Incoherent Light Sources

M.Sc. Chemical Engineering / M.Sc. Photonics / M.Sc. Material Science and Engineering

July 12th, 2023

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Name: _____

Enrolment number: _____

Date of Birth: _____

Please keep in mind to clearly figure out the solution approach and the results! Please solely use IUPAC units!

Duration: 180 Minutes

Allowed aids: Periodic table of the elements, Pocket calculator, Dieke-Diagram, formulaic collection math

Points		**Mark**	
Task 1:	10 Points	1.0	95 – 100 Points
Task 2:	10 Points	1.3	90 – 94 Points
Task 3:	10 Points	1.7	85 – 89 Points
Task 4:	10 Points	2.0	80 – 84 Points
Task 5:	10 Points	2.3	75 – 79 Points
Task 6:	10 Points	2.7	70 – 74 Points
Task 7:	10 Points	3.0	65 – 69 Points
Task 8:	10 Points	3.3	60 – 64 Points
Task 9:	10 Points	3.7	55 – 59 Points
Task 10:	10 Points	4.0	50 – 54 Points
		5.0	0 – 49 Points

Success!

Task 1 **(10 Points)**

Physical basis of light generation

a) Please name the three physical processes, which are applied for the light generation in electrical light sources! (3 Points)

b) Explain the process of light generation according to chemiluminescence by simple reaction equations and speculate about a potential application area! (3 Points)

c) Please define the terms “luminescence” and “incandescence”! (2 Points)

d) Please explain the process of cathodoluminescence and sketch the light generation chain in a cathode-ray tube! (2 Points)

Task 2 **(10 Points)**

Vision and Colour

a) Please define the terms photopic and scotopic vision! (2 Points)

b) Please sketch the human exe sensitivity curve V(λ) for photopic vision and name the reasons for the edges at 380 and 780 nm! (3 Points)

c) Please name two consequences of the shape of the V(λ) curve for the spectral optimization of artificial light sources! (2 Points)

d) Please explain roughly the determination of the colour rendering index CRI with eight test colours! (3 Points)

Task 3 **(10 Points)**

Incandescent and halogen lamps

a) Please explain the term hot spot mechanism with respect to the lifetime of an incandescent or halogen lamp. Which impact has the required power loss on the hot spot mechanism (Power $P = U*I = R*I^2$, Resistance $R = \rho\ l/A$ with ρ = specific resistance)! (3 Points)

b) Please sketch schematically the spectrum of a black body radiator at a temperature of 2700 and of 5800 K! Please also subdivide the x-axis into the spectral ranges UV, VIS, and NIR! (2 Points)

c) Please calculate by the aid of Wien's displacement law ($\lambda_{max} = 2880 / T$ [µm*K]) the temperature of a black body radiator, at which the maximum of the emission intensity coincides with the maximum of the photopic sensitivity of the human eye (555 nm)! (2 Points)

d) Please explain why such an incandescent lamp cannot be constructed from a material scientist point of view? (1 Point)

e) Please name two technical measures in order to enhance the lifetime of incandescent lamps! (2 Points)

Task 4 **(10 Points)**

Quantitative Terms for Lighting Technology

a) Please explain the following terms used in lighting technology! (0.5 Points each)

- Radiant flux
- Luminous flux
- Spectral radiant flux
- Spectral luminous flux
- Color temperature

b) The term energy efficiency ε means the conversion of electrical input power P_{el} to optical output power P_{opt}. The term luminous efficacy ε_v describes the relation between the luminous flux Φ_v and the radiant flux Φ_e. (Please complete the following table! 0.5 Points each)

Light source	**Electrical input power P_{el}**	**Energy efficiency ε**	**Radiant flux Φ_e**	**Luminous efficacy ε_v [lm/$W_{optical}$]**	**Luminous flux Φ_v**	**Light yield [lm/$W_{el.}$]**
Halogen lamp	100 W	10%		250		
Low-pressure Na discharge lamp	200 W	40%		500		
Low-pressure Hg discharge lamp (fluorescent lamp)	36 W	30%		300		
Cool-white LED	5 W	80%		350		
Warm-white LED	5 W	40%		280		

