1959, **Stein** and **Moore** determined the amino acid sequence of pancreatic ribonuclease (RNase) which breaks down RNA so that its components can be reused. This was the first enzyme to have its function and structure to be completely described and confirmed that the amino acid sequence is a three-dimensional, chain-like structure which folds and bends in causing a catalytic reaction (Stein and Moore 1961).
In 1959, Bengt Ingemar **Samuelsson** and Sune K. **Bergström** isolated prostaglandins. Samuelsson deduced the process by which arachidonic acid is converted into endoperoxides and that into prostaglandins.
In 1959, Albert Bruce **Sabin** developed a oral, live-virus vaccine against poliomyelitus.
In 1959, H. Sherwood **Lawrence** proposed that infectious agents complex with transplantation antigens (self + *x*) and triggered lymphocytes to produce a soluble, specific receptor for this complex (Lawrence 1959).
In 1959, Konstantin **Gringauz**, employing Soviet Luniks Satellites, observed the first signs of the solar

wind.
In 1959, **Luna III**, a Soviet satellite, photographed the far side of the moon.
In 1959, James A. **Van Allen**, Carl E. **McIlwain**, and George H. **Ludwig**, in "Radiation Observations with Satellite 1958ε," established the existence of geometrically trapped electrons and protons in a belt 2000 km from the surface of the Earth. The following year, Van Allen arranged for a rocket with a particle detector aboard which found another radiation belt higher above the Earth. Today, these are known as the inner and outer Van Allen belts.
In 1959, George B. **Field**, Frank D. **Drake**, and S. **Hvatum** suggested that the planet Jupiter's radio emission is caused by synchrotron radiation of magnetically trapped electrons.
In 1959, Robert **Noyce** devised a way to "mass-produce integrated circuits by etching thousands of transistors simultaneously onto the surface of a single silicon wafer" (Waldrop 2001:339).
In 1959, students in **Rochester**'s and **McCarthy**'s computer programming class at the Massachusett Institute of Technology called elaborate switching networks for model railroads 'hacks,' and, tranferring the usage to programming, the designers of elaborate software solutions '**hackers**.' (Waldrop 2001:187).
In 1960, Sidney W. **Fox** converted amino acids into polymer proteinoid microspheres by heating them. They showed a wide variety of catalytic ability, albeit extremely weakly (Fox 1965:361-373).
In 1960, **Crick**, Sydney **Brenner**, and F. **Jacob** predicted the existence of messenger RNA, the substance that gets repressed. The latter two and **Meselson** soon isolated it (Brenner *et al*. 1961).
In 1960, F. **Jacob**, David **Perrin**, Carmen **Sanchez**, and **Monod** developed the 'operon model,' which showed that "the discovery of regulator and operator genes, and of repressive regulation of the activity of structural genes, reveal that the genome contains...a coordinated program of protein synthesis and the means of controlling its execution" (Jacob and Monod 1961:354). The rate of information transfer from genes to proteins could be controlled by oscillation, that is, turned 'on' and 'off' at a specific speed. The exogamous inducer was almost invariably the end-product so this model did much to popularize the notion of feedback among molecular biologists (Jacob *et al*. 1960).
In 1960, **Jerne** introduced the terms 'epitope' and 'paratope' to represent antigenic determinants and antibody-combining sites, respectively (Jerne 1960:342).
In 1960, Julius **Marmur** and Paul **Doty** reported that denatured, that is, unfolded, polypeptides could be renatured, regaining their original structure, provided that the two single strands were perfectly complementary (Doty *et al*. 1960).
In 1960, Max **Perutz** and John **Kendrew** worked out the crystallographic structure of the oxygen-carrying proteins, hemoglobin and myoglobin, a labor that Perutz had begun 23 years previously (Perutz 1960; Kendrew 1960).
In 1960, Juan **Oró**, using concentrated solutions of ammonium cyanide in water, produced the nucleotide adenine.
In 1960, Yoichiro **Nambu** and Giovanni **Jona-Lasinio** constructed a quantum field model in which the pion is a composite of fermion and anti-fermion of small, but non-zero, mass. This mass is obtained through the spontaneous breaking of chiral symmetry.
In 1960, **Wheeler** showed that "a completely geometric model [could be constructed] for electricity, as lines of force trapped in the topology of a multiply connected manifold" (Wheeler 1962b:xii). He also said that elementary particles "represent a first-order correction to vacuum physics [which is the physics of zero-point energy at absolute 0 degrees]. That vacuum, that zero-order state of affairs, with its enormous densities of virtual photons and virtual positive-negative pairs and virtual wormholes, has to be properly described before one has a fundamental starting point for a proper perturbation-theoretic analysis" (Wheeler 1960:129). Perturbation theory may be applied to the study of the orbits of planets, in classical physics, or to calculate the energy level of molecules, in quantum mechanics.
In 1960, Theodore H. **Maiman** described the first laser, which used a synthetic ruby rod as the lasing medium.
In 1960, Allan R. **Sandage** and Thomas A. **Matthews** isolated optically an intense radio source, 3C-48, which, a couple of years later, turned out to be a 'quasar.'
In 1960, Eugene Merle **Shoemaker** proved that an asteroid created the 1.2-mile diameter crater near Flagstaff, AR, and theorized that the moon's craters had a similar origin. This was confirmed by Apollo 17 in 1972.
In 1960, **McCarthy** invented a new language for AI, 'List Processor,' or 'Lisp,' in which every list defined a recursive mathematical function, e.g., *plus*, which could then be nested inside other functions, e.g., (*times* (*plus* 2 2)(*minus* 5 3)) becomes (*times* 4 2) becomes 8.
In 1960, Joseph Carl **Robnett** 'Lick' **Licklider**, in "Man-Computer Symbiosis," pictured "a network of [online 'thinking'] centers, connected to one another by wide-band communications lines and to

individual users by leased-wire services" (Licklider, quoted in Waldrop 2001:177).
In 1960, **Quine** suggested a strategy for discussing disparate conceptual schemes by a 'semantic ascent,' arguing that "words, or their inscriptions, unlike points, miles, classes, and the rest, are tangible objects of the size so popular in the marketplace, where men of unlike conceptual schemes communicate at their best" (Quine 1960:272); i.e., don't talk about things, talk about the way we talk about things.
In the early 1960s, Gabriele **Veneziano** proposed a model to explain the systematic relationship between the spin and the mass of certain short-lived 'hadrons,' which are any of a class of subatomic particles that interact by the strong interaction and, which turned out to be the quantized motion not of a particle or a point but of a 'string.' Later, it was realized that at higher energies his theory was "less accurate because [when] features at smaller distance scales are being probed...the flux tubes produced by the strong force are no longer strings" (Hooft 1997:157).
In the early 1960s, Roger **Penrose** introduced new mathematical techniques to solve Einstein's equations where exact answers were unavailable because of asymmetry.
In the 1960s, Robert **MacArthu**r and his colleagues invented simple holistic ecological models. His program in population ecology was aimed at bringing community ecology, e.g., the study of ant colonies, into the modern synthesis.
In the 1960s, Ilya **Prigogine** theorized that the first cells were thermodynamic 'dissipative structures,' that is, they organized themselves, and with the influx of energy (in the form of food or sunlight), became more instead of less organized.
In 1961, Benjamin D. **Hall** and Sol **Spiegelman**, working with phage, published proof that messenger RNA carries a specific message, confirming Volkin's and Astrachan's results (Hall and Spiegelman 1961).
In 1961, Marshall Warren **Nirenberg** and J. Heinrich **Matthaei** deciphered the first code group, a sequence of nucleotides that specified the amino acid phenylalanine. This they accomplished by adding artificial RNA, in this case, polytidylic acid, to a cell-free system in which the ribosomes would bind with the tRNA molecule complementary to the codon carrying the specific amino acid called for by the one-word message. Their announcement set off a race to decipher the rest of the code by Brenner, Ochoa, Crick, and others (Nirenberg and Matthaei 1961).
In 1961, Peter Denis **Mitchell**, developing Keilin's idea of a respiratory chain in the context of oxidative and photosynthetic phosphorylation, postulated energy coupling by an ion gradient, which is known as the chemiosmotic hypothesis. Mitchell proposed that electron transport and phosphorylation are not chemically linked, but rather coupled only by a transmembrane current of protons (Mitchell 1961).
In 1961, **Wigner** proposed that self-replication is probable in terms of quantum mechanics, assuming that living states exist (which is to say that the formation of a single protein molecule by random means is infinitely improbable)(Wigner 1961:168-181).
In 1961, David **Hubel** and Torsten **Wiesel** published results which showed that an anesthetized cat's visual cortex showed activity even though its brain waves showed it more asleep than awake. Later, they determined that, in the physiology of vision, neurons respond first to dark edges, rather than a spot of light.
In 1961, Roger W. **Sperry** published results of his studies of lateralization in animal brains in which disconnected cerebral hemispheres could be taught in such a way that one hemisphere learned one response while the other hemisphere learned a different response.
In 1961, Richard C. **Lewontin** was the first to explicitly apply game theory to evolutionary biology, pitting species against nature and seeking survival strategies.
In 1961, **Holland** circulated a technical report entitled "A Logical Theory of Adaptive Systems Informally Described," in which he propounded a general theory of adaption, i.e., if an agent is going to be adaptive, it requires feedback.
In 1961, **Gell-Mann** and, independently, Yuval Ne'eman invented a three-dimensional symmetrical particle physics equivalent of the periodic table for 'baryons' and a similar one for mesons--hadrons consist of baryons and mesons--according to a field theory model Gell-Mann called the 'Eightfold way.' Consisting of Lie group SU(3), the simplest group which isn't a composite of SU(2) and SU(1), it has eight generators, two of which "represent isotopic spin and strangeness; the other six are rules for changing the value of the first two...during elementary particle interactions" (Crease and Mann 1986:266). All the particles have the same spin (½) and the same parity (+1); two of the particles are at the center of a hexagon and the other six are at the points (Gell-Mann 1961:7-57; Ne'eman 1961:58-65). The reality of the scheme for mesons was predicated on the existence of a new particle, 'omega-minus (or -negative),' which was confirmed three years later.
In 1961, Sheldon Lee **Glashow** and **Gell-Mann** established that the dominant feature of the Yang-

Mills strong interaction was its SU(3) symmetry (Glashow and Gell-Mann 1961:437-460).
In 1961, Jeffrey **Goldstone** created a theorem in which he "generalized Nambu's work, using as his example a renormalizable theory of a complex spin-zero quantum field" (Brown et al. 1997b:483). This massless particle of zero spin came to be known as the Nambu-Goldstone boson.
In 1961, Vitalii Lazarevich **Ginzburg** suggested that the "enormous energy required to power a [radio] source like Cynus A might be provided by the gravitational contraction of the central part of the galaxy concerned" (Gribbin 1995:105). In the following few years, this suggestion was developed by Shklovski, Fowler, Hoyle, Salpeter, Yakov B. Zel'dovich, Igor D. Novikov, and others who hooked up the discovery of quasars with black-holes lying at the heart of distant, i.e., young and gaseous, galaxies.
In 1961, E. A. **Ohm** reported ineliminatable microwave static with a temperature of about 3 degrees K.
In 1962, **Monod**, Jean-Pierre **Changeux**, and F. **Jacob** concluded that the inhibition of an enzyme by the end product of its pathway required a second active site on the molecule; they named the structural movement between these sites an 'allosteric transition' (Monod et al. 1963).
In 1962, Hans **Ris** noticed the similarity in appearance of the DNA in chloroplasts to that of cyanobacteria.
In 1962, Werner **Arber** predicted the existence of 'restriction endonuclease' enzymes, which are bacterial enzymes capable of cleaving viral DNA at points where specific nucleotide sequences occur .
Between 1962 and 1964, **Edelman**, Baruj **Benacerraf**, Joseph **Gally**, and colleagues confirmed that antibodies of different specificities had different primary structures, i.e., amino acid sequences. They proposed, and Christian Anfinsen, Edgar Haber, and colleagues confirmed, that antibodies also had different three-dimensional structures, i.e., they fold differently (Edelman and Benacerraf 1962; Edelman and Gally 1962). That antibodies could be denatured and then be allowed to reform in the absence of antigen was the final disproof of the template hypothesis (E. Haber 1964). Extending these proposals, Smithies pointed out that "for the combination of H [for heavy] and L [for light] chains to hold implications for antibody diversity..., they would have to be able to combine randomly" (Podolsky and Tauber 1997:65; Smithies 1963).
In 1962, John B. **Gurdon** demonstrated totipotency, that is, that a fully differentiated cell still contains the genetic information to direct development of the cells in the entire animal. He accomplished this by removing the nuclei from fertilized frogs' egg and replacing them with a cell from a single tadpole's intestine. The frogs grown in this way had identical genetic constitutions, that is, they were clones.
In 1962, S. **Cohen** isolated epidermal growth factor.
In 1962, Michel **Jouvet** showed that REM sleep was controlled by the pontine brain stem.
In 1962, Rachel Louise **Carson** published Silent Spring, which concerned the dangers of pesticides.
In 1962, **Lederman**, Melvin **Schwartz**, and Jack **Steinberger** identified the muon neutrino, "produced primarily as a result of the decay of the pion" (Danby et al. 1962:36).
In 1962, **Gold**, in "The Arrow of Time," said that the Universe's expansion is the only real marker for the privileged direction of time (Gold 1962).
In 1962, an Aerobee rocket, flown by a group led by Riccardo **Giacconi**, found the first source of X-rays, Scorpius X-1, outside the Solar System and, also, the more general X-ray background. X-rays, like gamma rays and infrared radiation rarely penetrate the Earth's atmosphere.
In 1962, Paul **Baran** described 'packet switching,' the breaking down of data into labelled packets, and how this would be crucial for the realization of a computer network.
In 1962, Thomas S. **Kuhn**, in The Structure of Scientific Revolutions, wrote that "discovery commences with the awareness of anomaly, i.e., with the recognition that nature has somehow violated the paradigm-induced expectations that govern normal science" (Kuhn 1962:52-53). Indeed, a new paradigm is formed because it is incommensurable in any of several possible ways to the old theory and retained because it is useful, not because it is real.
In 1963, Cyril **Ponnamperuma**, R. **Mariner**, and Carl **Sagan** irradiated a solution of adenine, ribose, and phosphoric acid with ultraviolet light at a strength comparable to the primitive terrestial atmosphere and produced the nucleoside adenosine in the laboratory (Sagan 1965:214).
In 1963, **Jerne** invented the hemolytic plaque technique for screening large numbers of cells and capable of finding rare antibody producers. It proved critical to the development of monoclonal antibodies ' (Monod et al. 1963).
In 1963, Stephanie Louise **Kwolek** synthesized polybenzamide, or PBA, a liquid crystalline polymer, used in lightweight body armor.
In 1963, Murray **Gell-Mann** and, independently, George **Zweig**, invented the notion of a more fundamental particle than neutrons and protons which Gell-Mann named the 'quark.' The eightfold way scheme requires that quarks have charges of 1/3 and 2/3, not previously allowed in elementary

