6. High Pressure Discharge Lamps

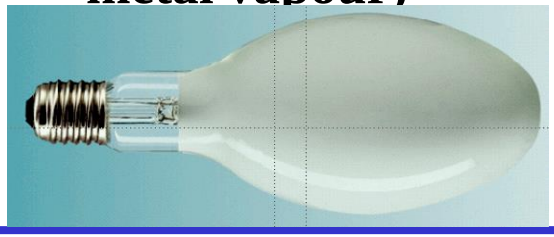
Content

6.1 Overview of Low- and High-Pressure Discharge Lamps

HID = High Intensity Discharge

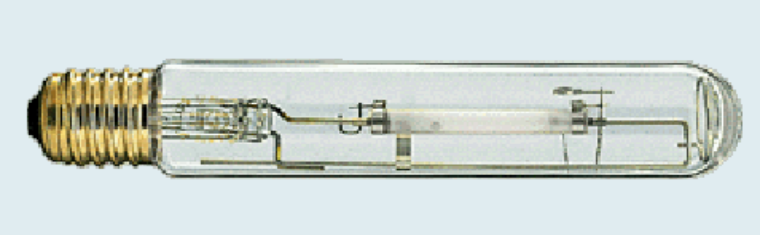
Hg low-pressure (TL)

Hg high-pressure (HPMV = high pressure metal vapour)

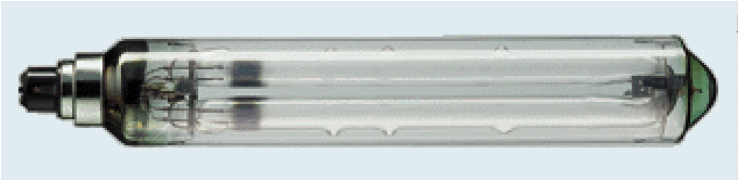


Hg low-pressure (CFL, PL)

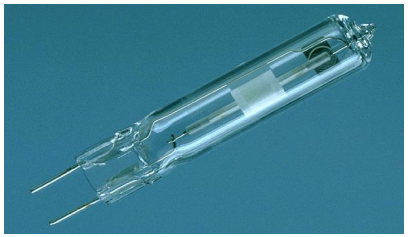
Na high-pressure (HPS = high pressure sod.)

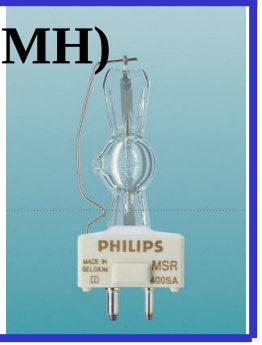


Na low-pressure (SOX)



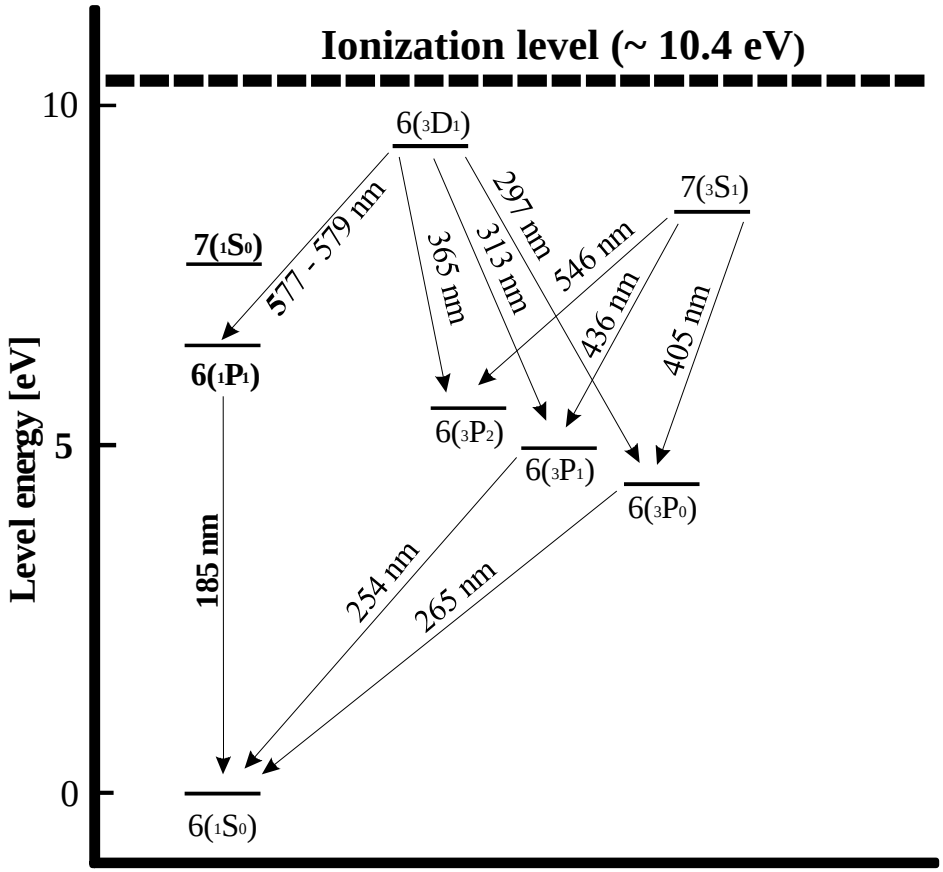
Metal-halide high-pressure (MH)