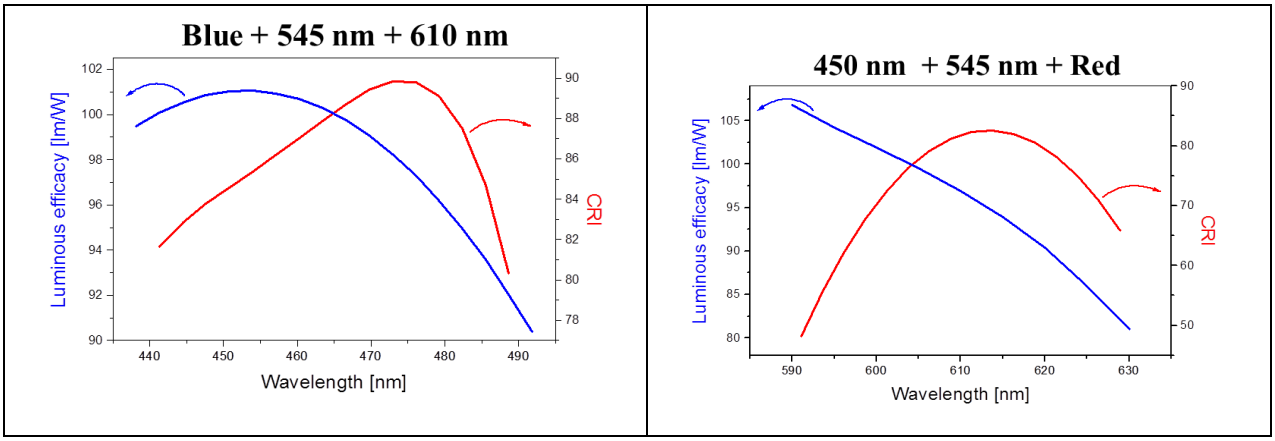
Task 5 **(10 Points)**

Low-pressure gas discharge lamps

a) Please calculate the wall plug efficiency (energy efficiency) $\eta_{el.} = \eta_{driver} * \eta_{discharge} * QE_{phosphor} *$ QD of a low-pressure Hg discharge lamp that emits 85% radiation at 254 nm, 12% at 185 nm, and 3% visible lines, if the driver efficiency η_{driver} is 95%, the discharge efficiency $\eta_{discharge}$ is 70%, the mean emission wavelength of the phosphor blend is 550 nm, and the Quantum Efficiency QE is 90% (QD = Quantum Deficit = $\lambda_{discharge}/\lambda_{phosphor}$). (2 Points)

b) Please sketch the light generation chain of a tubular fluorescent lamp! (2 Points)

c) The following graphs show the luminous efficacy and CRI of a trichromatic fluorescent lamp. Please name the optimal emission wavelengths for the choice of the blue and red emitting component with respect to the light yield and CRI of such lamps? (2 Points)



d) Name two activator ions, which are used in phosphors for low-pressure Hg discharge lamps! (2 Points)

e) Please explain why most fluorescent lamps are precoated by Al_2O_3 or Y_2O_3! (2 Points)

Task 6 **(10 Points)**

Inorganic luminescent materials

a) Sketch the working principle of luminescent materials upon using the terms absorption, energy transfer, and relaxation! (3 Points)

b) Please sketch the concentration quenching curve of an arbitrary luminescent material and explain the shape of the curve? (3 Points)

c) Please explain the tuning of the Ce^{3+} luminescence by a simplified energy level diagram! (2 Points)

d) Please explain by the aid of the Dieke diagram the importance of Eu^{3+} for light sources and colour displays! (2 Points)

Task 7 **(10 Points)**

Luminescence mechanisms

a) Please explain the principle of sensitization by a self-chosen example! (2 Points)

b) Please name two reasons for the wide use of trivalent lanthanide ions in laser crystals and luminescent materials! (2 Points)

c) Please explain the following physical processes. You may use self-elected examples for illustration! (1 Point each)

cross-relaxation

down-conversion

excited state absorption

up-conversion

d) Please explain by term afterglow and explain the physical basis by a simple sketch! (2 Points)

Task 8 **(10 Points)**

Inorganic Light Emitting Diodes (LEDs)

a) $(Ga_{1-x}In_x)N$ and $(Ga_{1-x}In_x)P$ are important solid solutions for semiconductor LEDs. Please sketch the course of the electronic band gap as function of x for the respective nitrides and phosphides. Please also explain the observation why the course of the electronic band gap as function of x is not a straight line! (3 Points)

b) Give to reasons for the success of III-V semiconductor LEDs! (2 Points)

c) Please mention three processes which determine the wall plug efficiency of inorganic LEDs! (3 Points)

d) Please explain the term flip-chip design and explain the advantage of such a design for the development of high-power LEDs! (2 Points)

Task 9 **(10 Points)**

Organic Light Emitting Diodes (OLEDs)

a) Please sketch the cross-section of an OLED comprising a glass substrate, an emitter layer, a hole and electron conducting layer, anode, cathode, and a hole blocking layer! (2 Points)

b) Explain the reason for the use of a hole blocking layer in modern OLEDs and compare this invention to Inorganic LEDs! (2 Points)

c) Give a reason for the use of Ir^{3+} complexes in OLEDs and name an alternative metal ion for OLED emitter complexes! (2 Points)

d) Mention two technical measures to improve the light extraction from planar OLEDs! (2 Points)

e) Mention two technical measures to improve the lifetime of OLEDs (2 Points)

Task 10 (10 Points)

UV Radiation Sources

a) The sun, as many celestial objects, also emit UV radiation. Please sketch the processes in the Earth's atmosphere to explain, why EUV, VUV, and UV-C radiation are not detectable at the surface (sea level)! (3 Points)

b) Please name three types of artificial UV radiation sources? (3 Points)

c) Explain the advantage of 222 nm radiation over 254 nm radiation for air disinfection in occupied spaces? (2 Points)

d) Calculate the energy efficiency $\eta_{el.}$ (wall-plug efficiency WPE) of an UV radiation source based on a Xe2* excimer discharge (172 nm, discharge efficiency = 70%, driver efficiency 90%) and an UV-C phosphor (241 nm, Quantum Efficiency QE = 85%)! (2 Points)

Appendix: Dieke Diagram for Ln^{3+}-Ions