particles. Quarks, described mathematically as SU(3) triplet groups, were predicted to come in six 'flavors,' of which there are three 'colors,' or charges of each: 'up,' 'down,' and 'strange.' For Gell-Mann, his model was purely "schematic" and quarks were "purely mathematical" (Gell-Mann 1964:169), "not little objects so much as they were patterns, symmetries underlying nature" (Johnson 1999:216). For Zweig, on the other hand, they were always tiny particles, as indeed it turned out they are. Most physicists believe that quarks and leptons represent the simplest level of structure.
In 1963, Roy Patrick **Kerr** described the anticipated properties of a rapidly rotating black-hole: it is elliptical; its surface area is less than that of a static black-hole of equivalent mass; if its rotation is sufficiently rapid, the area of the event horizon is reduced to zero; the area around the rotating hole rotates as well; and "a new, inner event horizon forms, and it becomes possible to travel through the black-hole, and emerge into a new universe or perhaps another part of our Universe" (Dictionary of Astronomy 1997:255).
In 1963, a rocket, flown by a group led by Herbert **Friedman**, showed X-rays coming from the general direction of the Crab Nebulae, which Friedman suggested might be coming from a neutron star left behind by a supernova.
In 1963, Edward **Lorenz** found what was probably the first example of a 'strange attractor,' a flow in phase space in which orbits converge to an object which is neither a fixed point nor a limit cycle.
In 1963 and 1964, Imre **Lakatos**, in Proofs and Refutations, suggested that mathematics develops by a process of conjecture, followed by attempts to prove it, that is, reduce it to other conjectures.
In 1964, Louis **Leaky** identified and named Homo habilis.
In 1964, **Nirenberg** and Phillip **Leder** found that lengths of artificial RNA as short as three bases were sufficient to make the ribosomes bind with the kind of transfer-RNA complementary to one codon (Nirenberg and Leder 1964).
In 1964, Har Gobind **Khorana** perfected the biochemistry needed to make long strands of RNA with known, simple repeating sequences.
In 1964, Charles **Yanofsky** established the co-linearity of the gene and the enzyme for making tryptophan in E. coli.
In 1964, William D. Hamilton contributed to the theory of evolution the notion of 'inclusive fitness,' i.e., that fitness--high fitness meaning high selectibility--should include the survival and reproduction of kin. The formula by which this is ascertained states that a gene will increase in frequency in a population if b, the benefit to the recipient, divided by c, the cost to the actor, both measured as changes in the expected number of offspring resulting from the act, is equivalent to k where k is greater than 1 divided by r, the relatedness of the actor to the recipient, or "the coefficients of relationship appropriate to the neighbors whom he affects: unity for clonal individuals, one-half for sibs, one-quarter for half-sibs, one-eighth for cousins, [etc.] and finally whose relationship can be considered negligibly small" (Hamilton 1964:8).
In 1964,Bell, in "On the Einstein-Podolsky-Rosen Paradox," using the E-P-R assumption of 'local reality,' turned the E-P-R thought experiment into "an accurately formulated mathematical theorem" ('t Hooft 1997:175), which set "a strict limit on the possible level of correlation for simultaneous two-particle results.... Quantum mechanics à la Bohr predicts that, under some circumstances the degree of cooperation should exceed Bell's limit [and] thus opens the way for a direct test of the foundations of quantum mechanics, and the decisive discrimination between Einstein's idea of a locally real world, and Bohr's conception of a somewhat ghostly world full of subatomic conspiracy" (Davies and Brown 1986:17). In other words, the measurements, on a statistical basis, will be unequal, if common sense prevails. This is known as Bell's inequality. If Bell's inequality is violated, this "reveals a fundamental truth about the Universe, that there are correlations which take place instantaneously, regardless of the separation between the objects involved" (Gribbin 2000:24). "Bell's theorem was a great discovery because it showed that an important question that had previously been considered as a philosophical one could be decided by experiment" (Park 1990:343).
In 1964, James Cronin and Val Fitch demonstrated that when one type of kaon, a neutral particle which is its own antiparticle, decays it leaves very slightly more positrons than electrons. This process violates conservation of charge conjugation (C) and sometimes parity (P), but in combination with time (T), or CPT, symmetry is always maintained.
In 1964, Peter Higgs invented a way of evading Goldstone's theorem, known as the 'Higgs mechanism.' "It solved the mass problem for particles of spin-1 at the cost of introducing a new kind of massive particle, the spin-0 'Higgs boson'" (Brown et al. 1997a:11). Higgs particles drag on the movement of quarks and electrons, producing inertia, the essence of mass.
In 1964, Nicholas Samios, using the Brookhaven accelerator, discovered the particle, omega-minus, whose existence Gell-Mann and Ne'eman had predicted on the basis of their periodic table.
In 1964, Wheeler, while contemplating classical gravitation as it approaches the final state of

recontraction, pointed out "a direct tie between classical and quantum concepts [by way of] the integral [or Hamiltonian] of the Lagrange function" (Wheeler 1964:330). The question he asked was this: With the help of the quantum principle, can geometry be constructed out of more basic elements without dimensionality? Later, Wheeler called this underlying element 'pregeometry.' More primordial than either Riemann's geometry or Bohr's particles, pregeometry is identical to 'quantum fluctuation,' and, somehow, the quantum principle itself (Wheeler 1971:1203).
By 1964, Merle F. Walker, Alfred H. Joy, and Robert P. Kraft had established that "membership in a binary system is a necessary condition for a star to become a nova.... One of the components is usually a blue white dwarf star and the other is a red star of about the same mass. Apparently, as the large, cool red star evolves, it expands into a region where the gravity of the small hot white dwarf predominates. As a result, some of the hydrogen-rich material of the red star flows onto the white dwarf star" (Lang and Gingerich 1979:421-422).
In 1964, Jesse L. Greenstein and Maarten Schmidt identified several known radio sources as 'quasi-stellar' objects, or quasars, and interpreted them to be distant and superluminous with large cosmological redshifts and small angular sizes.
By the mid-1960s, Ruth Sager reported numerous incidences of non-chromosomal mutation in a green algae, Chlamydomonas, all of which demonstrated the same pattern of maternal transmission.
In the mid-1960s, Sonneborn, still working with Paramecium, confirmed by grafting tests that the genetic basis for its morphology is contained in its cortex (Sonneborn 1970).
In 1965, Emile Zuckerkandl and Pauling said that molecular sequences can reveal evolutionary relationships to an extend that phenotypic criteria and molecular functions cannot (Zuckerkandl and Pauling 1965).
Beginning in 1965, Eric R. Kandel published reports on the synaptic facilitation of memory in Aplasia californica, a marine mollusk with a remarkably simple nervous system, and proved that biochemical change at the receptor level is the molecular basis of memory (Kandel and Tauc 1965).
In 1965, Norbert Hilschmann sequenced Bence-Jones proteins, which are light chains of myeloma globulins found in the urine of myeloma patients, and determined that they possessed different amino acid sequences in their 'variable' and 'common' regions.
Later in 1965, William Dreyer and J. Claude Bennett proposed that within each Bence-Jones cell the variable region existed as an episome which would pair with the single common gene at a specific base sequence. Today, this is known as 'V-C translocation,' although at the time their theory was most noted for its hypothesis that the genetic material was in the germline (Dreyer and Bennett 1965).
In 1965, R. Bruce Merrifield and John Morrow Stewart invented solid-phase peptide synthesis in which one end of a growing peptide is attached to a tiny plastic bead and amino acids are added individually(Merrifield and Stewart 1965).
In 1965, Cambridge Instruments produced the first commercial scanning electron microscope. [added 02/01/03]
In 1965, Holley achieved the first sequencing of a nucleic acid, a transfer RNA molecule known as alanine (Holley 1968). [added 02/01/03]
In 1965, Nambu proposed an unbroken-symmetry color gauge theory for hadrons which "had to consist of each of the three colors, or a color and an anti-color, so that the net [charge] was always zero" (Johnson 1999:283; Nambu 1966:133-142).
In 1965, Arno Allan Penzias and Robert Woodrow Wilson, while testing some microwave-receiving equipment, discovered cosmic background radiation (CBR) which yielded "noise temperature [of] a value about 3.5 degrees K. higher than expected" and concluded it was coming in all directions with no obvious source and was not "due to radio sources of types known to exist" (Penzias and Wilson 1965:421). Robert Henry Dicke, Phillip James Edwin Peebles, and colleagues explained the "excess radiation as the residual temperature of the primeval explosion that initiated the expansion of the Universe" (Lang and Gingerich 1979:873). The implication is that intergalactic space is above absolute zero, or about 3 degrees K. CBR together with the extant amount of helium is corroberated by extrapolation to the point in time when the Universe was a few seconds old and hot enough for nuclear reactions to occur. This, in turn, led to a drastic shift of the consensus to favor acceptance of the big-bang cosmology.
In 1965, Hoyle and Jayant V. Narlikar revised the steady-state model by raising the coupling constant by an extremely large factor in order to account for background radiation and through the suggestion that, rather than the old homogenous model, the Universe was locally fluctuating and unstable (Hoyle and Narlikar 1966:168,170).
In 1965, Orhan Berktay, building on earlier work by sonar researchers, discovered that ultrasound signals are distorted in water in a mathematically predictable way.
In 1965, Roger Brown, in Social Psychology, wrote that categorization, or naming, for a child, begins

at the level of distinctive action: you smell flowers and you pet cats and you throw balls. Further categorization moves in either an abstract or a concrete direction: upward to superordinate categories (like plant and animal) and downward to subordinate categories (like jonquil and Siamese).

In 1965, Noam Chomsky, in Aspects of the Theory of Syntax, said that grammars of particular languages "are supplemented by [an innate] universal grammar that accomodates the creative aspect of language use and expresses the deep-seated regularities which, being universal, are omitted from the [particular] grammar itself" (Chomsky 1965:6). The universal aspects of "the linquistic intuition--the tacit competence--of the native speaker" he called 'generative grammar' (ibid.:27).

In 1966, David Phillips solved the three-dimensional structure of an enzyme, lysozyme (Blake et al. 1967).

In 1966, Walter Gilbert confirmed the existence of repressor molecules, establishing that the gene responsible for making betagalactosidase was repressed by something which would only detach from the gene when lactose was present (Gilbert and Müller-Hill 1966). Shortly thereafter, Mark Ptashne also isolated a repressor and confirmed it was DNA (Ptashne 1967).

In 1966, Terje Lømo observed that a brief high-frequency train of stimuli to the hippocampus produces an increase in the excitory synaptic potential in the post-synaptic neurons which can be long lasting. This is known as 'long-term potentiation (LTP).'

From 1966 until the 1980s, Kwang W. Jeon observed amoeba being infected by bacteria and then the few survivors losing their disease but not the bacterial 'germs' which had become indispensible, i.e., symbiotic, to the lives of the amoebae.

In 1966, Jacques Oudin chose the term 'ideotype' to denote the class of antigenic determinants peculiar to a particular antibody from a specific individual. This may contrasted with 'allotypes,' a term coined earlier by Oudin, which are protein products of different alleles of the same gene.

In 1966, Brenner and Cesar Milstein devised a hypermutation model of antibody diversity in which they postulated an error-prone polymerase (Brenner and Milstein 1966).

By 1966, through the use of Nirenberg's and Khorana's techniques, all twenty amino acids were decoded, including a number of 'degenerate' variations. "Degeneracy is different from strict redundancy but can include redundancy as a specific case.... Degenerate groups are isofunctional but nonisomorphic" (Edelman 1978:59). "Three codons, the triplets UAA, UAG, and UGA, had no amino acids assigned to them. One by one, in experiments in phage genetics by Brenner and independently by Alan Garen..., and last by Brenner and Crick in 1967, these three triplets were proved to be nonsense codons, whose function was to signal the end of the polypeptide chain" (Judson 1979:488; Stretton et al. 1966; Crick and Brenner 1967). Also in 1966, Crick, in The Croonian Lecture, proposed a compact table of the standard bases of RNA, uracil (U), cytosine (C), adenine (A), and guanine (G), in which the code is still always displayed (Crick 1966). In DNA, thymine replaces uracil. [revised 02/01/03]

In 1966, Lewontin and J. L. Hubby, surveying gene-controlled protein variants, demonstrated that between eight and fifteen percent of the loci in the Drosophila pseudoobscura genome are heterozygous (Lewontin and Hubby 1966).

In 1966, Benzer, working with Drosophila mutants, intiated the study of the relations between genes and behavior (Benzer 1967). [added 02/01/03]

In 1966, George C. Williams, in Adaption and Natural Selection, supported genic selection, defining a gene "as any hereditary information for which there is a favorable or unfavorable selection bias equal to several or many times its rate of endogenous change" (Williams 1966:25).

In 1966, Zel'dovich and Novikov proposed that neutron stars and black-holes would be found in close binary systems.

In 1966, S. S. Gershtein and Zel'dovich noted that "relict neutrinos could make an appreciable contribution to the present cosmic mean mass density" (Peebles 1993:422), making neutrinos a candidate for dark matter.

In 1966, Robert V. Wagoner, Fowler, and Hoyle established that "significant quantities of only [deutrium, helium3, helium4, and lithium7] can be produced in the universal fireball" or in large masses of gas that collapse to a similarly hot, dense state; also, the synthesis of elements at very high temperatures and very short time scales, i.e., 'bounces,' "bridge the mass gaps through 3 He4 ® C12 and mainly produce metals of the iron group, plus a small amount of heavier elements" (Wagoner et al. 1967:3).

In 1967, Lynn Margulis established that the main internal structures of eukaryotic cells originated as independent living creatures. Known as 'endosymbionts,' these organisms were "originally taken up in the course of feeding by an unusually large host cell that had already acquired many properties now associated with eukaryotic cells" (de Duvé 1996:).

In 1967, Edwin S. Lennox and M. Cohn revised the Brenner-Milstein model, characterized it as a 'somatic' model, as opposed to a 'germline' model, and named the nucleotide, where the error-prone polymerase operated, the 'generator of diversity,' or GOD (Lennox and Cohn 1967).

In 1967, Kornberg, Mehran Goulian, and Robert L. Sinsheimer synthesized a biologically active viral DNA, using as a template a single-stranded DNA chain from fX174 which requires no protein coat to infect bacteria (Kornberg et al. 1967).

In 1967, Reiji Okazaki showed that newly synthesized DNA requires a DNA fragment as a starter. These fragments are replicated discontinuously and then spiced together.

In 1967, Judah Folkman began the development of his theory that cancerous tumors could be stopped by inhibiting the first growth of blood vessels to them. Earlier, he had developed the first implantable drug-delivery system, later called Norplant.

In 1967, Gurdon, by transplanting somatic material into frog's eggs, discovered that the synthesis of RNA and DNA changes to the kind of synthesis characteristic of the host cell nucleus (Gurdon 1968).

In 1967, Aaron Klug concluded that viruses had a geodesic and crystalline structure.

In 1967, Donald Mosier established experimentally that, in order to generate an immune system antibody response, lymphocytes must interact with non-lymphoidal cells, such as macrophage (Mosier 1967).