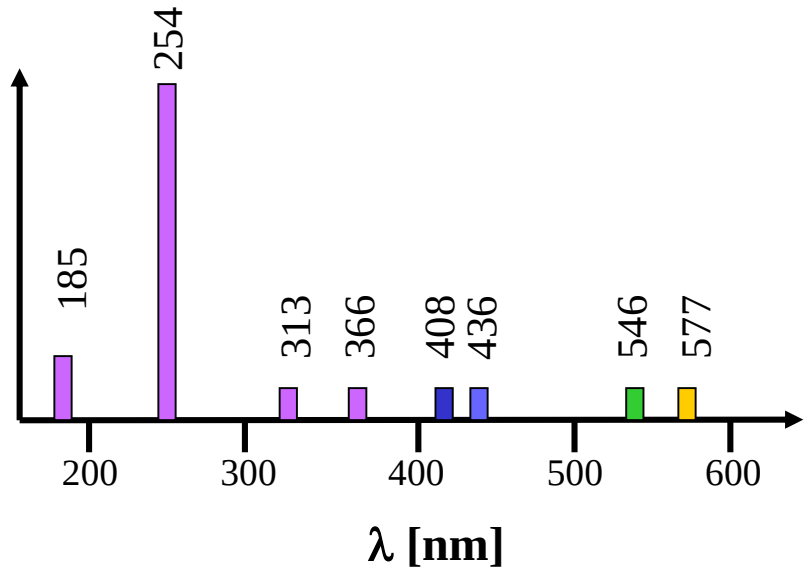


6.2 Spectrum of Hg Discharges

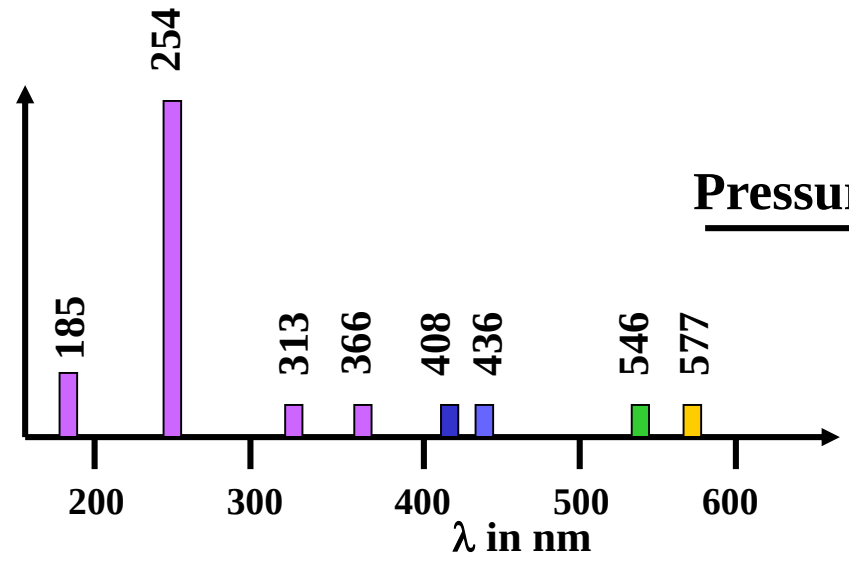
Energy level scheme of Hg



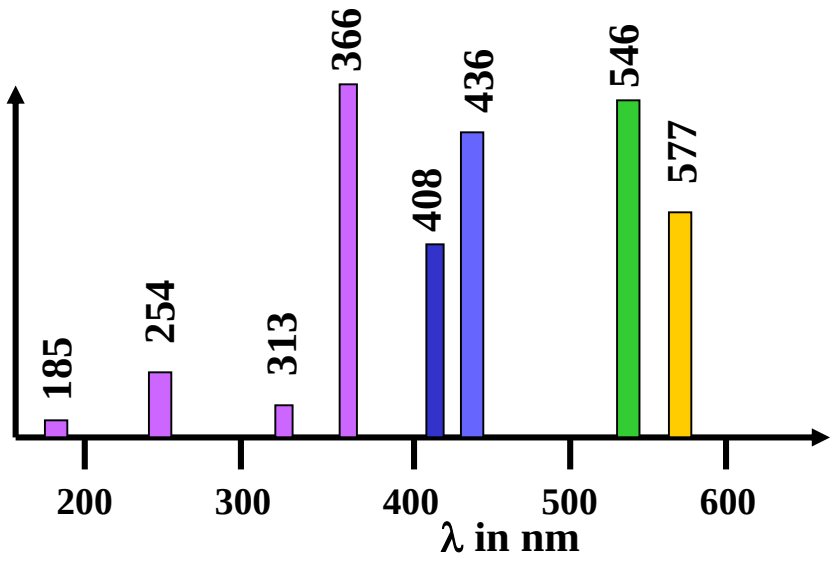
Schematic emission spectrum of a Hg discharge at a low pressure, i.e. in the mbar range

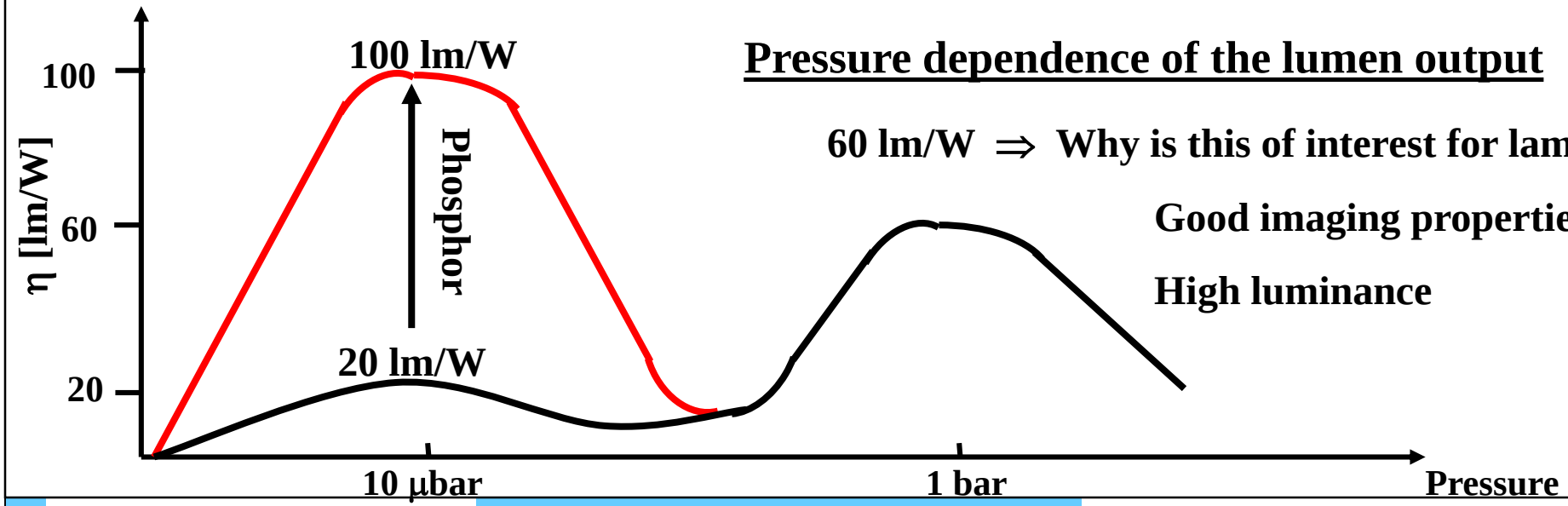


6.2 Spectrum of Hg Discharges



Pressure increase





Pressure dependence of the lumen output

60 lm/W ⇒ Why is this of interest for lamps?