[In 1967, Jerne, facetiously imposing molecular terminology on immunologists, labelled those favoring the cellular point of view, such as Metchnikoff, Burnet, and M. Cohn, 'cis-immunologists' and those favoring the molecular point of view, such as Edelman and Porter, 'trans-immunologists.' These attitudes fell roughly from the traditional disagreement between the 'globalists,' or holists, and the reductionists. At the time and in the sense which Jerne intended the distinction, it referred to where the respective disciplines were coming from: "The trans-immunologists...start at the end, with the structure of antibody molecules, hoping to work their way backwards, and the cis-immunologists...start at the beginning, and with the effects of antigenic exposure, hoping to work their way forwards" (Jerne 1967:591).

In 1967, Steven Weinberg and, independently the following year, Abdus Salam completed the somewhat earlier observation of Glashow that the weak and electromagnetic forces share a number of common features: If the main difference between them is mass versus massless, "the spontaneous breaking of the underlying gauge symmetry" by a minute violation of parity in a weak neutral interaction permits the mass of the weak force to be treated as "a secondary phenomena, leaving the gauge symmetry of the dynamics itself intact" (Davies and Brown 1988:54-55). A violation of parity may be illustrated by two asymmetric options after a phase transition, e.g., one among the iron filings around a cooling magnet "will arbitrarily pick one of the possible directions [as the negative pole and] the effect propagates" (Johnson 1999:278). Applying this idea to cosmogeny, the primordial symmetry of the fourfold superforce broke down as the Universe cooled (Ibid.:355); "pure spirit gives way to material being," like the myth of falling from grace (Ibid.:278). Glashow's algebra unified these forces by combining two mathematical groups--what Cartan called SU(2) x U(1)--into a theory of 'electroweak force,' reminiscent of Maxwell's demonstration that electricity and magnetism were part of a more embracing scheme. The theory predicts the existence of the carriers of the weak force, the 'Z,' 'W+,' and 'W -,' all confirmed in 1983/1984, and a heavy particle with spin 0, the Higgs boson. This process, also known as the Weinberg-Salam phase transition, probably occurred about 10-10 of the first second.

In 1967, Sakharov set forth three principles that "must apply to any process which could produce matter particles preferentially in the early Universe.... First, there must be processes which produce baryons out of non-baryons. ['Baryons' are made up of three quarks with a quantum number +1.] Second, these baryon interactions...must violate both C and CP conservation.... And, third, the Universe must evolve from a state of thermal equilibrium into a state of disequilibrium--there must be a definite flow of time, so that CP processes together can be non-conserved, even though CPT remains conserved" (Gribbin 1998a:251).

In 1967, Sakharov proposed that "the metrical elasticity of space [is] a sort of displacement effect" (Sakharov 1968:1040), or, in other words, he proposed a microscopic foundation for gravitation based on the energy of an elastic deformation (curvature) created by quantum fluctuations of the vacuum.

In 1967, Bryce Seligman DeWitt took the canonical Hamiltonian approach to quantizing gravity, providing a cosmological formalism, HY = 0, with the wave function obeying a functional differential equation, known as the Wheeler-DeWitt equation, which is an analogue of the Schrödinger equation. Imagine the four-dimensional space-time sliced up into three-surfaces and concentrate on the variables defined thereon: The Hamiltonian wave function "evolves into a superposition of vectors representing the possible values of some system variable together with apparatus 'readings' " (DeWitt 1967:1140). Since, due to the uncertainty relations, no spacetimes exist at the quantum gravity level, the equation is timeless, or, alternatively, "different possible configurations [in Everett's sense] are the instants of time" (Barbour 2000:247).

In 1967, Franco Pacini pointed out the the gravitational energy released when a star collapses would be converted to rotational energy. "A normal star like the Sun [would] speed up from a rotation period of 27 days to a rotation period of much less than a second when it becomes a neutron star" (Lang and Gingerich 1979:494). He further pointed out that a "very strong magnetic field" would be created and that "by this means a large amount of energy and momentum could be pumped from the neutron star into the supernova remnant," such as in the Crab Nebulae (Pacini 1967:567).
In 1967, Anthony Hewish brought into use a dipole radio telescope designed to investigate 'scintillting' radio sources, that is, quasars, and S. Jocelyn Bell determined that the highly regular pulses of a radio source from outer space originate in neutron stars. These were named 'pulsars,' even though it was soon obvious they were not pulsing, but rotating and emitting radio waves in the manner that a lighthouse emits light.
In 1967, Arthur Samuels finished building a computerized checkers player which could model the opponent's options, recognize its tactics, and make predictions on that basis.
In 1967, Walter J. Ong, in The Presence of the Word, wrote that the academic tradition in the West is "a massive device for institutionalizing the polemic stances originally fostered in oral culture because of its problems of information storage and its consequent overspecialization in heroic figures and interpersonal struggle as a means of interpreting actuality" (Ong 1967:236).
In 1968, Norman Geschwind and Walter Levitsky showed that in male and female humans there are characteristic anatomical differences, e.g., the size of the planum temporale in the hemispheres of the brain (Geschwind and Levitsky 1968).
In 1968, Donald Roy Forsdyke proposed that, within the immune system, "two separable and distinquishable signals [were] required to separate inactivation by self from activation by nonself" (Cohn 1994:30; Forsdyke 1968).
In 1968, Lionel F. Jaffe, working with Fucus eggs, described the role of ionic current in developmental patterning (L. F. Jaffe 1969; L. A. Jaffe and Cross 1986).
In 1968, Motoo Kimura formulated the neutral theory of evolution which holds that almost all evolution at the molecular level is due to random drift, in contrast to neo-Darwinians who hold that natural selection plays the more prominent role. Subsequently, the discovery of various 'silent' genes, invisible to natural selection, have lent support to the concept of evolution by neutral genes. Neutral theory offers a baseline for evaluating the significance of selection and adaptive change.
In 1968, Arber discovered the restriction endonuclease in Escherichia coli B. At the same time, Meselson and Robert Yuan discovered it in Escherichia coli K. These endonuclease recognize specific sequences but cut the DNA at random places and were known as Type I (Arber 1968). [added 02/01/03]
In 1968, Sanger and colleaques, applying another new sequencing technique in which a DNA molecule is stopped at various stages of replication, reported a twelve nucleotide sequence from bacteriophage gamma. [added 02/01/03]
In 1968, Elias James Corey and colleagues synthesized five different prostaglandins using a methodology, retrosynthetic analysis, Corey had developed wherein the planning process began with the desired molecule, instead of the initial chemicals, and created maps of many possible compounds and reactions. This system made it possible to use computers for chemical synthesis. [added 02/01/03]
In 1968, Jurgen Habermas pointed out that "psychoanalysis consists of the hermeneutic interpretation of the complex text that is provided to the analyst by his subject," not the physics of the mind, as Freud supposed (Stent 1985:217).
In 1968, Gold predicted that a rotating neutron star ought to gradually slow down, which was soon confirmed by the pulse rate at the Crab Nebulae.
In 1968, Eric E. Becklin and Gerry Neugebauer showed that the Milky Way's galactic nucleus is observable at 22,000 Å.
In 1968, ARPA , under Lawrence G. Roberts, contracted with Bolt, Beranek, and Newman, or BBN, to build ARPANET, the prototype of the computer internet.
In 1969, Kilmer McCully discovered a correlation between heart disease and high homocysteine levels, probably occasioned by deficiencies in vitamins B6, B12, and folic acid.
In 1969, Calvin published Chemical Evolution in which he gave several autocatalytic scenarios for the origin of life.
In 1969, de Duvé identified the role of 'peroxisomes,' a subcellular microorganism, to be oxygen detoxifiers. They accomplish this by converting oxygen to hydrogen peroxide which in turn destroys an enzyme called 'catalase.' They also contain an enzyme which removes superoxide ions (de Duvé 1996:56).
In 1969, Glashow, John Iliopoulos, and Luciano Maiani introduced a fourth quark, named 'charm.'

In 1969, Marcian Ted Hoff designed the first microprocessor, an integrated circuit semiconductor chip which was able to receive instructions and send data.
In 1969, Penrose discovered a process for extracting energy from a rotating, or Kerr-type, black-hole: If, when sending a pair of 'virtual particles' against the direction of the spin and into the area immediately outside a black-hole, the ergosphere, the pair were to split, one part entering the black-hole and the other escaping and becoming 'real,' the latter fragment may have greater energy than its entirety had to begin with. This extra energy is surrendered by the black-hole which must slow its rotation slightly. This is known as the Penrose process (Penrose 1969:252; Penrose and Floyd 1971:177-178).
In 1969, L. E. Snyder, D. Buhl, B. Zuckerman, and P. Palmer identified the organic molecule formaldehyde in interstellar space by its characteristic spectroscopic signature at radio wavelengths. Polyatomic molecules are formed perhaps when "large particles of carbon capture other atoms in interstellar dust and form more complex organic molecules" (Oparin 1972:324-325; Snyder et al. 1969:679-681).
In ! 1969, Brent Berliner and Paul Kay published Basic Color Terms:Their Universality and Evolution, in which they concluded that "there appears to be a fixed sequence of evolutionary stages through which a language must pass as its basic color vocabulary increases" (Berliner and Kay 1969:14); i.e., first, black and white encompass the entire spectrum, then red is added, then green or yellow, then blue, then brown, then many categories.
In the late 1960s, Ralph Lewin discovered a microbe which he named Prochloron, a missing link in the history of symbiosis, combining the physiology of a plant with the structure of a bacterium.
In 1970, K. A. Kvenvolden reported that the amino acids found in the Murchison meteorite are incontestably extraterrestial because they are 'racemic,' i.e., their handedness occurs in equal amounts whereas all naturally-occurring amino acids on Earth are left-handed (Kvenvolden et al. 1970). Others showed that there is a slight preference for left-handedness in extraterrestial amino acids (Engel and Nagy 1982). This discrepancy would be explained if the amino acid molecules had been circularly polarized, a theoretical possibility (Darling 2001:36).
In 1970, Lewontin took the position that the synthetic theory of evolution ought to be expanded to include multiple units of selection, e.g., cell organelles, haploid organisms, and gametes, as well as individual organisms. This is widely known as the anti-adaptionist position and is less reductive than the adaptionist position in which genes are the sole unit of selection. The latter position was explicit in the ideas of Williams and W. D. Hamilton. The issue seems to be the assumption which adaptionists make that selection strives for optimality which their opponents, i.e., Stephen Jay Gould and Lewontin, ridicule as 'Panglossian' (Gould & Lewontin 1978). [added 02/01/03]
In 1970, Mort Mandel demonstrated that placing E. coli cells in a cold calcium chloride solution rendered them permeable to nucleic acid fragments. This manuver is virtually indispensible in genetic engineering operations.
In 1970, Peter A. Bretscher and M. Cohn published a two-signal theory of self-nonself discrimination. Signal one occurs when a lymphocyte's antigen-specific receptor, that is, either B-cell antibody or T-cell receptor, contacts the appropriate antigen. If the lymphocyte receives no other signal, it is inactivated irreversibly, i.e., killed. This is the tolerance pathway. The second or activation signal was at that time thought to have been supplied only by helper T-cells, which are antigen-specific, thus maintaining tolerance. Their theory was based on its analogy to neural associative learning, i.e., plasma cells learned to respond to or tolerate a signalling antigen by virtue of its associated signal from a carrier-antibody cell (Bretscher and Cohn 1970).
In 1970, Hamilton Othanel Smith and colleagues, working with the bacterium Hemophilus influenzae, discovered Type II restriction endonuclease which cuts between specific DNA sequences when paired with a matched set of methylase enzymes (H. O. Smith 1970). [added 02/01/03]
In 1970, Woodward and Roald Hoffman, in The Conservation of Orbital Symmetry, designed a set of rules for postulating the areas around atoms where it is most probable that electrons will be found. These reaction outcomes are based on stereochemistry and quantum mechanics. [added 02/01/03]
In 1970, Howard Temin and Satoshi Mizutani, taking up Lwoff's 1950 speculation and working with Rous sarcoma virus which has RNA as its genetic material, proved that the RNA had a DNA intermediate; that is, the virus has an enzyme by which the RNA directs the behavior of the DNA (Temin and Mizutani 1970). The same month David Baltimore, working with the virus that gives mice leukemia, made the same claim (Baltimore 1970). The enzyme is now known as 'reverse transcriptase.' By this process biologists can make DNA copies of active genes, or messenger RNA. [revised] *eIn 1970, Changeux isolated a receptor for the first time in a lab. The receptor was for acetylcholine and was from an eel (Changeux et al. 1970). [added 02/01/03]
In 2001, Richard Ellis, Michael R. Santos, Jean-Paul Kneib, and Konrad Kuijken discovered a star

cluster 13.4 billion light years from Earth, employing a combination of the W. W. Keck Telescope and the HST with a gravitational lens, two billion light years away, the star cluster Abell 2218. The significance of their discovery lies in its age, an age when the Universe was several hundred times denser than today. [added 02/01/03]
In 1970, Susumu Ohno published Evolution by Gene Duplication in which he described gene duplication as an escape from the pressure of natural selection. "By duplication, a redundant copy of a locus is created. Natural selection often ignores such a redundant copy, and, while being ignored, it accumulates...mutations and is born a new gene locus with a hitherto non-existent function. Thus, gene duplication emerges as a major force of evolution. [Also], when the metabolic requirement of an organism dictates the presence of an enormous amount of a particular gene product, the incorporation of multiple copies of a gene locus by the genome often fulfills that requirement" (Ohno 1970:59-60).
In 1970, John Schwarz and André Neveu discovered a second string theory that described fermions. The following year, together with Pierre Ramond, they revised this model, reducing the dimensions to ten. This model came to be called the Superstring Theory of Everything, or a 'Grand Unified Theory' (GUT). " ((It should not be supposed that a universal theory would result in an explanation of all natural phenomena: "All we would know is a rather formal--though exact--series of equations which all phenomena would obey" ('t Hooft 1997:179)). In the case of a Superstring, the different harmonics correspond [not to different sounds, but] to different elementary particles" (Whitten 1988:93). String theory includes gravitons, which carry the force of gravity, and 'supersymmetry.' Supersymmetry would occur if every boson had a corresponding fermion --two sides of the same coin united at a higher symmetry-- and infinities might not require renormalization since bosons and fermions could cancel each other. However, direct tests of GUT predictions can only be done at energies way beyond the reach of present accelerators. The notion of supersymmetry led to the prediction of the existence of ' weakly interacting massive particles,' or WIMPs, and their discussion as a conceivable constituent of dark matter (Gribbin 1998a:270-272).
In 1970, H. Dieter Zeh showed that quantum mechanics gives rise to 'superselection rules' which state, for example, that "superpositions of states with different charge cannot occur...for similar reasons as those valid for superpositions of macroscopically different states: They cannot be dynamically stable because of the significantly different interaction of their components with their environment" (Zeh 1970:348). This effect became known as 'decoherence' because an ideal, or pristine, superposition is said to be coherent.
In 1970, Brandon Carter suggested that in principle conventional physics could have predicted the existence of 'large number coincidences,' e.g., a star's mass is in order of magnitude the inverse of the gravitational coupling constant, provided use was made of the 'anthropic principle:' "What we can expect to observe must be restricted by the conditions necessary for our presence as observers" (Carter 1973:291). This is the weak version. The strong version, which Carter finds distasteful, holds that the Universe must be such that life can evolve in it.
In 1970, Stephen Hawking and Penrose proved that the Universe must have had a beginning in time, on the basis of Einstein's theory of General Relativity. The implication of this is that near the beginning of time, when the Universe was sufficiently small, the laws of quantum mechanics would have applied. Earlier, Penrose had shown that black-holes produce singularities, mathematical points where certain physical quantities attain infinite values. Hawking now showed mathematically that the big-bang must have arisen from a singularity.
[Cosmologists' interest in the age of the Universe and in the value of the Hubble constant relates to the Universe's probable fate by way of the density of matter in it. This density is denoted in cosmology by W, the Greek capital letter omega. "This parameter is defined in such a way that if the cosmological omega is less than one, the Universe is open and will expand forever, while if it is [one or] bigger than one the Universe is closed and must inevitably end in the Big Crunch (sometimes called the 'omega point').... If...omega has the critical value of one, then the age of the Universe...is exactly two-thirds of 1/H" (Gribbin 1998a:188). The value of H, the Hubble constant, is controversial. "Deviations from the simple Hubble's law are calculated in terms of a deceleration parameter, often labelled q, which is defined in such a way that q = 1/2 corresponds to W = 1" (Ibid.:201). The inverse of the Hubble constant, called Hubble time, gives an approximate age for the Universe; e.g., if omega equals one, the age is thought to be 6.5 billion years to 13 billion years.]
In 1970, Sandage asserted that there is a maximum brightness limit for "first-ranked [galaxy] cluster members, [permitting] a universal K correction," and thus reducing the plotting error in the deceleration (q0) equation to 15% (Sandage 1970:39).
In 1970, the first X-ray astronomical satellite, built by NASA, was launched and over the next three years discovered many X-ray sources.
In 1970, the Westerbork Synthesis Radio Telescope (WSRT), belonging to the Netherlands