Good imaging properties

High luminance

6.2 Spectrum of Hg Discharges

Measured spectra of a water-cooled capillary mercury discharge lamps

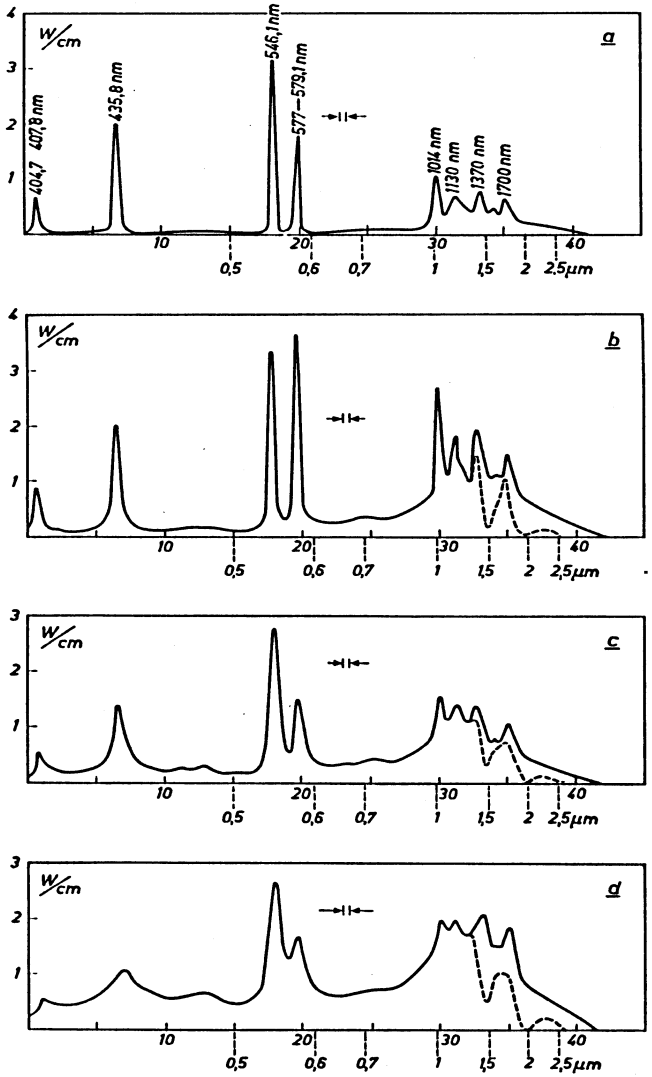
Broadening of emission lines due to

temperature increase
- **Doppler broadening**
- **Rotational broadening**

pressure increase
- **Collisional broadening**
- **Reabsorption**

field strength increase
- **Gravitational broadening**
- **Magnetical broadening**

Source: W. Elenbaas, Quecksilberdampf-Hochdrucklampen (1966)



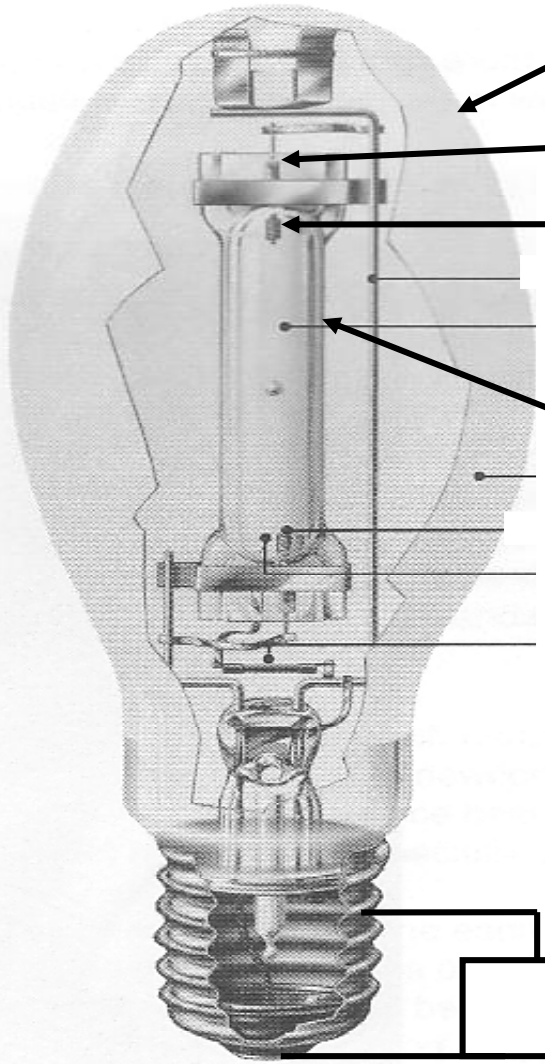
P = 25 atm.

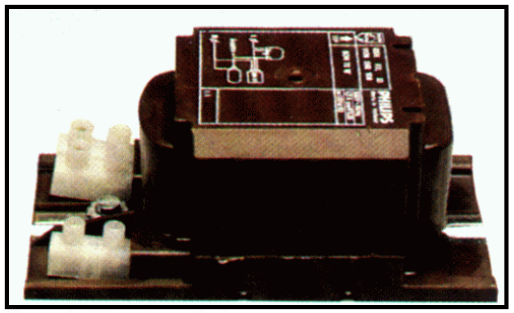
P = 30 atm.

P = 100 atm.

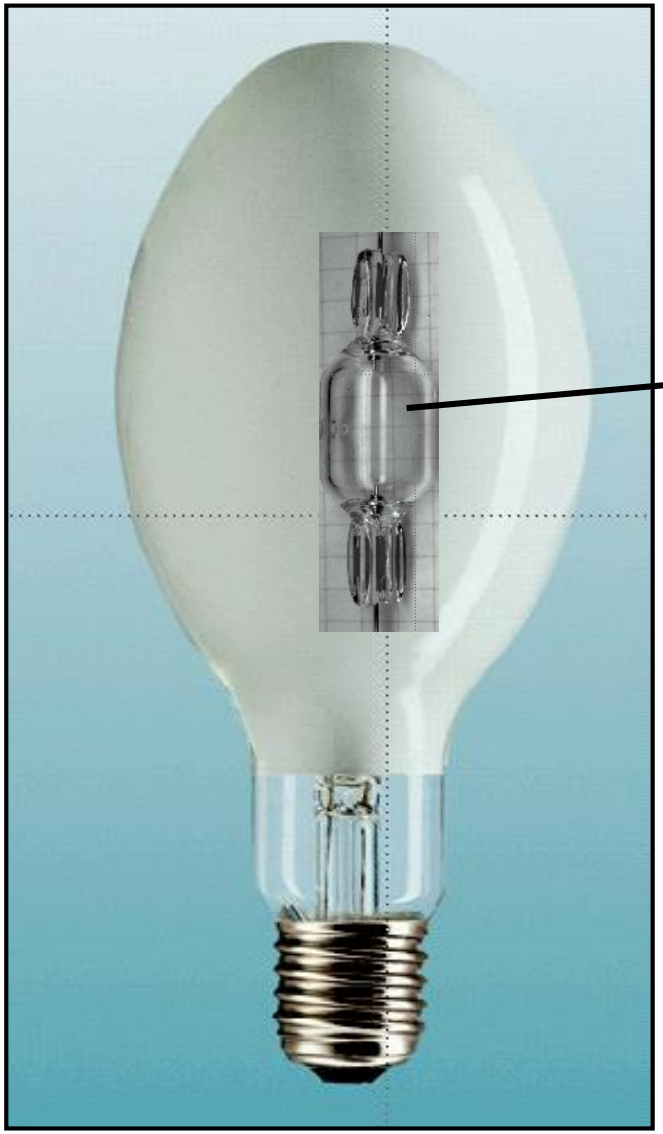
P = 150 atm.

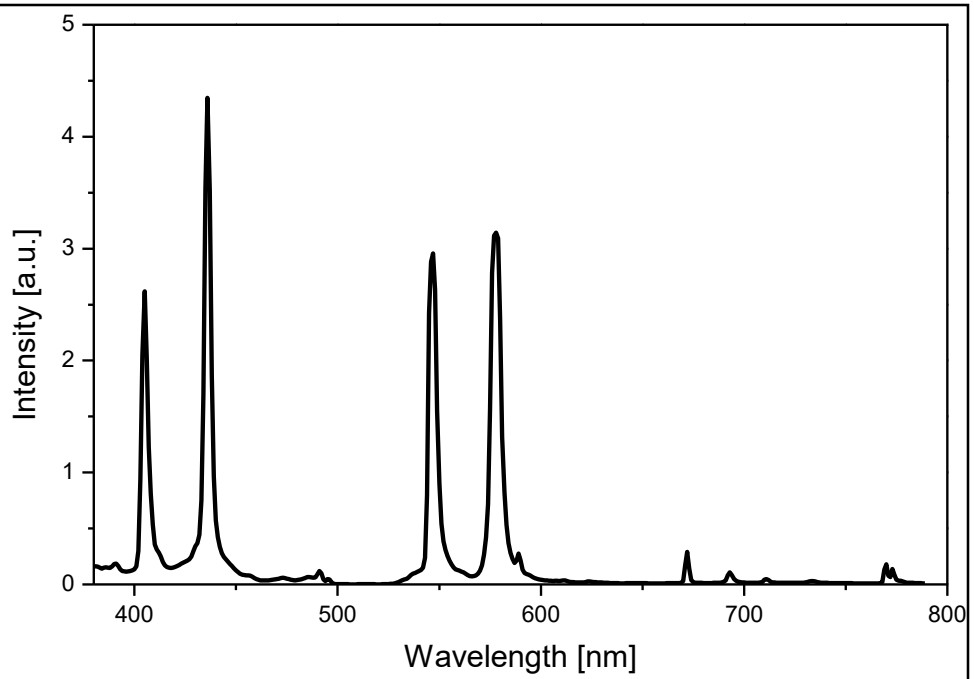
6.3 The High-Pressure Mercury Lamp (HP)





6.4 Phosphors for High-Pressure Mercury Lamps

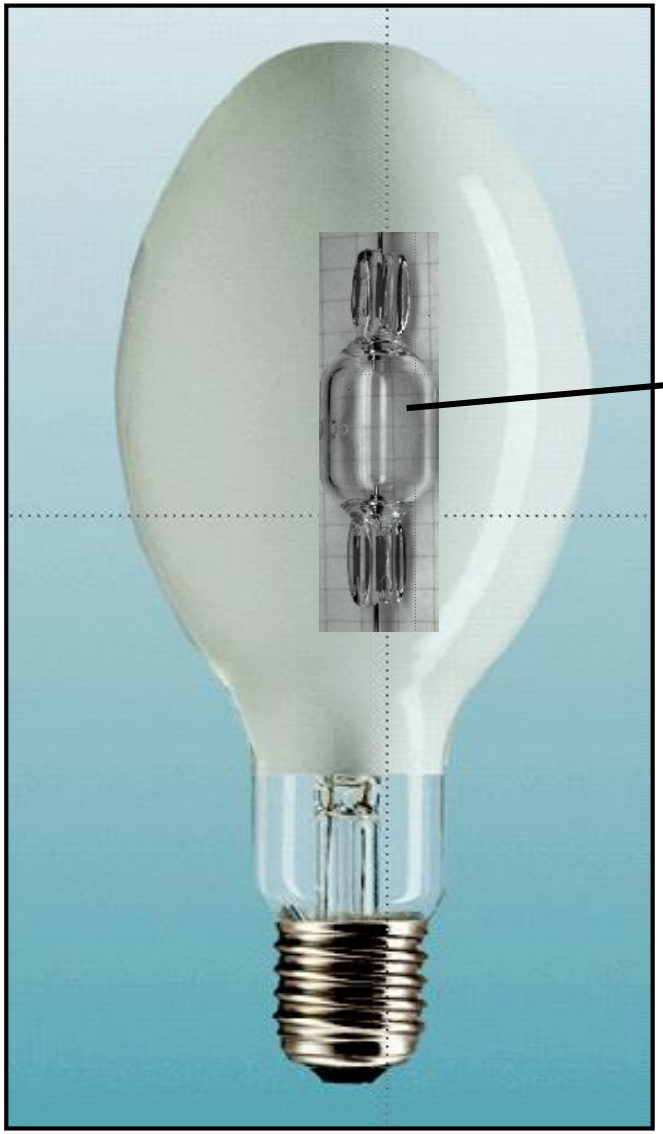


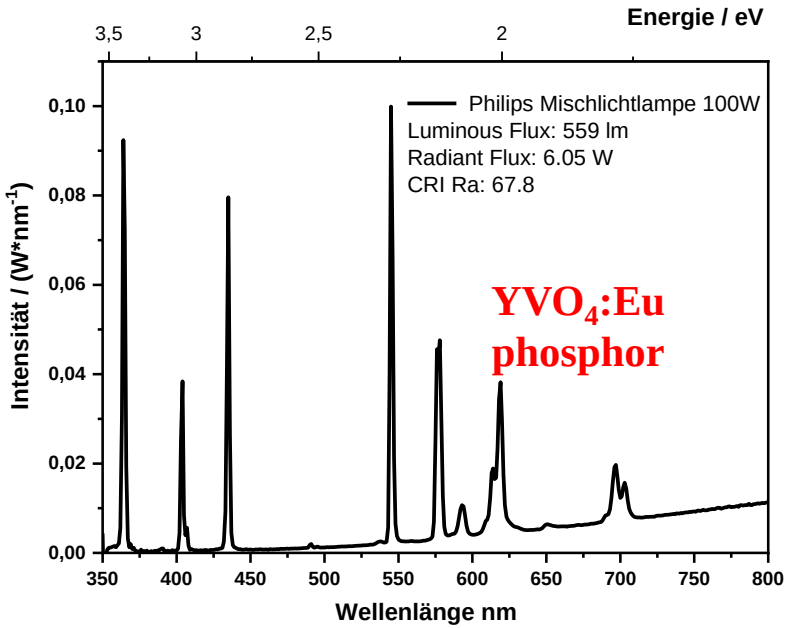


η = 60 lm/W
R_a = 20
Lifetime = 20.000 h

Blue-white light due to the lack of red radiation in the emission spectrum
Solution: Phosphor layer