Foundation for Research in Astronomy, began operating an 'aperture synthesis telescope.' These are "interferometers in which the whole or part of a large, imaginary aperture is built [making] use of the fact that over a period of 12 hours the Earth's rotation will move the elements to sweep out half a ring of the synthesized aperture; the other half of the ring can be derived from the observations of the first half.... In practice, some aperture-synthesis telescopes employ several movable dishes to reduce observation time.... Aperture synthesis requires complex data-reduction techniques and powerful computers" (Dictionary of Astronomy 1997:21).
In 1970, John Conway developed the Game of Life, a computer program which began with randomly arranged white, or alive, squares and black, or dead, squares. These squares live or die according to a few simple rules centered on the density of the population, and, in the meantime, arrange themselves into all manner of coherent structures.
In the early 1970s, Sandage, as it had become "evident that galaxy classification studies offered vast insights into questions of galaxy formation,...began a program...to complete the classification of all galaxies in the Shapley-Ames Catalogue" (Sandage and Bedke 1994:6).
In 1971, Manfred Eigen, in "Selforganization of Matter and the Evolution of Biological Macromolecules," described certain "random effects are able to feed back to their origin and thus become themselves the cause of some amplified action" (Eigen 1971:467), and this he called a hypercycle. A hypercycle is a "reaction cycle with superimposed coupling" (Eigen 1992:108). This means that, if one of the replicators or one of the translation products is encoded as the replication enzyme, the rate of the reaction of catalysis will rise with the square of the RNA concentration, that is, hyperbolically. The feedback loop that connects the replication enzyme to its RNA template will only come into effect if the genotype and the phenotype are encapsulated together so that the phenotype cannot act on the genotypes of other, competing replicators (Eigen 1992:108). "The hypercycle...unites several genes that are working just below their error limit, and thus bypasses the error threshold, allowing the quantity of information to rise to the much higher levels needed for the nucleation of apparatus of translation" (Eigen 1992:111). [added 02/01/03]
In the 1970s, Manfred Eigen sought the origin of life in ribonucleic acid, the apparatus of replication. He was able to make RNA using an enzyme but no template. Leslie Orgel made RNA using a template but only zinc ions for a catalyst.
In 1971, Ronald J. Konopka, working in Benzer's lab, published his discovery in Drosophila of the first gene known to control a biological clock. On the X chromosome there are three alleles of a locus, which he named the period locus, that shape a fly's sense of time (Konopka and Benzer 1971).
In 1971, Michael S. Brown and Joseph L. Goldstein hypothesized that abnormalities in the regulation of 3-hydroxy-3-methylglutarl coenzyme A reductase are the cause of familial hypercholesterolemia, a genetic disease in which excess cholesterol accumulates in blood and tissues.
In 1971, Susan Leeman determined the eleven amino acid structure of the peptide, Substance P.
In 1971, Robert Trivers extended the notion of reciprocity to the explanation of altruism.
In 1971, Kenneth G. Wilson demonstrated the ubiquity, or 'universality,' of critical point phenomena, such as phase transitions, by using renormalization groups. In the phase transition from liquid to vapor, for example, configurations are formed by the microscopic degrees of freedom near the critical point, that is, the point where the difference in the densities of the two phases vanishes and at which it is susceptible to renormalization group transformation.
In 1971, Gerhard 't Hooft proved that theories like the Yang-Mills theory could be described in the language of quantum mechanics, i.e., renormalized, and that theories with massive particles, like those postulated by Glashow, Weinberg, and Salam, were sensible so long as the masses come from spontaneous symmetry breaking. With Martinus J. G. Veltman, 't Hooft developed a dimensional-regularization method, involving temporarily modifying the number of space dimensions in a calculation.
In 1971, the Mariner 9 spacecraft began to map Mars, and quickly established that there were no channels and that the seasonal variations were caused by the alternate deposition and displacement of windblown dust.
In 1971, Alan Kay and Jeff Rulifson, in the course of designing an iconic programming language and wondering about ways to keep the screen from getting too crowded, discovered "a way to let documents appear in separate but overlapping ' windows' (Waldrop 2001:362).
In 1972, Gould and Niles Eldredge published their conclusion that the stratigraphic record of fossil remains is indeed accurate and evolution proceeds over time by 'punctuated equilibria,' or stasis punctuated by episodic events, rather than by phyletic gradualism. "Most morphological divergence of a descendant species occurs very early in its differentiation, when the population is small and still adjusting to local conditions" (Eldredge and Gould 1971:95). [added 02/01/03]
In 1972, Paul Berg, D. A. Jackson, and R. H. Symons spliced the DNA of two different types of virus

together in vitro (D. Jackson et al. 1972).
In 1972, computerized axial tomography, or CAT scanning, was introduced.
In 1972, René Thom , in Stabilité Structurelle et Morphogénèse: Essai d'une théorie général des modèles, pointed out that structures, e.g., cells, have boundaries and a boundary implies a discontinuity. Moreover, "all creation or destruction of forms, or morphogenesis, can be described by the disappearance of the attractors representing the initial forms, and their replacement by capture by the attractors representing the final forms. This process [is] called 'catastrophe'" (Thom 1972:320). His description is similar to Thompson's, but much more sophisticated mathematically.
In 1972, Sidney Coleman and Erick Weinberg arqued that elementary scalars might be constrained to have 'zero bare mass' which would lead to symmetry breakdowns through radiative corrections. "When symmetry breakdown occurs in a fully massless field theory, so does dimensional transmutation; one dimensionless coupling constant disappears, to be replaced by a mass parameter." This led them to speculate that in the case when a gauge group has two coupling constants, "one would survive, and the fine structure constant would still be a free parameter [and] all mass ratios could be computed in terms of it" (Coleman and Weinberg 1973:1904-1905).
In 1972, Andrei Linde and David A. Kirzhnits proposed the idea that the early Universe was a series of phase transitions.
In 1972, Louise Webster, Paul Murdin, and, independently, David Dunlap, having found that the star HDE 226868 is a member of a binary system, deduced that its X-radiating companion exceeds the Oppenheimer-Volkoff limit, making it a black-hole.
In 1972, Jacob D. Bekenstein proposed "a unification of black-hole physics with thermodynamics," i.e., he maintained that the event horizon around a black-hole provides a direct measure of its entropy, i.e., is a black-hole's entropy, and that a quantum violation of Hawking's theorem--that the area of a black-hole can never decrease--is possible (Bekenstein 1973b:2333-2334; Bekenstein 1973a:950).
In 1972, Ray Tomlinson created the first electronic mail program.
In 1973, through the collaborative efforts of Janet Mertz, Ronald Davis, Peter Lobban, Berg, Herbert Boyer, Stanley N. Cohen, and John Morrow, animal genes were spliced into the plasmids, or small rings of DNA, of bacterial cells at places which readily rejoined even foreign DNA; thus was recombinant cloning begun, which, for once, answered more questions than it raised. For example, it permitted the identification of those genomic components which have no effect on development. It also permitted the launching of the biotechnology industry (Mertz and Davis 1972; Lobban and Kaiser 1973; S. N. Cohen et al. 1973). [revised 02/01/03]
In 1973, Jerne propounded a cognitive theory of immune ideotypic networks, envisaged as an autonomous, homeostatic system, with self-knowledge preceding the first antigenic encounter. In the course of this, he proposed the study of the brain from the point of view of epigenetic selection.(Jerne 1973) Changeux took up his suggestion that same year (Changeux et al. 1973).
In 1973, Solomon H. Snyder and Candace B. Pert identified specific opiate receptors in the brain (Pert and Snyder 1973).
In 1973, Timothy V. P. Bliss and Lømo demonstrated that a brief high-frequency train of stimuli to the hippocampus produces an increase in the excitory synaptic potential in the post-synaptic hippocampal neurons, which slowly dissipated back to the base rate. They called this long-lasting potentiation (Bliss and Lømo 1973).
In 1973, Ralph M. Steinmann and Z. A. Cohn observed dendritic cells in the spleen and lymphoid organs of mice (Steinman and Cohn 1973).
In 1973, David Gross, Frank Wilczek, and, independently, David Politzer proved mathematically that the Yang-Mills field theory was 'asymptotically free' (Gross and Wilczek 1973; Politzer 1973). Asymptotical free theories have negative coupling constants; i.e., quarks when they are close to each other are unaware of each other, but when they move apart their interactive force gets progressively stronger, as if confined by an elastic band which is floppy when not taut (Gribbin 1998b:25). Their proof of asymptotic freedom meant that a QED field theory for the strong force could be built.
In 1973, Edward Tryon, in "The Self-Reproducing Inflationary Universe," proposed a simple, specific big-bang model in which "our Universe is a fluctuation of the vacuum, where 'vacuum fluctuation' is to be understood in the sense of quantum field theory" (Tryon 1973:396), that is, where the uncertainty relation requires a vacuum to be imperfect and permits the spontaneous, temporary emergence of particles. A Universe which appears from nowhere must have a zero net value for conserved quantities. This is accomplished in this model by balancing matter and anti-matter and by assuming that the Universe is closed and will ultimately return to singularity. At that point 'gravitational potential energy' is reduced to zero and E=-mc2.
In 1973, Zel'dovich and Alex Starobinsky discovered that "rotating black-holes could create particles

out of energy and eject them into space" (Gribbin 1995:149) by quantum fluctuations.
In 1973, John Maynard Smith and G. R. Price, along with W. D. Hamilton and Richard Dawkins, developed von Neumann's game theory where they substituted population dynamics and stability for rationality and fitness for self-interest. In both cases, they were concerned with optimization models, the proper role for which "is to provide the means for recreating short-term evolution in the imagination" (Oster and Wilson 1978:312). Since optimization is based on the assumption that populations strive to be adapted to the contemporary environment, maladaptive traits and the fact of continuous evolutionary change are obstacles to testing optimization theories (Maynard Smith and Price 1973). [added 02/01/03]
In 1973, Vinton Cerf and Robert E. Kahn began development of a protocol, later called TCP/IP, which allows diverse computer networks to interconnect and communicate with each other.
In 1974, Brenner described methods for inducing, isolating, and mapping mutations in a nematode, or worm, Caenorhabditis elegans (Brenner 1974).
In 1974, Peter Milner proposed the necessity of correlated, or simultaneous, firing by neural assemblies. He also argued that early cortical areas would have to be involved in visual awareness and suggested the mechanism for this would be backprojection from the higher cortical areas.
In 1974, Rolf M. Zinkernagel and Peter C. Doherty proved that immunization results when antigen-specific T-cells and the major histocompatibility complex (MHC) are the same haplotype, or haploid genotype, which is the configuration of alleles of the MHC on one chromosome of a specific individual. They also established that MHC-restriction occurs during the generation phase as well as during the effector phase (Zinkernagel and Doherty 1974).
In 1974, R. W. Hedges and A. E. Jacob discovered in E. coli a mobile DNA sequence, which they named a 'transposon.'
In 1974, William G. Quinn, working in Benzer's lab, established that flies can learn, i.e., they can remember, some for twenty-four hours, which is the equivalent of six years of a human life (Quinn et al. 1974).
In 1974, Berg led ten colleagues in writing a letter to Science explaining their concern "that some of these artificial recombinant DNA molecules could prove biologically hazardous.... Thus, new DNA elements introduced into E. coli might possibly become widely disseminated...with unpredictable effects" (Berg et al. 1974:303). The letter led to a meeting the following year of a hundred scientists from sixteen countries, and the year after that to new U. S. government regulations. [added 02/01/03]
In 1974, Henry Jay Heimlich, in Emergency Medicine, described a subdiaphramatic thrust, pushing up suddenly on the soft tissue of the diaphragm, which sharply reduced death from choking. This maneuver is based on the reserve volume of air that stays in the lungs after exhalation. [added 02/01/03]
In 1974, Samuel Ting and, independently, Burton Richter discovered a massive meson, predicted by the developing quark model and named therein as a charmed quark/anticharmed quark. Ting called it a 'J particle' and Richter a 'psi particle,' and, for awhile, it was known as the J/psi particle.
In 1974, Hawking assimilating the work of Bekenstein, Zel'dovich, and Starobinsky, postulated the existence of small black-holes and calculated that every black-hole radiates a constant flow of particles of which the intensity is inversely proportional to the square of the black-hole's mass. This "radiation, though tiny, is just enough to bring about consistency with Bekenstein's entropy postulate" (Wheeler 1998:315). When this "'Hawking radiation' exceeds the amount of matter and energy entering the black-hole, [the hole] will start to evaporate" (Dictionary of Astronomy 1997:208). In fact, the more it loses mass, the more its surface gravity increases, the more the rate of emission increases. "Near the end of its life the rate of emission would be very high and about 1030 erg would be released in the last 0.1 s..., [creating an explosion] equivalent to about 1 million 1 Mton hydrogen bombs" (Hawking 1974:30-31). These theoretical 'miniholes' are especially interesting to physicists because they may yield fundamental insights into how gravity links to the other forces of nature" (Begelman and Rees 1996:223). Indeed, "only a complete theory of quantum gravity will be able to predict and describe exactly what will happen to the black hole at [the final] moment ('t Hooft 1997:170).
In 1974, Joseph H. Taylor and Russel A. Hulse, using a radiotelescope, discerned that a pulsar was emitting radio waves in a regular pattern of alternately speeding up and slowing down. They realized that this pulsar must be part of a binary system and that the alternation must be caused by gravitational waves, predicted to exist by Einstein's general theory of relativity.
In 1974, Dagfinn Føllesdal formulated the conception that "meaning...is the joint product of all the evidence that is available to people who in their daily life try to communicate" (Føllesdal 1975:43).
In 1975, E. M. Southern devised an extension of gel electrophoresis, known as 'Southern blotting,' which greatly aided cloning by enabling the identification and sizing of DNA fragments (Southern