6.4 Phosphors for High-Pressure Mercury Lamps





Suitable phosphors

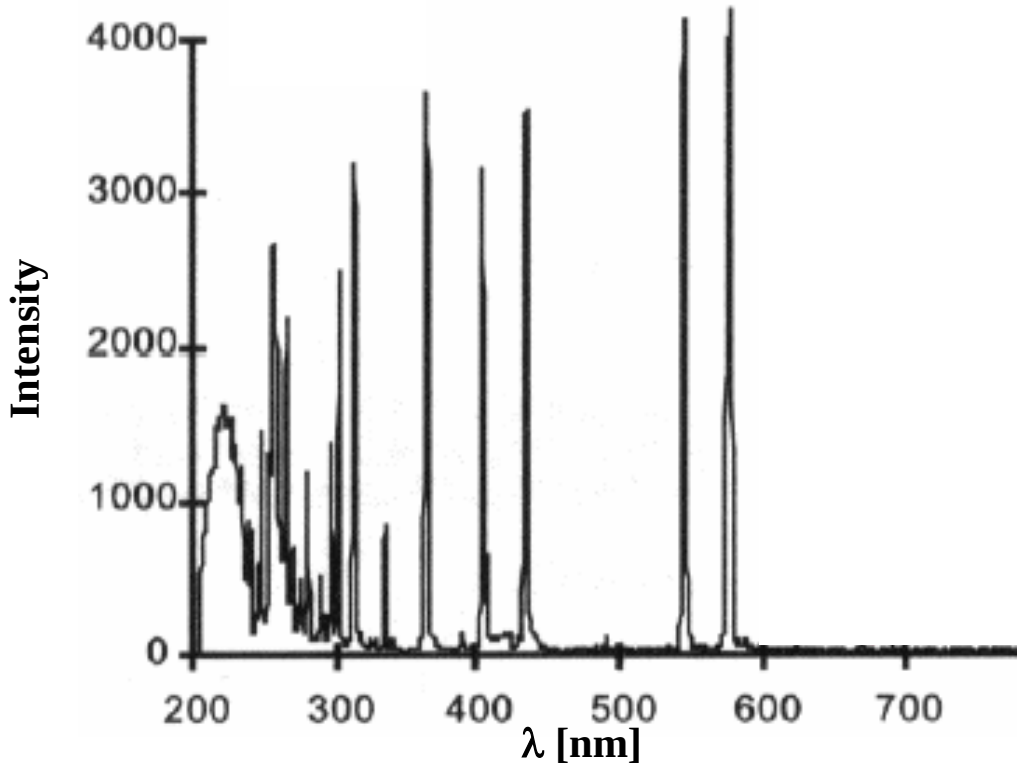
$(Sr,Mg)_3(PO_4)_2:Sn^{2+}$	620 nm	Broadband emission
$Mg_4GeO_{5.5}F:Mn^{4+}$	660 nm	Line emission
$YVO_4:Eu^{3+}$	620 nm	Line emission
$Y(V,P)O_4:Eu^{3+}$	620 nm	Line emission

η = 60 lm/W
R_a = 50-70
Lifetime = 20.000 h

6.4 Phosphors for High-Pressure Mercury Lamps

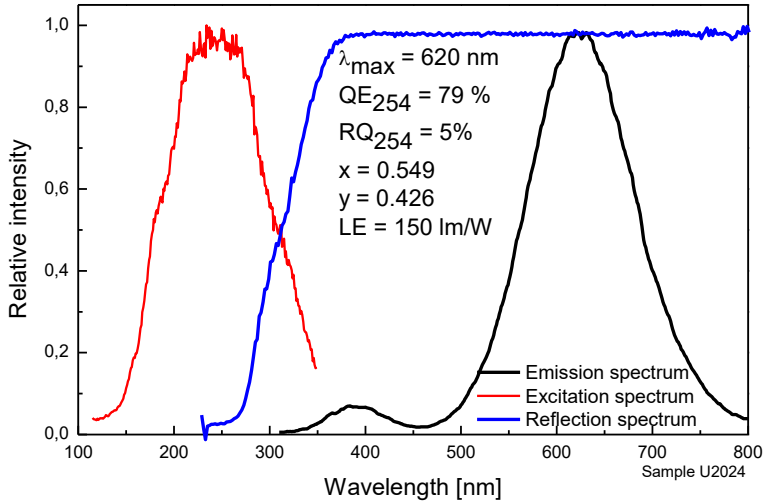
Sn^{2+} or Mn^{4+} phosphors as UV → Red converter

Hg HP lamps emit UV radiation substantially

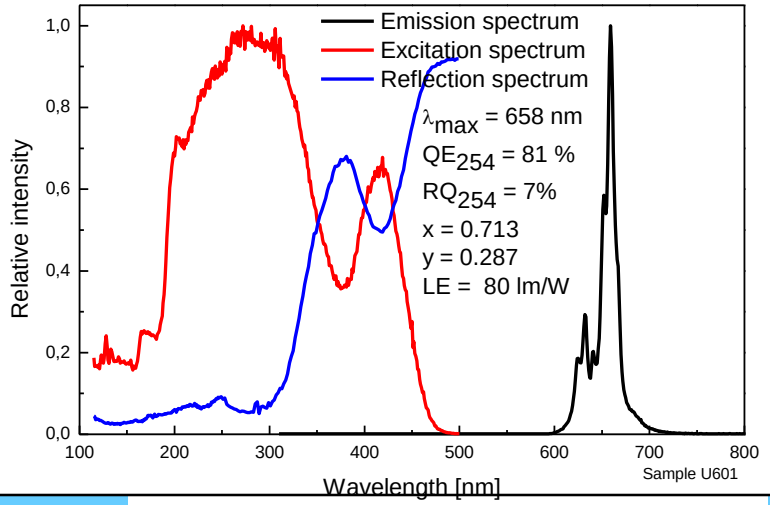


Problem: Low luminous efficacy of these phosphors

Luminescence spectra of $(Sr,Mg)_3(PO_4)_2$:Sn



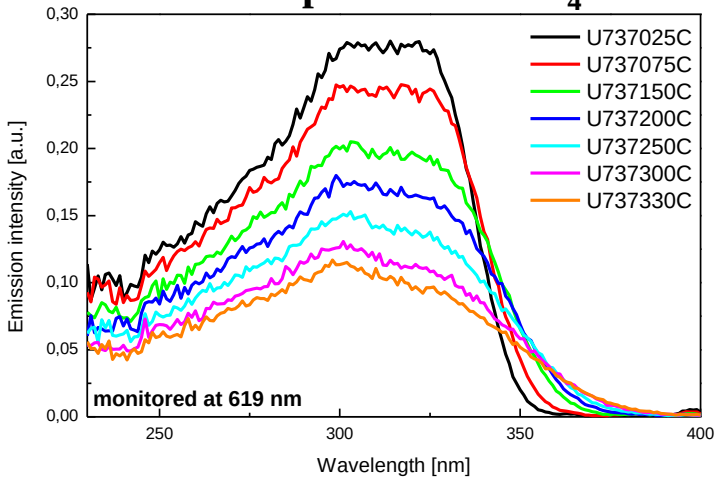
Luminescence spectra of $Mg_4GeO_{5.5}F$:Mn



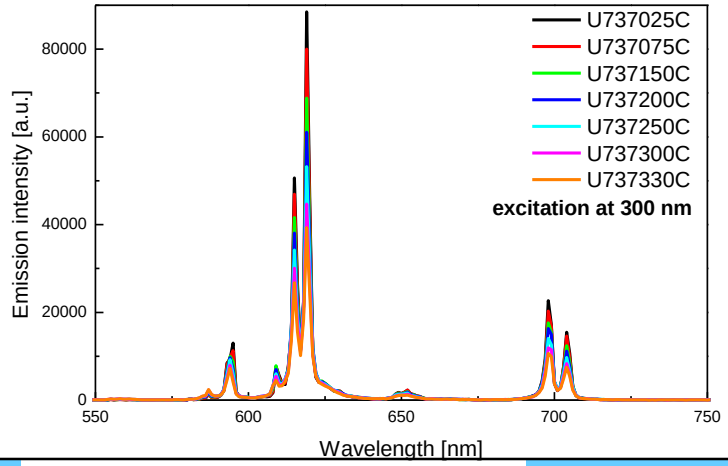
6.4 Phosphors for High-Pressure Mercury Lamps

$YVO_4:Eu^{3+}$ phosphors - Thermal behavior

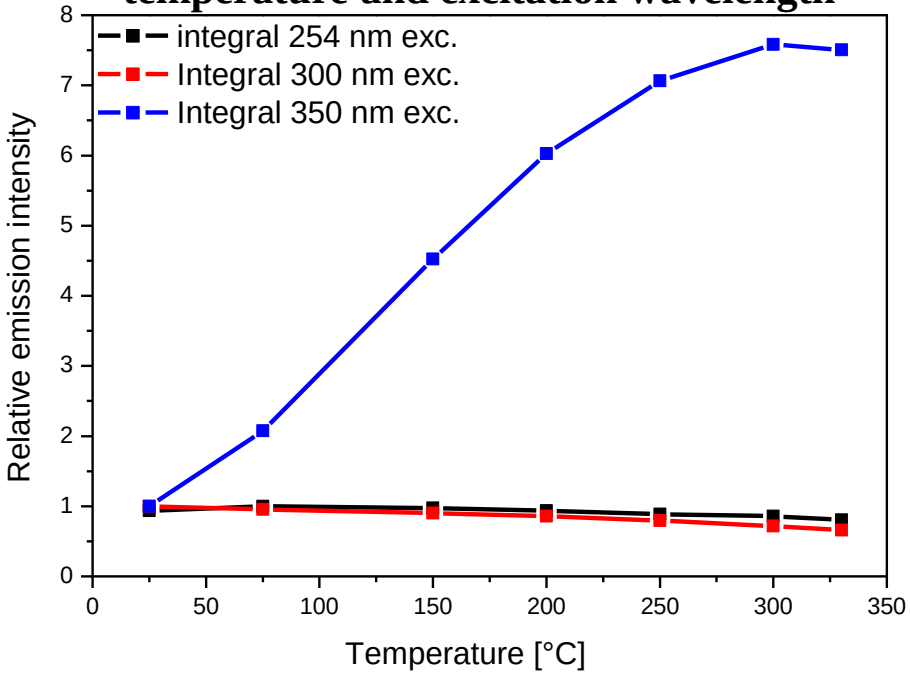
Excitation spectra of YVO_4:Eu



Emission spectra of YVO_4:Eu



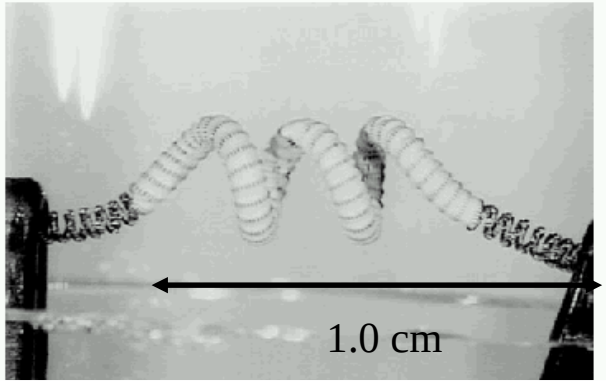
Luminescence intensity as a function of temperature and excitation wavelength



The luminous efficacy under UV-A excitation increases up to about 300 °C
Cause: Increase in spectral overlap with Hg high-pressure discharge emission spectrum