1975; Podolsky and Tauber 1997:409n7). [added 02/01/03]
In 1975, Sanger and colleages devised the 'plus and minus' method for determining the sequences of bases on a strand of DNA. Until then, genetic map-makers had relied on the relative position of changes, i.e., mutations, in the genes (Sanger et al. 1977) .
In 1975, Milstein and Georg J. F. Köhler devised a method to fuse myeloma cells with normal B-cells, in bulk, that would grow just the hybrids which produce monoclonal antibodies. The basic process involves injecting an antigen into a mouse, thereby inducing the mouse's B-lymphocytes to produce antibodies to that antigen. Unfortunately, these murine antibodies can produce a HAMA, or human anti-mouse antibodies, response (Köhler and Milstein 1975).
In 1975, Kevin Lafferty and A. J. Cunningham proposed a model of immune system activation in which the second signal, or 'co-stimulation,' comes from an antigen-presenting cell (APC) which need not display specificity for antigen (Lafferty and Cunningham 1975).
In 1975, Viktor Hamburger confirmed that the neuronal system is regressive, i.e., adults have far fewer axons and synapses than newborn infants but more order (Hamburger 1975).
In 1975, Hans W. Kosterlitz and John Hughes identified and named 'enkephalins,' which are pentapeptides with opiate-like activity, rather like endogenous morphine, or endorphins.
In 1975, Edward O. Wilson, in Sociobiology: The New Synthesis, analyzed the social instincts that bring together colonies of ants and bees, herds of antelope, and tribes of chimpanzee and human beings. His inclusion of the last of these was controversial: His opponents argued that the human animal was not enslaved by instincts, but rather was ruled by culture. Along with MacArthur and Trivers, Wilson led the emergence of a new paradigm, sociobiology.
In 1975, Richard D. Schwartz reckoned that Herbig-Haro objects are heated gases flowing away from a star. Subsequently, by extrapolating backward in time, other astronomers deduced the the source was "invariably...a star only a few hundred thousand years old" (Ray 2000:45).
Since 1975, a screen for environmental chemicals, devised by Bruce Ames and colleagues, has been in wide use. The test "uses histidine-requiring mutant strains of Samonella typhimurium and measures the frequency of back mutations that no longer require histidine supplements" (Hale and Margham 1991:28).
In 1975, Robert W. McCarley and J. Allan Hobson designed the reciprocal-interaction model of sleep cycle control in which waking occurs at the expense of REM sleep and vice-versa. McCarley recognized that this relation could be described by the equations of Lotka and Volterra.
In 1975, Martin L. Perl, using the Stanford Positron-Electron Ring, discovered traces of an anomolous electron-muon event which he later named the 'tau' lepton, or 'tauon,' a new elementary particle. The tau lepton is identical to the electron except that it is 3500 times heavier and survives less than a trillion of a second.
In 1975, Mitchell Feigenbaum created the theory of universality in the rate of bifurcations.
In 1975, David Blackstock and Mary Beth Bennett determined that air, like water, propagates audible ultrasound in a nonlinear way.
In 1975, Holland, in Adaption in Natural and Artificial Systems, propounded the 'schema' theorem, a genetic algorithm to the effect that any compact population of genes, a schema, that offers above average fitness will grow exponentially in the presence of reproduction, crossover, and mutation.
In 1976, Susumu Tonegawa, with the assistance of Nobumichi Hozumi, proved that about 1,000 pieces of genetic material in the variable portion of the B-cell can be shuffled (or translocated or recombined) in different sequences. This permits the production of antibodies specific for over a billion different antigens, and occurs somatically, i.e., by mutation in the adult organism, not in the germline (Hozumi and Tonegawa 1976; Tonegawa 1976). This model is "a paradigm for the generation of maximum information storage from a minimal apparatus" (Podolsky and Tauber 1997:95).
In 1976, Dawkins, in The Selfish Gene, coined 'meme,' for bits of information which are replicated, like genes, in selected variants.
In 1976, George P. Smith argued that repeated DNA sequences evolved by random 'unequal crossover' between sister chromosomes (Smith 1976:528). [added 02/01/03]
In 1976, Alexander Rich and S. H. Kim and Klug and colleagues, using X-ray diffraction, described the three-dimensional structure of the transfer RNA molecule (Rich and Kim 1978). [added 02/01/03]
In 1976, Harold Eliot Varmus, J. Michael Bishop, Dominique Stellin, and Peter Vogt proved the theory that cancer has a genetic component by demonstrating that proto-oncogenes are normal genes that have been altered in someway, e.g., that the tumor generating properties of the Rous sarcoma virus are due to a protein encoded by the v-src gene (Bishop 1982). [added 02/01/03]
In 1976, Robert Swanson and Boyer founded Genentech on the premise that patents could replace business secrecy, attracting academic scientists who could still publish.

In 1976, Mircea Steriade showed that in non-REM sleep the transmission of information is inhibited, i.e., certain brain cells are at rest, whereas in REM sleep they are reactivated.
In 1976, Julian Jaynes, in The Rise of Consciousness in the Breakdown of the Bicameral Mind, wrote that, before consciousness, the stress of making a decision would instigate an auditory hallucination of a voice which had to be obeyed. After a certain point in history, perhaps the introduction of writing, what had been innate affects interplay with newly conscious emotions: Shame generates guilt, fear produces anxiety, mating sex, anger hatred, etc. The behavioral world supplies by metaphor and analogy the referents for mental events: Problems are 'approached' and must be 'grappled with' and solutions are 'clear,' 'obscure,' etc. We speak of the conscious mind as 'quick' or 'slow,' or somebody as 'strong-' or 'weak-minded' and 'broad-' or 'narrow-minded.'
In 1976, Vera Rubin and colleagues compared the motion of the Milky Way against a frame of reference provided by a spherical shell of distant spiral galaxies and showed that the 'Local Group' is moving through space at 600 kilometers a second, not including the motion of the universal expansion.
In 1976, Kenneth Appel and Wolfgang Haken announced that they had solved the four-color mapping problem by establishing by trial-and-error that there is an unavoidable set of 1,936 graphs of reducible configurations, and then confirming their conclusion by computer.
In 1977, Elso S. Barghoorn excavated fossil bacteria embedded in 3.4 billion year old rock.
In 1977, Gold, in an op-ed piece in the Wall Street Journal, hypothesized that there is much more oil and natural gas than is available near the surface of the Earth and that this 'deep-Earth-gas' is not of biological origin. Three years later in a Scientific American article, his argument begins with the observation that "most of the carbon in meteorites...is in the form of complex hydrocarbons with some chemical similarity to oil tars" and follows with a discussion of the implications of "the escape of methane...along the crustal faults and fissures of the tectonic-plate boundaries" (Gold and Soter 1980:154,157).
In 1977, Jack Corliss, in a diving bell 2600 meters below the surface of the Pacific Ocean, observed boiling, lightless deep-sea thermal vents with hundreds of species, including a nine-foot tube worm, most of them new to science. This led to an entirely alternative proposal for the origin of life (Corliss et al. 1981:59-69).
In 1977, Gilbert induced bacteria to produce the non-bacterial proteins insulin and interferon.
In 1977, groups led by R. J. Roberts and Phillip A. Sharp discovered split genes in adenovirus 2. R-loop mapping by L. Chow and S. Berget showed the position of intron loops. Subsequently, Pierre Champbon described intervening sequences in chicken ovalbumin genes (Roberts et al. 1977; Berget et al. 1977).
In 1977, Ferid Murad discovered that nitric oxide is a vasodilator, and thus controls blood pressure by relaxing the smooth muscle cells in the veins.
In 1977, Alfred G. Gilman and E. M. Ross showed that adenylcyclase is regulated by a protein that binds guanosine triphosphate, or GTP. Guanine nucleotide-binding regulators, or G-proteins, are activated in the presence of GTP. Activated G-proteins dissociate from their receptors and activate effector proteins, such as adenylcyclase, which control the level of 'second messengers.' Second messengers are small molecules or ions generated in response to the binding of a signal molecule to its receptor on the outer surface of the cell membrane.
In 1977, Christiane Nüsslein-Volhard, working with the development of Drosophila eggs, discovered that cell differentiation begins before fertilization at oogenesis with an accumulation of mRNA at what will become the head-end of the egg (Nüsslein-Volhard 1992). Subsequently, it has been learned that about 80 per cent of Drosophila gene products are maternally-derived (Lawrence 1992:7). [revised 02/01/03]
In 1977, Hideki Shirakawa, Alan G. MacDiarmid, and Alan J. Heeger announced that they had modified polyacetylene, by blasting it with iodine vapor, and increased its conductivity by a factor of 10 million. This was accomplished by adding (or subtracting) electrons from the polymer's chain of alternating double and single carbon bonds, in effect, bumping the charge and creating a current.
In 1977, Coleman described the fate of a 'false vacuum' by analogy to the boiling of a superheated fluid, the false vacuum, where bubbles of the vapor phase, the true vacuum, materialize: "Once in a while, a bubble of true vacuum [created by a quantum fluctuation] will form large enough so that it is classically energetically favorable for the bubble to grow. Once this happens, the bubble spreads throughout the universe converting false vacuum to true" (Coleman 1977:2929). A false vacuum is a local state of minimum energy which may tunnel to the true vacuum, or general state of minimum energy. Mathematically, Coleman described the tunneling by a semiclassical bounce solution to Euclidean, i.e., imaginary-time, field equations.
In 1977, James L. Elliott, "monitoring a star's brightness as Uranus passed in front of of it, noticed the

signal blinking on and off [and] inferred that a series of narrow bands, slightly elliptical or inclined, circumscribed the planet" (Burns et al. 2002:66).

In 1977, Benoit B. Mandelbrot published The Fractel Geometry of Nature in which complex curves are reduced to straight lines, or fractels, and undergo invariant scaling. He modified and generalized Zipf's law, demonstrating that fractels and scaling laws are closely related to the chaos of nonlinear dynamics.

In 1977, television signals were transmitted on optical fibers.

In 1978, Mary Leaky announced the discovery of fossilized human footprints from about 3.5 million years ago.

In 1978, Gilbert coined the terms 'intron' and 'exon' in the course of arguing that information for new and potentially useful proteins can be quickly and reversibly assembled from parts, already proven useful, of old proteins. He called this 'exon shuffling.'

In 1978, Edward B. Lewis announced that genes in the 'bithorax complex' in Drosophila are arranged in the same order along the chromosome as the parts of the body they affect and, during development, turn on in anatomical order, beginning at the head and ending at the anus. In a sense, therefore, a fly's body is a map of its genes (E. B. Lewis 1978).

In 1978, D. J. Finnegan, G. M. Rubin, Michael W. Young, and D. S. Hogness made detailed analyses of dispersed, repetitive DNAs in Drosophila, which vastly increased the understanding of mutability, transposition, hybrid dysgenesis, and retroviruses in eukaryotes (Finnegan et al. 1978).

In 1978, Vernon B. Mountcastle described a cortical model in terms of its columns being elementary functional units (Mountcastle 1978).

In 1978, Edelman published a study in which inherently variable neuronal groups constitute the units of of epigenetic selection. Stimuli themselves make the selection, reinforcing or ignoring the connectivity. Thus genetically identical brains will form different connections as they are exposed to different experiences. Redundance is created by the formation of a secondary repertoire of connections which respond to signals similar to those which formed them (Edelman 1978).

In 1978, Tonegawa's group revealed the existence of J sequences in light chains of immunoglobin (Tonegawa et al. 1978), but only later that year was their role in V-J shuffling appreciated by Martin Weigart (Weigert et al.1978a).

In 1978, in a joint article by the groups of Weigart and Hood, the somatic mechanism of 'combinatorial joining,' or association, of any class of heavy chain with molecules from any type of light chain was added to the model of antibody diversity (Weigert et al.1978b).

In 1978, Octavio Pompeiano demonstrated that, during REM sleep, sensory nerve terminals are depolarized by signals from the brain stem, thereby reducing the amount of neurotransmitter reaching them and reducing external information. Moreover, he established that while internal motor commands are generated, inhibitory signals prevent their external activation.

In 1978, Motohiko Yoshimura proposed that X-bosons, very unstable and non-existent on Earth, might have existed during the Universe's first 10-35 second when they would have been the main constituent of matter. This possibility was soon confirmed when it was found that X-bosons could produce an excess of baryons over antibaryons.

In 1978, Lotfi A. Zadeh published an article on PRUF, or Possibilistic Relational Universal Fuzzy, a logical language where variables represent the degree to which a set is a fuzzy set. Near a boundary in a fuzzy set, one cannot be sure which side an element is on.

In 1978, Holland published a computer program utilizing bottom-up, learned control with feedback reinforcement or weakening, as appropriate, of the rules, or 'classifiers.' Relying on this program, 'agents' offer bids for message space in an auction-type market. The classifiers are treated like business firms who had to repay their suppliers, that is, other classifiers, thus transferring some of their reinforcement.

In 1978, Ronald Rivest, Adi Shamir, and Leonard Adelman proposed "a mathematical procedure whereby a message can be encoded using a large (say 250-digit) number as a key.... Any message encoded with it can only be decoded given a knowledge of the factors of that number" (Deutsch 1997:215). This method is known as the 'RSA cryptosystem,' and is a type of 'public-key cryptography.'

In 1978, Eleanor Rosch observed that categories, in general, have best examples which she called 'prototypes,' or better, degrees of prototypicality: e.g., substituting Paris for the fashion world or Wall Street for the business world.

["In the late 1970s, elementary particle physicists began speaking of the 'Standard Model' as the basic theory of matter" (Brown et al. 1997:3). "The two types of interactions that Yukawa set out to explain in terms of intermediary particles, i.e., the strong and the weak, could now be viewed, together with classic electromagnetism, as different manifestations of gauge fields, i.e., the color SU(3) and flavor

SU(2) x U(1), acting on the fundamental fermions, i.e., quarks and leptons" (Nambu 1985:105). Fermions, particles of matter with spin ½, are either leptons, including electrons, muons, and tauons and their neutrino counterparts, or quarks, including up, charm, and top and their charge complements, down, strange, and bottom. Of these, only up and down quarks exist in the ordinary world; the others exist only in high energy events and quickly decay. Leptons and quarks interact by exchanging generalized quanta, particles of spin 1. Bosons are particles involved in the transmission of forces and include 'gluons,' which carry the strong force that binds quarks together. Thus bound together, the quarks form hadrons. The proton and the neutron which combine to make atomic nuclei are hadrons. Bosons also include photons, which carry the weakly interacting electromagnetic force, known in the Standard Model as the electroweak force, and attract electrons to orbit the nuclei. Other weak interactions are carried by the ' W -,' ' W+,' and ' Z' particles. Additional forces are carried by gravitons and Higgs particles, neither of which have ever been observed, but are required by the theory of General Relativity.]
In 1979, Stanley M. Awramik discovered well-preserved multicelled filaments and microstructures in rocks of the Warrawoona Formation, Australia, which were confirmed in 1991 to be 3,400 million years old.
In 1979, Michael Potter, Stuart Rudikoff, and D. Narayana Rao used protein sequencing to predict the presence of heavy chain J regions and their role in the diversity of immunoglobin (Rao et al. 1979).
In 1979, David Marr's Vision was published posthumously. It described the theory of a computational process by which internal representations are thought of as a mapping from one representation to another by way of a 'primal sketch.' The idea underlying the primal sketch is the pre-understanding of the shapes of objects, which in turn depends on the variation in the light intensities.
In 1979, Toshiki Tajima and John M. Dawson proposed the idea of a 'laser wake-field accelerator:'"When an ultraintense pulse of light strikes a plasma, it propels the electrons forward close to the speed of light.... The plasma's positive ions, being thousands of time heavier than the electrons, are left behind. This separation of positive and negative charges produces a large electric field, which can be used to accelerate other particles. The region of high electric field travels through the plasma as a wave, trailing in the wake of the light pulse" (Mourou and Umstadter 2002:830). Their idea has enabled a new generation of tabletop lasers.
In 1979, the spacecraft Voyager 1 photographed Jupiter's rings.
In 1979, Anatol Rapoport, after years of considering the logical conundrum called the 'prisoner's dilemma,' established that the best game theoretical strategy in iterated encounters was the simplest, 'tit-for-tat:' Cooperate in the beginning and then do whatever the other player had done in the previous round.
In 1980, L. Alvarez and Walter Alvarez reported finding in a layer of clay near Gubbio, Italy, a high concentration of 'iridium,' abundant in meteorites, and hypothesized that it is residue from an asteroid of 10 to 14 kilometers diameter. That the clay had been dated to the end of the Cretaceous era, 65 million years ago, led to their further hypothesis that the impact was the cause of the dinosaurs' mass extinction. Later in the same year in Yucatan, Mexico, the crater, more than 180 km across, was recognized.
In 1980, Temin hypothesized that retroviruses originated from retrotransposons.
In 1980, Allan M. Maxam and Gilbert published the 'chemical method' of gene sequencing in which an electric current causes the gene fragments to pass through a gel (i.e., gel electrophoresis) which, when exposed to X-ray film, permits the DNA code to be read (Maxam and Gilbert 1980). [added 02/01/03]
In 1980 [?], Jerome Karle and Herbert Hauptman devised the appropriate constraints mathematically to enable small molecules to be read off an X-ray crystallograph.
In 1980, Jesse Roth and Derek Le Roith and others discovered insulin-like material in single-celled organisms, establishing that the peptide hormone could be produced outside the pancreatic beta cells (LeRoith et al. 1982).
In 1980, Nüsslein-Volhard and Eric F. Wieschaus characterized zygotic segmentation mutations in Drosophila melanoster (Nüsslein-Volhard and Wieschaus 1980).
In 1980, Hood, Phillip Early, Mark Davis, and others uncovered the D segment in the heavy chains of immunoglobin, and thus V-D-J shuffling (Early et al. 1980).
In 1980, Baltimore and Fredrick W. Alt proposed a model in which following the completion of a light chain, no further rearrangement is possible, and therefore any one B-lymphoid clone will make one type of light chain. This eventually obviated the allelic exclusion controversies (Alt et al. 1980).
In 1980, David Botstein, Ray White, Mark Skolnick, and R. Davis showed how 'restriction fragment length polymorphisms' (RFLPs) could be used to find human disease genes.
In 1980, Prigogine, in From Being to Becoming: Time and Complexity in the Physical Sciences,

suggested that oscillations "near bifurcations play a crucial role because there the fluctuation drives the average" (Prigogine 1980:132). "The best understood example of metabolic oscillation is that which occurs in the glycolytic cycle.... The catalytic effects responsible for the oscillations...lead to a phase shift" (Ibid. 122-123).
In 1980, Klaus von Klitzing, G. Dorda, and M. Pepper found that variation of gate voltage in a silicon metal-oxide-semiconductor (MOS) in a strong magnetic field "gave regions in which the current was accurately perpendicular to the electric field, and the entire ratio of current to field [is] constant" (Thouless 1989:232-233). It also conforms to the 'quantum Hall effect;' that is, the current is a multiple of e2/h, where e is the electron charge and h is Planck's constant.
In 1980, Heinrich Rohrer and Gerd Binnig developed 'scanning tunneling microscope,' which brings "a very tiny metal tip within one nanometer [or .001 microns or 4 atoms] of the surface under observation. A small voltage causes electrons to flow from the tip to the surface, creating the tunnel through which feedback to the microscope creates scans of it" (Murphy 2002:3). [revised 02/01/03]
In 1980, Alan Guth proposed an 'inflationary' theory of the early Universe in which, during the first split second of creation and before the standard model of the big-bang, the Universe expanded exponentially, i.e., 'supercooled,' and then, in a phase change, went to a less energetic state. In this phase change, huge numbers of pairs of particles and very heavy monopoles were created and re-heated in the big-bang (Guth 1981:347-356). The hypothesis obviates the problems of the Universe's homogeneity and its flatness: "The ultra-rapid expansion stretches out any primordial 'wrinkles' in the the curvature of spacetime, rendering the Universe almost smooth and isotropic [or similar in all directions] on the scale we can observe" (Dictionary of Astronomy 1997:234).
In 1980, the Multi-Element Radio-Linked Interferometer Network, or MERLIN, came into operation. It consists of seven radio telescopes distributed across England whose data are gathered at Jodrell Bank. Its maximum baseline is 217 km. In the same year, a Very Large Array, or VLA, aperture-synthesis telescope was constructed in Socorro, NM. It consists of 27 movable dishes mounted on a railway with a maximum baseline of 36 km.
In the early 1980s, Peter E. Wheeler argued that, with the shift to bipedalism, whole body cooling (retaining only head hair and developing sweat glands) released a physiological constraint on brain size in Homo.
In the early 1980s, Hendric Mario Geysen, seeking to devise a vaccine containing the peptides which form the antigenic regions, or epitopes, of viral strains, used mixtures of amino acids to identify the peptides which mimicked the epitopes. He coined the term 'mimotope' for such compounds, the production of which is known as 'combinatorial chemistry.'
In the early 1980s, Marvin Carruthers devised a way to synthesize strands of DNA of any desired base sequence.
In 1981, Thomas R. Cech, working with Tetrahymena, discovered a catalytic RNA molecules with the sophisticated reactivity previously known only in proteins: It could catalyze the cutting and splicing that leads to removal of part of its own length. An implication is that if RNA can catalyse as well as carry information, it may have evolutionarily preceded protein and DNA (Cech 1986).
In 1981, Stanley B. Prusiner isolated the infectious protein which causes scrapie in sheep and goats and spongiform encephopathies or Creutzfeldt-Jakob disease in people. Both are transmissible and heritable degenerative diseases of the nervous system, presumably occasioned by misfolded proteins which catalyze other proteins to a similar misfolded state. Prusiner called this particle a 'prion' and, noting its small size, determined that it had not a single gene (Prusiner 1982).
In 1981, Derek Bickerton published Roots of Language in which he argued that, in Hawaii, "the first creole generation produced rules for which there was no evidence in the previous generation's speech" (Bickerton 1981:60). The implication of this is that the children made up these rules out of their genetic endowment.
In 1981, David Atkatz and Heinz Pagels explored a model of cosmogenesis in which "the Universe originated as a tunneling event from a classically stable, static spacetime configuration." The tunneling leads to a "fireball state,...analogous to a single radioactive decay, on a huge scale," and particle creation, which ceases as the expansion continues and the post-big-bang scenario begins (Atkatz and Pagels 1982:2065).
In 1981, Andrei Linde modified Guth's inflationary Universe scenario by examination of the symmetry-breaking phase transitions in the Coleman-Weinberg model and suggesting the potential energy of a 'scalar field' as the mechanism which generated the inflation (Linde 1982:392; Linde 1994:34). The following year, Andreas Albrecht and Paul J. Steinhardt published, independently, a similar model.
In 1981, James Lovelock built a computerized simulation, Daisyworld, in which the biological and physical worlds are tightly coupled such that the biota ensures optimal physical conditions for itself. Using only conventional evolutionary rules and by increasing solar radiation a few degrees, a pattern

of equilibrium is punctuated by a rapid proliferation of species.
In 1981, Robert Axelrod and Stephanie Forrest confirmed in a computer simulation via the genetic algorithm that a population of coevolving individuals could discover the tit-for-tat strategy which would spread quickly through the community.
In 1981, programmers at Microsoft Corporation developed a computer disk operating system, MS-DOS.
In 1982, Alt and Baltimore proposed that terminal deoxynucleotidyl transferase, or TdT, could insert the N region, as they chose to call the unencoded, inserted nucleotides, at immunoglobin junction sites (Alt and Baltimore 1982).
In 1982, J. Edwin Blalock discovered interaction between the endocrine and immune systems in which the immune system produces the opoid peptide endorphin and adrenocorticotropic hormone (ANTH). These in turn modulate the behavior of the major types of immune cell.
In 1982, Leder calculated the potential combinatorial antibody diversification at 18 billion according to the formula sm(f1[VxJ]xf2[VxDxJ]), with VxJ and VxDxJ representing the combinatorial diversification achieved by the light and heavy gene segments, f1 representing the factor of light chain flexible joining, f2 representing the combined factors of heavy chain flexible joining and N insertion, and sm representing the factor of somatic point mutation (Leder 1982:111).
In 1982, Gabriel Dover defined 'molecular drive' as the "fixation of variants in a population as a consequence of stochastic and directional processes of family turnover [which] is different [from natural selection and genetic drift] in that it is an outcome of a variety of sequence exchanges [unequal exchange during meiosis leading to duplication or deletion, gene conversion, and DNA transposition] within and between chromosomes that give rise to persistent non-mendelian patterns of inheritance" (Dover 1982:111). [added 02/01/03]
In 1982, Samuelsson discovered 'leukotrienes,' compounds found in white blood cells which are involved in asthma and in the anaphylatic shock that may follow exposure to foreign substances, like bee stings (Samuelsson 1983). [added 02/01/03]
In 1982, Kandel and James H. Schwartz established that long-term facilitation, that is, the consolidation of short-term memory into long-term, requires cyclic AMP-responsive element-binding (CREB) genes (Kandel and Schwartz 1982).
In 1982, the Food and Drug Administration (FDA) approved the first recombinant pharmaceutical, insulin.
In 1982, Alain Aspect, Jean Dalibard, and Gérard Roger described an experiment which established that what Einstein called 'spooky action at a distance' does exist. This is not the common sense view which was proffered by him, Podolsky, and Rosen in their 1935 paper. Twenty years later, J. Bell showed how "Bohm's variation on the E-P-R theme might, in principle, form the basis of a real experiment" (Gribbin 2000:22). Using using two lasers focused on an atomic beam to provoke the atoms to disgorge two photons simultaneously, the experimenters were able to measure statistically the likelihood that the two photons would be able to vary their randomly-induced polarizations simultaneously and came to the conclusion that they did correlate: i.e., in causally disconnected regions, there was faster than light interaction. In this way they proved that Bell's inequality was broken (Davies and Brown 1986; Aspect et al. 1982).
In 1982, Alexander Vilenkin, going Tryon one better, suggested a cosmological model in which "the Universe is spontaneously created from literally nothing,...does not have a singularity at the big-bang, and does not require any initial or boundary conditions" (Vilenkin 1982:26,27-28). He goes on to show how this is mathematically equivalent to electron/positron pair creation/annihilation.
In 1982, John Hopfield proposed a simple computer network which operated along Hebbian lines. Each of its units could have only two outputs, inhibition or excitation, but numerous inputs. Moreover, it faintly resembled human memory since any appreciable part of the input pattern acted as an address.
In 1982, Richard Rorty distinguished between 'truth,' as a property "of sentences or actions and situations," and 'Truth,' as "goals or standards..., objects of ultimate concern" (Rorty 1982:xiv).
In 1983, A. Roche-Lecours indicated that humans are probably born with two language areas, but the left area is innately able to soon dominate.
In 1983, Arthur L. Koch published his surface stress theory of microbial morphogenesis.
In 1983, Sidney Altman discovered an enzyme, ribonuclease P, which is intertwined with RNA, and that the RNA alone could weakly catalyse (Guerrier-Takada et al. 1983).
In 1983, Luc Montagnier, François Barre, and Jean-Claude Chermann isolated human immunodeficiency virus, or HIV, from acquired immune deficiency syndrome, or AIDS, patients.
In 1983, Arthur T. Winfree published predictions on inducing and halting heart fibrillation based on non-linear dynamics and topology.

In 1983, Carlo Rubbia and Simon van der Meer, using the CERN particle accelerator, confirmed the existence of the Z and Ws particles.
In 1983, Reinhard Mundt and Josef Fried made the first astronomical observations with a 'charge-coupled device,' a semiconductor offering greater sensitivity and contrast than traditional photographic plates. What they observed were jets from young stars, verifying the extrapolation from Schwartz' reckoning.
In 1983, David Goldberg built a genetic algorithm, classifier system computer program which learned to simulate central control of a gas pipeline, and from which a default hierarchy emerged, i.e., whenever the strong 'leak' message appeared, the default, or weak 'no leak,' disappeared.
In 1983, William Brian Arthur and others published a description of increasing-returns, or positive feedback, that is, "how chance events work to select one equilibrium point from many possible in random processes [permitting economists to] see mathematically how different sets of historical accidents could cause radically different outcomes to emerge" (Arthur, quoted in Waldrop 1992:46).
In 1984, Richard Leaky and Alan Walker excavated a Homo erectus skeleton, dated 1.6 million years ago.
In 1984, Jeremy Thorner and colleagues, using yeast cells, discovered the prototype prohormone processing enzyme, Kex2 endopeptidase (Julius et al. 1984:1075-1089). Closely related enzymes were later found to be responsible for processing the precursors of all peptide hormones and neuropeptides in mammalian cells.
In 1984, W. McGinnis and W. J. Gehring and colleagues demonstrated that the homeobox gene sequence in Drosophila also exists in the mouse (McGinnis et al. 1984). This close similarity suggests an essential role in animal development.
In 1984, Yasutomi Nishizuka, having earlier discovered protein kinase C, published a paper in which he showed that it not only had a role in signal transduction but that its uncontrolled production--under the influence of phorbol esters--led to the production of tumors (Nishizuka 1984).
In 1984, George C. Glenner discovered that a principal component of the plaque in the brains of Alzheimers patients was a peptide, now termed beta-amyloid peptide.
In 1984, Jeffrey C. Hall, Michael Rosbash, and, independently, M. Young identified and cloned period, the gene controlling a fruit fly's biological clock (Zehring et al. 1984; Bargiello et al. 1984).
In 1984, Francis O. Schmitt coined the term 'information substances' to include not only neurotransmitters and steroid hormones but peptide hormones, neuropeptides, and growth factors and their receptors.
In 1984, Alec John Jeffreys discovered 'genetic fingerprinting,' the pattern of nonfunctional repetitions unigue to each individual's DNA.
In 1984, Stephen Wolfram, pointing out that cellular automata are similar to non-linear dynamics, contended that all cellular automata fell in one of four 'universality classes.' The first two classes are either static or orderly, the third is chaotic, and the fourth is complex, like Conway's Game of Life (Wolfram 1984).
In 1985, Kary Banks Mullis and co-workers invented the polymerase chain reaction (PCR) which multiplies DNA sequences in vitro, replacing the cumbersome process of bacterial cloning and making it possible to clone specific DNA sequences rapidly without the need of a living cell (Mullis et al. 1986).
In 1985, Kandel, in Principles of Neural Science, recognized that psychotherapy, that is, the repetition of a 'new' story, changes and reinforces the functional connections between neurons: "Insofar as social intervention, such as psychotherapy or counseling, works, it must work by acting on the brain, and quite lightly on the connections between nerve cells (Kandel 1985:831).
In 1985, Richard E. Smalley, Robert Curl, and Harold W. Kroto, in the course of laboratory experiments designed to mimic carbon clusters, or stardust, discovered 'fullerenes,' or 'buckminsterfullerenes' or 'buckyballs,' molecules of 60 carbon atoms by firing an intense pulse of laser light at a carbon surface in the presence of helium and then cooling the gaseous carbon to near absolute zero.
In 1985, Binning invented the 'atomic force microscope,' which uses "a tip of one atom [of diamond] to read the surface of a material by traveling over it like a needle on a record. It can probe for, image or move individual atoms" (Murphy 2002:3). It works on both conductive and non-conductive surfaces which means it is suitable for use in biotechnology.
In 1985, Edwin D. Loh and Earl D. Spillar, using redshift measurements, reported that a galaxy study showed the density parameter W = 0.9 ± 0.3 with a 95% confidence, i.e., barely closed (Loh and Spillar 1986:L4).
In 1985, Christopher G. Langton deduced the critical lambda (l) value at the exact edge of chaos, and reasoned that Wolfram's cellular automata Class IV, complexity, the phase transition between solid

and fluid, and Turing's 'undecidability theorem' are all analogous.