6.5 The Electrode

Hg low-pressure

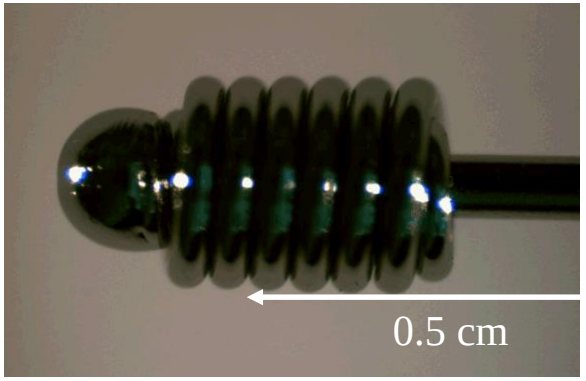


36 W
I = 0.36 A

Tungsten + emitter
BaO / SrO / CaO

T = 1350 K

Hg high-pressure



400 W
I = 4 A

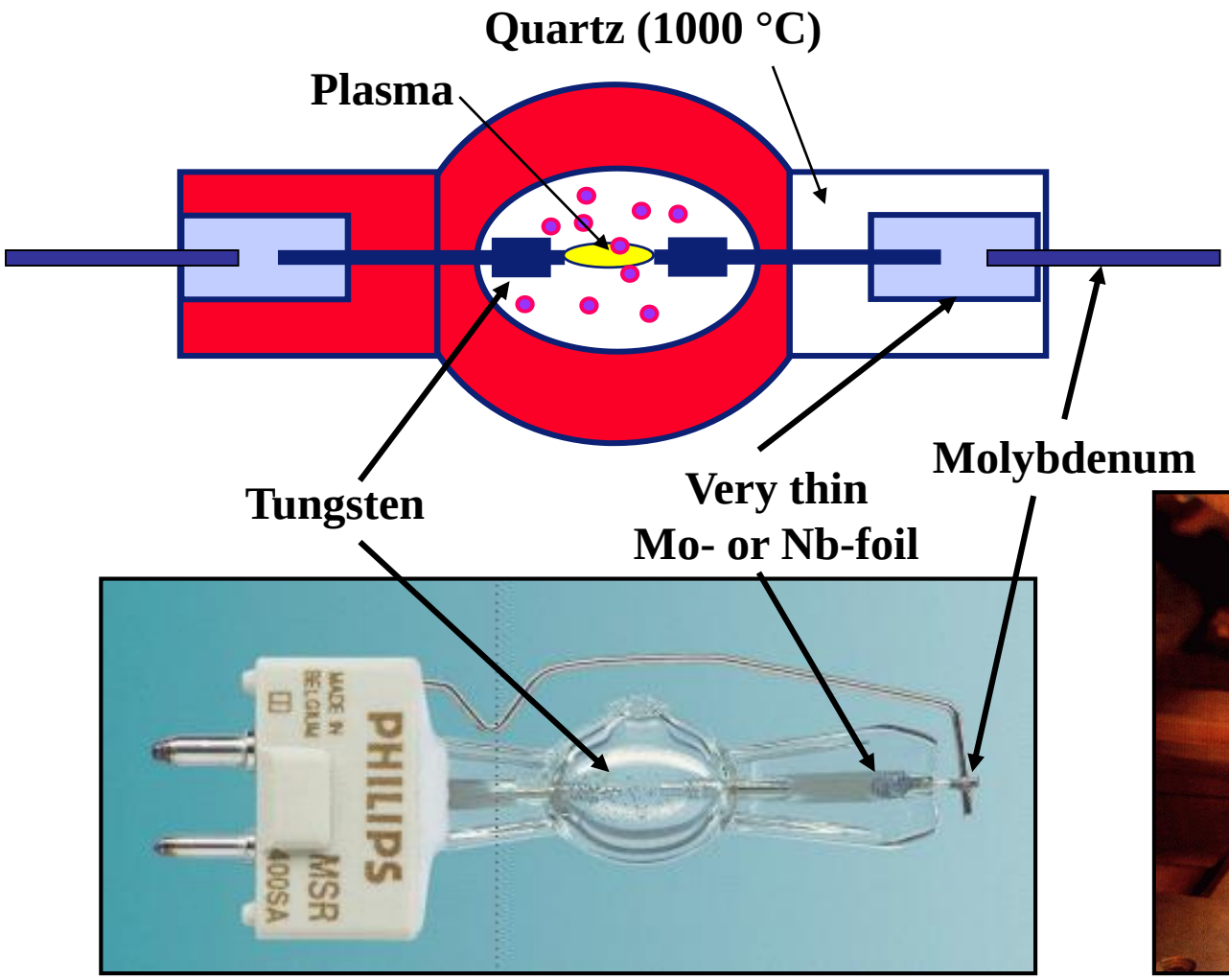
Tungsten + emitter
BaO / SrO / Y_2O_3 / ThO_2

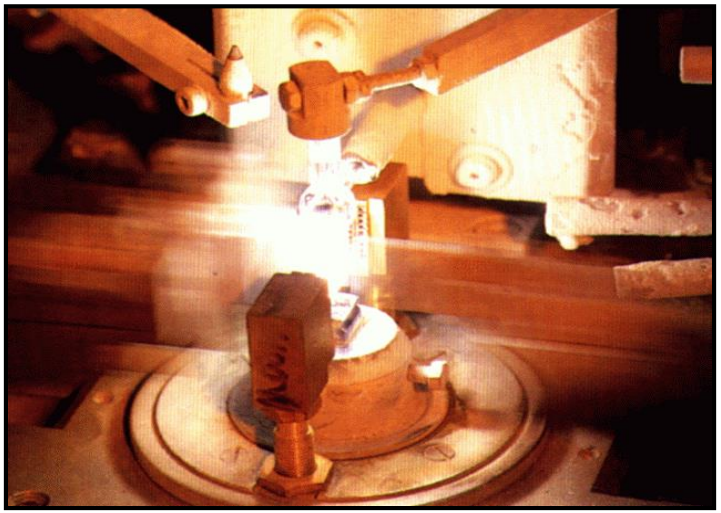
T = 2000 - 3000 K

6.6 The Electrode Feedthrough

Problem: Different thermal expansion coefficients

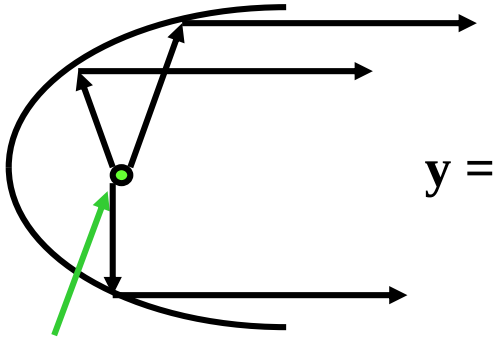
SiO_2	$\alpha = 0.5*10^{-6}\ K^{-1}$
W	$\alpha = 4.3*10^{-6}\ K^{-1}$
Mo	$\alpha = 2.8*10^{-6}\ K^{-1}$
Nb	$\alpha = 7.3*10^{-6}\ K^{-1}$





6.7 Types of Reflectors

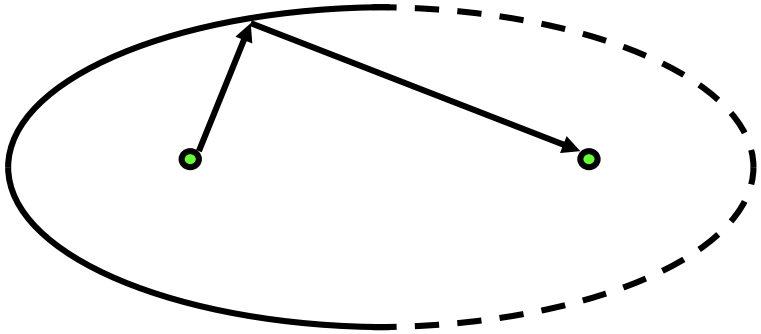
Parabolic reflectors



$y = x^2$

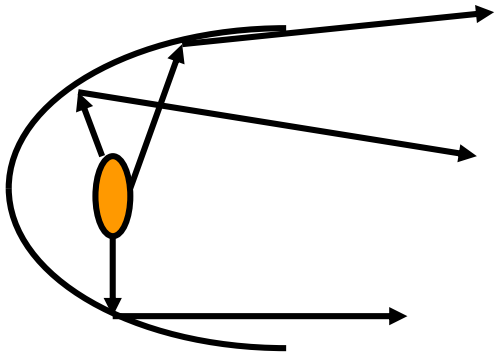
Focal point (light source)