Later in 1985, Stuart A. Kauffman, Norman H. Packard, and J. Doyne Farmer built a computer simulation in which simple polymers could "catalyze the formation of each other, generating autocatalytic sets that evolve in time to create complex chemical species whose properties are tuned for effective collaboration with each other. The system thus bootstraps itself from a simple initial state to a sophisticated autocatalytic set, which might be regarded as a precurser life form" (Farmer et als 1985:51). This is based on Kauffman's earlier searches for the origin of order, in which he used an iterating, parallel-processing model of random, self-organizing Boolean networks: Small changes in initial conditions unleashed bifurcating avalanches of changes from which appear the 'attractors' of chaos theory. Boolean networks are sufficiently similar to cellular automata to permit their assimilation.

In 1986, Dean Falk published data supporting the co-evolution in hominids of brain size and emissary foramina, small holes in the skull which contain blood veins.

In 1986, Howard Cooke hypothesized that the general erosion of telomeric DNA forecasts senescence in humans (Cooke and Smith 1986).

In 1986, the rival clock labs of Young and J. C. Hall and Rosbash determined the complete sequence of letters in the period gene's code. This means that mutant behavior can be isolated to a single letter; e.g., "at nucleotide 1390, counting from the start of the coding sequence, [if] the letter C is changed to a T, [this] transforms the three-letter word CAG (which means 'glutamate') into the three-letter word TAG (which means 'stop')" (Weiner 1999:173). Thus the manufacture of period's RNA ceases at this point (F. Jackson et al.1986; Reddy et al. 1986).

In 1986, Colin Masters proposed that Alzheimer's disease is caused by oxidative stress.

In 1986, Hood's lab introduced an automated DNA fluorescence sequencer (L. M. Smith et al. 1986).

In 1986, Per Bak, Chao Tang, and Kurt Weisenfeld, in the course of studying charge-density waves, discovered that self-organized criticality manifests itself like a pile of sand on a plate which is added to in a steady drizzle: Variously sized avalanches spill from the plate according to its power-law, i.e., the average frequency of a given size of avalanche is inversely proportional to some power of its size, e.g., 22 or 24.

In 1986, Johannes Georg Bednorz and Karl Alexander Müller found a new class of layered materials which semiconduct at much higher temperatures than any which had been found previously. In a pure state these materials insulate; with impurities they conduct.

In 1986, David Rumelhart, James McClelland, and others, in their book Parallel Distributed Processing, produced the algorithm known as 'the backpropagation of errors,' in which the error is graded, not binary, that is, it differentiates into a non-linear curve, and the network, as a whole, is always adjusted to reduce its errors.

In 1987, Rebecca L. Cann, Mark Stoneking, and Allan C. Wilson erected a genealogical tree which suggested that all human mitochondrial DNA can be traced back to a common African maternal ancestor (Cann et al. 1987).

In 1987, Nüsslein-Volhard and others show that a small group of maternal effect genes determine the polarized pattern in Drosophila embryo development (Nüsslein-Volhard et al. 1987).

In 1987, Hood's lab introduced an automated DNA synthesizer.

In 1987, Hans Reichenbach and Gerhard Hofle separated out of the Sorangian cellulosum strain of myxobacteria, which they had isolated two years earlier, a cell-killing chemical which they named 'epothilone.'

In 1987, James van House and Arthur Rich invented the positron microscope.

In 1987, Ahmed H. Zewail and colleagues, using lasers capable of pulsing in femtoseconds, observed the dissociation of cyanogen iodine (ICN).

In 1987, a supernova, SN 1987A, exploded in the Large Magellanic Cloud. It was "the nearest supernova to have been observed since the invention of the astronomical telescope...and involved the explosion of a star with about seventeen to eighteen solar masses about 160,000 light years away" (Gribbin and Gribbin 2000:176). The collapsing core produced about 1058 neutrinos, which translates into "100 billion neutrinos [passing] through every square centimeter of the surface of the Earth in the space of about ten seconds" (Ibid.:177).

In 1987, George Lakoff, in Women, Fire, and Dangerous Things, made a case for embodiment as the basis for meaning and mind: "Truth is very much a bootstrapping operation, grounded in direct links to preconceptually and distinctly structured [personal, physical] experience and the concepts that accord with such experience" (Lakoff 1987:297); that is, image schemas are metaphorically mapped on to the corresponding abstract configuration, e.g., categories are understood in terms of container schemas, hierarchical structure is understood in terms of part-whole and up-down schemas, relational structure is understood in terms of link schemas, radial structure in terms of center-peripheral schemas,

foreground-background structure in terms of front-back scemas, and linear quantity scales in terms of up-down and linear order scemas. Mark Johnson, who, in the same year, published The Body in the Mind, made a similar case.
In 1988, W. A. Devane discovered a cannabinoid receptor, CB1, which is the most abundant member of the brain's G-protein-coupled family and even approaches the glutamate receptor in quantity (Devane et al. 1988).
In 1988, Etienne Baulieu developed the RU-486 abortion pill. [added 02/01/03]
In 1988, Antonio Coutinho and Francisco Varela, in an early offspring of Jerne's network theory, pointed out that "the only valid sense of immunological self is the one defined by the dynamics of the network itself. What does not enter into its cognitive domain is ignored (i.e., [nonself] is nonsense)" (Varela et al. 1988:365). [added 02/01/03]
In 1988, Corey isolated and synthesized the active substance in an extract from the ginkgo tree, ginkgolid B, which interferes with platelet activating factor.
In 1988, Alfred Shapere and Wilczek, while studying the gauge theory of locomotion, concluded that, in viscous fluids, micro-organisms swim using "wave-like motions symmetric about the axis of propulsion. The waves propagate from front to rear, achieving maximum amplitude near the middle" (Shapere and Wilczek 1989:575).
In 1988, Packard published "Adaption to the Edge of Chaos," and Kauffman, acknowledging that at the border between order and chaos lies complexity, i.e., life and its constraints, added selection to his computer model. Life without selection, describable in Kauffman's model, provides a 'null hypothesis,' or a baseline, which can "be used to detect the perturbing effects of selection or other 'agents' of evolutionary change" (Burian and Richardson 1991:269).
In 1989, John L. Hall, Z. Ramanis, and David J. L. Luck published their discovery of centriole-kinetosome DNA, which travels in mitosis, packaged as its own 'motility' chromosome.
In 1989, Folkman proposed the theory that tumors contain both stimulators and inhibitors of angiogenesis to explain tumor metastases after the tumor is removed (Folkman 1990).
In 1989, Penrose, in The Emperor's New Mind, denied that "the outward manifestations of conscious mental activity [can] be simulated by calculation." He went on to speculate that the conscious brain may be achieving "its nonalgorithmic effects" in the mathematical gap between physics and quantum theory (Penrose 1990:705).
In 1989, Pauling and Matthias Rath, on the theory that 'lipoprotein a,' or Lp(a), is necessary for the repair of over-stressed blood vessels, hypothesized that the higher the blood concentration (by supplementation) of the amino acid lysine the more likely it is that Lp(a) molecules will bind with this lysine, rather than the lysine which has already been attached to the Lp(a) lubricating the blood vessel walls.
In 1989, John Byl devised a self-reproducing automata so small, twelve cells in six states with fifty-seven transition rules, that it undermines "von Neumann's 'complexity threshold' separating trivial from non-trivial self-replication" (Sigmund 1993:24).
In 1989, Richard Palmer and Arthur built a computer simulation of the stock market in which agents taught themselves a sort of primitive technical analysis which led to bubbles and crashes.
In 1989, Holland built the ECHO artificial life simulation, a complex adaptive system, which provided "a distinction between phenotype and genotype, so that the fitness of a genotype depends on interactions of the phenotype with other agents and the local environment," complete exogamy, and analogs of "sophisticated ecological processes, such as biological arms races and speciation" (Holland 1995:48-49).
In 1989, Charles Bennett and Gilles Brassard built a quantum computer in which "messages are encoded in the states of individual photons emitted by a laser." This computer consisted of a pair of quantum cryptographic devices which are by their nature secure: "If one makes any measurement [i.e., eavesdrops] on a quantum system, one alters its subsequent interference properties" (Deutsch 1997:218).
In 1990, Steven Pinker and Paul Bloom maintained that languages, including all linguistic universals, are naturally selected biological adaptions by Homo sapiens to communicate information, not a side effect of other evolutionary forces, the position held by Chomsky (Chomsky 1972:97), Gould, and others. Pinker and Bloom based their claim on the facts that "language show signs of complex design for the communication of propositional structures, and the only explanation for the origin of organs with complex design [e.g., the eye] is the process of natural selection" (Pinker and Bloom 1990:726).
In 1990, W. French Anderson performed the first gene transplant on a human being, injecting engineered genes into a four-year-old to repair her faulty immune system.
In 1990, J. Milicki, K. Schughart, and W. McGinnis introduced a mouse gene into a Drosophila embryo, establishing that, in animals that have been evolving independently for hundreds of millions

of years, genes will generate products that function interchangeably.
In 1990, teams led by Robin Lovell-Badge and Robin Goodfellow isolated the testis-determining factor gene, the master switch for mammalian sex determination. This they named SRY, for sex-determining region, Y chromosome. When introduced into newly fertized mouse eggs, it caused genetic females to develop into males.
In 1990, Howard Hall demonstrated that conscious intervention, e.g., guided imagery and biofeedback, could increase the stickiness of white blood cells.
In 1990, Andrew Simon Bell, David Brown, and Nicholas Kenneth Terrett patented 'sildenafil citrate,' a pyrazolopyrimidinone antianginal which dilated blood vessels, increasing the flow of blood and, incidently, under the name 'Viagra,' proving to be a useful treatment for erectile impotence.
In 1990, Jan Sapp, in Where the Truth Lies: Franz Moewus and the Origins of Molecular Biology, reflects on partisan representations of scientific roots, bias in gathering and interpreting data, the social negotiation of standards, especially for new paradigms,the technique problem in the replication of experiments, and the 'experimentalist-statistician paradox,' where data can be good to be true.' Far from being purely deductive, it is scientists' "anticipation of results that informs them of what experiments to perform...and what data to report.... 'The scientific paper' is...rhetoric" (Sapp 1990:116), and the science student's "version of 'truth' is closely associated with getting an 'A'" (Sapp 1990:306). The scientist decontextualizes knowledge, and the historian recontextualizes it (Sapp 1990:301).
In 1990, the United States National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA) launched the Hubble Space Telescope, or HST. Servicing missions were carried out in 1993, 1997, and 2002. [revised 8/19/02]
In 1990, Tim Berners-Lee and CERN, The European Organization for Nuclear Research, implemented a hypertext system for information access for physicists.
In 1990, Walter Fontana built a computer simulation which he called algorithmic chemistry, or 'alchemy.' In it he exploited the fact that computer code is both a program and a data string: Program A reads program B as input data and interpretes it as program C. From the random interaction of a vast accumulation of these program strings emerges a variety of catalytic responses.
In 1990, Stephen Muggleton published software, Inductive Logic Programming (ILP), which permits a computer to be fed knowledge and then assimilate that knowledge into a theory, look for further implications that arise from that theory, and come up with ideas that are different from the initial input.
Beginning in 1990, Fred Wendorf and colleagues uncovered on the Nabta Playa, Egypt, the earliest-known megalithic astronomical calendar site.
In 1991, D. R. Knighton and colleagues determined the three-dimensional structure of the catalytic core of protein kinase.
In 1991, J. C. Hall, Charalambos P. Kyriacou, Rosbash, and colleagues cloned the period gene of Drosophila simulans, injected it into the egg of a Drosophila melanogaster, with the result that the rhythmic 'song' behavior of simulans was performed by melanogaster.
In 1991, John R. Lawrence, Douglas E. Campbell, and J. William Costerton, studying the structure of biofilms by laser scanning confocal microscopy, demonstrated that bacteria grow in tiny enclaves.
In 1991, Sumio Iijima observed nanoscopic threads, now known as 'nanotubes.' These are hollow cylinders made of pure carbon lattices, as regular and symmetric as crystals, and reminiscent of buckyballs.
In 1992, Gold, extending his deep-Earth-gas theory, hypothesized that early life began in the rocks of the 'deep, hot biosphere,' kilometers below the Earth's surface. "This life is not dependent on solar energy and photosynthesis for its primary energy supply, [which comes instead] from chemical sources, due to fluids that migrate upward from deeper levels in the Earth" (Gold 1992:6045). Presumably some of this anerobic bacteria migrated still farther upward into the sunlight and evolved into more complex life-forms.
In 1992, Robin I. M. Dunbar said the neocortex volume and group size among primates suggest that "the number of neocortical neurons limits the organism's information-processing capacity and that this then limits the number of relationships that an individual can monitor simultaneously.... Thus [it] appears...large groups are created by welding together sets of smaller grooming cliques" (Dunbar 1992:469).
In 1992, a team led by Raphael Mechoulam and Devane discovered the first endogenous cannabinoid neurotransmitter, anandamide, an arachidonic acid derivative (Devane et al. 1992).
In 1992, Robert D'Amato deduced that the mechanism by which thalidomide operates is angiogenic inhibition, the inhibition of the generation of blood vessels.
IIn 1992, Irun R. Cohen said that the "aim of the immune system is not to distinquish self and nonself.... It is to enhance fitness" (Cohen 1992:442). [added 02/01/03]

In 1992, the United States' COBE, or 'Cosmic Background Explorer,' astronomical satellite detected very small variations, or ripples or lumps, in the background cosmic radiation which are thought to be imprints of quantum fluctuations from the early Universe, or, in other words, the seeds of later giant structures. This radiation was much stronger than anticipated.
In 1992, CERN released to the public their hypertext for physicists, naming it the World Wide Web.
In 1993, J. William Schopf announced the discovery of fossilized bacteria in 3.5 billion-year-old rocks from Western Australia.
In 1993, Ephriam J. Fuchs suggested that "injury by pathogen (rather than self-nonself discrimination) would serve as a plausible fulcrum for molding immune responses within an evolutionary context" (Podolsky and Tauber 1997:365; Fuchs 1993). [added 02/01/03]
In 1993, Allen D. Roses and Warren J. Stritmatter isolated apolipoprotein E, or APOE, which transports cholesterol in the bloodstream and is involved in cellular repair and regeneration.
In 1993, Dean H. Hamer and colleagues produced evidence employing polymerase chain reaction that male homosexuality is preferentially transmitted through the maternal side and is genetically linked to chromosomal region Xq28, which is thought to contain several hundred genes.
In 1993, C. Robert Dell and collaborators, using the Hubble space telescope, saw swirling disks of gas and dust, such as Laplace had predicted, within the constellation Orion.
In 1993, the United States National Science Foundation's (NSF's) Very Long Baseline Array, or VLBA, of interferometers, i.e., a VLBI, was completed. It consists of ten telescopes spread across the United States with a maximum baseline of 8000 km and is operated by the National Radio Astronomy Observatory, or NRAO.
In 1993, Marc Andreeson and others developed a graphical user interface for the World Wide Web, called 'Mosaic X.'
In 1994, W. C. Orr and R. S. Sohal constructed transgenic lines of Drosophila having extra copies of the genes for the antioxident enzymes catalase and super oxide dismutase, which slowed the aging process.
In 1994, Polly Matzinger, following Fuchs' lead, hypothesized that what the immune system recognizes is danger to the organism, rather than making a distinction between the self and nonself. In her reanalysis, she found that antigen presenting cells (APCs), such as dendritic cells, make the distinction between dangerous and harmless. With the benefit of an alarm signal, APCs are able to deliver the second signal in the two signal model to T-cells. B-cells receive the second signal from activated helper T-cells (Matzinger 1994).
In 1994, Jerry Yin cloned a Drosophila gene which makes cyclic-AMP responsive element-binding (CREB) protein. This protein is a toggle swithch, activating or deactivating memory genes (Yin et al. 1994). Yin, Tim Tully, Quinn and a few colleagues proved this by injecting Drosophila with a second CREB gene, switching it on, and testing the flies' long-term memory, which was now extraordinary (Yin et al. 1995).
In 1994, Arturo Alvarez-Buylla, Chang-Ying Ling, Wen Shan Yu, and, independently, Anat Barnea and Fernando Nottebohm established the neurogenesis, including both new neurons and the replacement of old ones, occurs in adult song birds (Alvarez-Buylla et al. 1994:233-248; Barnea and Nottebohm 1994:11217-11221).
In 1994, Gerard Foschini proposed modifying Shannon's information theory so that, instead of points, spatial volumes could be linked by means of multiplying transmitters and receivers. A set of high-speed processors "look at the signals from all the receiver antennas simultaneously, [extracting] the strongest signal from the jumble, then [working] through the weaker signals one by one" (Mullins 2000:36).
In 1994, Peter Shor discovered a quantum computer algorithm for factoring large numbers, implicitly rendering RSA cryptosystems vulnerable someday.
In 1995, J. Craig Ventner and many colleagues published the first complete nucleotide sequence of a free-living organism, Haemophilus influenzae.
In 1995, R. Sherrington, Peter H. St. George-Hyslop, and Gerald D. Shellenberg and many colleagues isolated and characterized two genes responsible for early-onset, familial Alzheimer's disease.
In 1995, Staffan Kjellerberg and Peter Steinberg established that Delisea pulchra, a red algae, "uses chemicals called 'substituted furanones' to keep free of [bacterial] biofilms.... Apparently, the substituted furanones bind to bacterial cells at the sites normally used by other signals" thus blocking them (Costerton and Stewart 2001:81).
In 1995, Eric A. Cornell and Carl E. Wieman created the first gaseous Bose-Einstein condensates, using laser cooling and a 'time-averaging orbiting potential magnetic trap,' or TOP trap, inside a vacuum chamber. Later that year, Wolfgang Ketterle and colleagues achieved a Bose-Einstein

condensate of much higher densities by 'plugging' the magnetic field hole with a laser. The laser's photons pushed the escaping atoms back into the trap (Davis et al. 1995).
In 1995, Michel Mayor and Didier Queloz detected the first extra-solar planet using the 'wobble technique:' Inferring the orbit and minimum mass of a planet by periodic Doppler shifts as a star is pulled by the force of a planet's gravity. The planet circles the star 51 Pegasi in the constellation Pegasus.
In 1996, Folkman found angiostatin, a molecule that inhibits angiogenesis more powerfully than thalidomide.
In 1996, Matzinger, Fuchs, and J. P. Ridge, by increasing the ratio of dendritic cells to B-cells, were able to show experimentally that neonatal mice would respond to foreign antigen (Ridge et al. 1996). This disproved Medawar's theory that immunological tolerance existed at birth. [added 02/01/03]
In 1996, Leland H. Hartwell led a team from the Seattle Project in deciphering the genome of Saccharomyces cerevisiae, or baker's yeast. This was the first organism with a nucleus to have its genome deciphered. 38 percent of yeast proteins are similar to known mammalian proteins.
In 1996, Michael Rowan-Robinson and colleagues, using the ESA's Infrared Space Observatory, or ISO, found excess infrared radiation and suggested that light from newly forming stars, perhaps at their stage of heavy metal production, is being absorbed by dust particles and re-emitted as infrared radiation.
In 1997, Joseph Kirschvink presented evidence that the Earth's axis of rotation moved 90 degrees to what had formerly been the equator. This it did in a geologically brief amount of time at the beginning of the Cambrian era.
In 1997, Ian Wilmut and Keith Campbell cloned a sheep, 'Dolly,' from adult cells.
In 1997, the Fermi National Accelerator Laboratory, or Fermilab, conducted an experiment which provided the first direct evidence of the existence of the 'tau neutrino.'
In 1997, Tian Yu Cao, in Conceptual Developments of 20th Century Field Theories, in claiming that "metaphysical assumptions are indispensible for physics," asserted that, with the replacement of the Aristotelian telos, all developments "can be regarded as being driven by searching for a model, mechanical or otherwise, for describing forces, understood as causal agents.... The assumption [by the historically emergent hypothico-deductive method] of some ultimate ontology in a theory provides the basis for reducing some set of entities to another simpler set, thus endowing the theory with a unifying power" (Cao 1997:xvii-xviii). The question of the "concrete mechanism for transmitting force...is so central to the subsequent development of physics that it actually defines the internal logic of the development" (Ibid.:8).
In 1998, Robert Waterston and John E.Sulston and numerous colleagues reported the mapping of the entire genome of Caenorhabditis elegans. About 33 percent of this worm's proteins are similar to those found in mammals.
In 1998, Shellenberg identified a mutation in the tau gene by looking at patients with frontotemporal dementia characterized by a buildup of tau.
In 1998, vascular endothelial growth factor genes were therapeutically inserted in a human heart and formed new blood vessels.
In 1998, Richard S. Stephens and colleagues mapped the 900 genes in the genome of Chlamydia trachomatis.
In 1998, James Thomson isolated human embryonic stem cells. Shortly thereafter and independently, Ariff Bongso also isolated human embryonic stem cells.
In 1998, Andrea G. Bodnar and colleaques confirmed Cooke's hypothesis that the erosion of telomeres forecasts senescence (Bodnar et al. 1998). [revised 02/01/03]
In 1998, Alan Sokal and Jean Bricmont distinguished between "knowledge (understood, roughly, as justified true belief) and mere belief," and added that, if one does not "take into account empirical aspects, then scientific discourse indeed becomes nothing more than a 'myth' or 'narration'" (Sokal and Bricmont 1998:195,197).
In 1999, Jochen J. Brocks and colleagues published their discovery of fossil molecular lipids which push back the horizon for eukaryotes to around 2.5 billion years ago.
In 1999, Paul A. Moore and numerous colleagues discovered and characterized B-Lymphocyte Stimulator (BLyS), a monocyte-produced growth factor molecule which causes B-cells to produce antibodies.
In 1999, Ian Dunham and 129 colleagues from the Human Genome Project announced the sequencing of the euchromatic part of human chromosome 22.
In 1999, Angelo Vescovi showed that mouse brain stem cells could produce blood cells.
In 1999, Jean-Loup Puget and Guilaine Lagache, analyzing data from the ISO photometers, concluded that the lumps in the infrared background are coming from ultraluminous primordial

galaxies. ISO's 60-centimeter telescope has a resolving power 25 times that of COBE's best effort.

In 1999, Wendy Freeman announced the results of HST's refinement of the Hubble constant: The Universe is expanding at a rate of 21 kilometers per second per million light-years which translates to an age of the Universe of approximately 12 billion years. A few weeks later, radio astronomers Jim Herrnstein, James Moran, Lincoln Greenhill, and colleagues, using the NSF's VLBA, measured a distance of 23.5 million light-years to a galaxy called NGC 4258 and found a different revised value for the Hubble constant which translates to an age of 10.2 billion years.

In 2000, teams led by Martin Schwab and Stephen Strittmatter published their identificaton of a gene, dubbed nogo, which codes for a protein, found in the protective sheaths of nerve cells, that blocks the regrowth of nerve cells in the brain and spine.

In 2000, Ventner led a team which sequenced Drosophila melanogaster's genome. 60 percent of known human disease genes have equivalents in this fruit fly, including p53, the so-called tumor suppressor gene which when mutated permits rampant cell division. About 50 percent of fly proteins are similar to mammalian proteins.

In 2000, Hervé Tettelin, Ventner, and numerous colleagues sequenced the genome of Neisseria meningitidic Serogoup B strain MC58, a bacterial agent which causes meningitis and septicemia, especially in infants.

In 2000, groups from the Human Genome Project under the leadership of André Rosenthal and Yoshiyuki Sakaki mapped the sequence of human chromosome 21, the smallest chromosome. A duplicate of this chromosome or additional genes from it produces Down syndrome.

In 2000, Thomas A. Steitz, Nenad Ban, Poul Nissen, and colleagues resolved the atomic structure of the large subunit of a ribosome of a bacteria, Haloarcula marismortui, using X-ray crystallography. As proteins "are largely absent from the regions of the subunit that are of primary functional significance to protein syntheses" (Ban et al. 2000:905), the view that RNA preceded proteins at the origin of life is supported.

In 2000, Sakaki and colleagues sequenced the bacterium Buchnera's single chromosome and established its symbiosis with its host, Aphid cells: Of Buchnera's 583 genes, 54 code for enzymes dedicated to making the Aphid's essential amino acids. In return, since Buchnera lacks most of the genes essential to the construction of its cell membrane, the Aphid cells provide them (Shigenobu et al. 2000:81-86).

In 2000, Karl Gebhardt, John Kormendy, Douglas Richstone, and, independently, Laura Ferrarese and David Merritt determined that the mass of a black hole correlates with the average velocity of the stars within its ellipsoidal host. This supports theories that quasars are growing black holes.

In 2000, Vescovi's team demonstrated that mouse brain stem cells could turn into muscle cells after coming into physical contact with those cells.

In 2000, Cornelia M. Weyand and colleagues found that rheumatoid arthritis patients had age-inappropriate deterioration of telomeres in T-cells, rather than overactive immune systems as had previously been thought (Koetz 2000:9203).

In 2000, Pasko Rakic and collaborators discovered that astrocytes are the brain cells which arose from stem cells and differentiated into neurons.

In 2000, The Arabidopsis Genome Initiative sequenced the genome of Arabidopsis thaliana, or thale cress, a flowering plant, finding 25,498 genes in five chromosomes encoding proteins from 11,000 families, similar to the functional diversity of Drosophila and Caenorhabdidtis elegans (Arabidopsis Genome Initiative:2000:796).

In 2000, Peter J. Oefner, Luigi Luca Cavalli-Sforza, and an international team erected a phylogenetic tree, based on binary polymorphisms associated with the non-combining region of the human Y-chromosome, which indicated the most recent common male ancestor lived 40,000-140,000 years ago and migrated out of Africa 35,000-89,000 years ago (Underhill 2000:358-361).Peter A. Underhill, Cavalli-Sforza, and a somewhat different team determined the origin of the present Europeans also using nonrecombining Y-chromosome binary markers. They found three waves of immigration, the first about 40,000 years ago from Central Asia, the second about 25,000 years ago from the Middle East, and the third, only about 20% of the total, from Neolithic farmers who came from the Near East (Semino and Passarino 2000:1155-1159).

In 2000, Hideo Ohno led a team which demonstrated a way to manipulate the magnetic, or quantum spin, properties of an indium manganese arsenide transistor device by employing an electric field. This differs from electronic devices in using spin rather than electron properties and is similar to a computer hard-disk drive which uses a magnetic field to write information to a disk surface.

In 2000, Lorenzo Pavesi and colleagues demonstrated that light amplification is possible by forcing an electron to recombine with the hole from which it wandered away when excited. This can be accomplished by confining the pair inside a silicon nanocrystal (Pavesi 2000:440-444).

In 2000, Karl Gebhardt, John Kormendy, Douglas Richstone, and, independently, Laura Ferrarese and David Merritt determined that the mass of a black-hole correlates with the average velocity of stars within its ellipsoidal host. This supports theories that quasars are growing black-holes.
In 2001, Ventner, representing Celera Genomics, and Francis Collins, representing Human Genome Project, jointly published their decoding of the human genome. Their rapid sequencing progress was permitted by the automatic sequencer ABI PRISM 3700 DNA Analyzer, developed by Michael Hunkapiller. Assembling the fragments of the genome into a complete sequence depended on computer programs developed by Phillip Green.
In 2001, Ventner, Mark Adams, and colleagues completed a genetic map of the laboratory mouse, finding that the length of its genetic code is 10% smaller than anticipated.
In 2001, Roger Cayrel reported his team's finding of the age of the Universe to be at least 12.5 billion years old, give or take 3 billion. This number is extrapolated from the age of a very old star named CS31082-001, arrived at using a spectroscope attached to ESA's Very Large Telescope (VLT) at Paranal, Chile, to measure the abundances of the radioactive element thorium-232.
In 2001, Richard Ellis, Michael R. Santos, Jean-Paul Kneib, and Konrad Kuijken discovered a star cluster 13.4 billion light years from Earth, employing a combination of the W. W. Keck Telescope and the HST with a gravitational lens, two billion light years away, the star cluster Abell 2218. The significance of their discovery lies in its age, an age when the Universe was several hundred times denser than today.
In 2002, Manindra Agrawal developed a method for determining with complete certainty whether or not a number is a prime number.