Elliptical reflectors

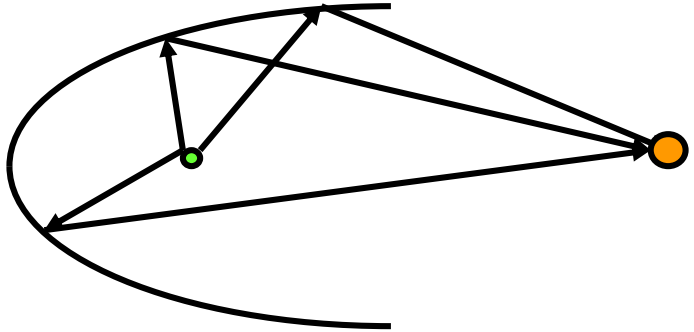


An ellipse has two focal points,
one is occupied by the light source

Only possible if the light source is point like



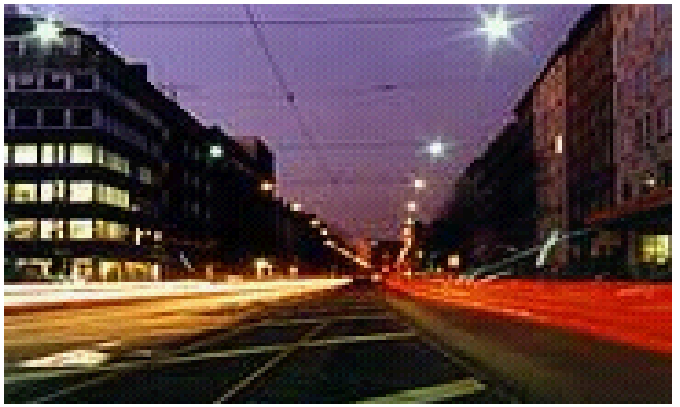
HID lamps



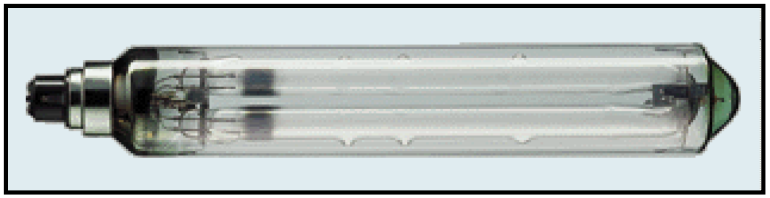
6.8 Application of HP-Lamps

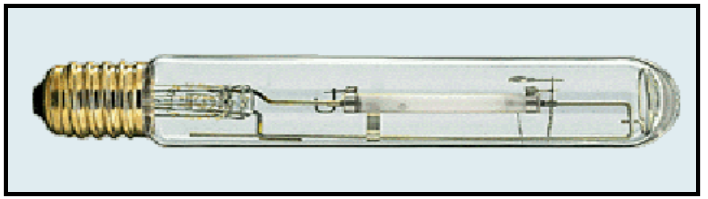
In street lighting (outdoor lighting)

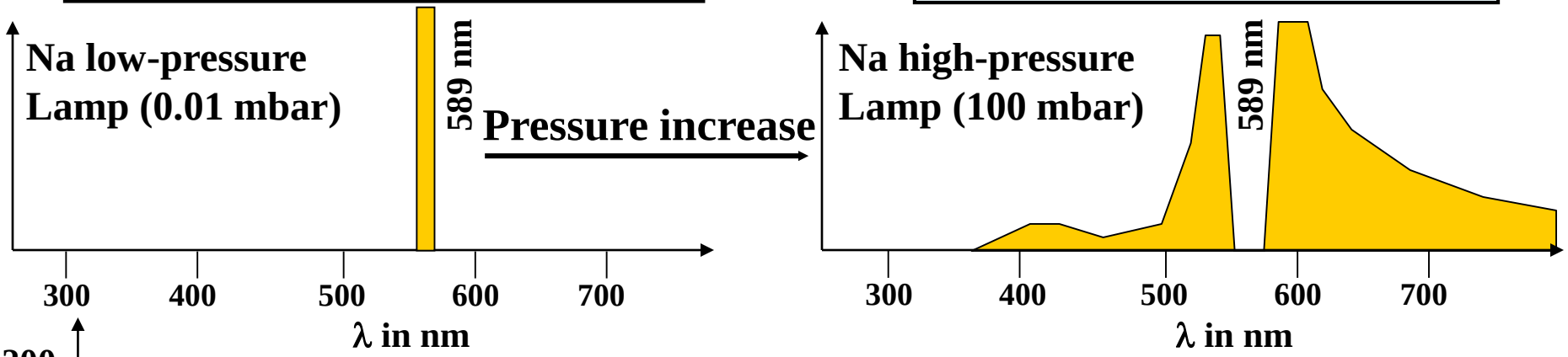
η = 60 lm/W
R_a = 50
Lifetime = 20.000 h
P = 100 W - 2000 W

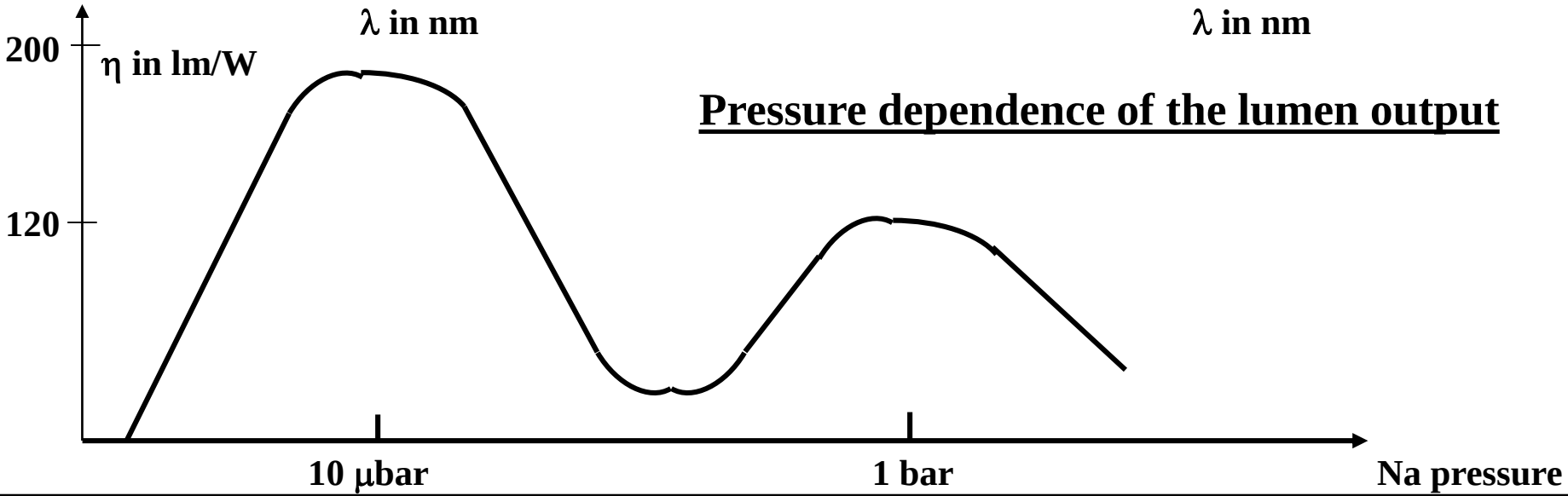


6.9 The High-Pressure Sodium Lamp (HPS)









Pressure dependence of the lumen output

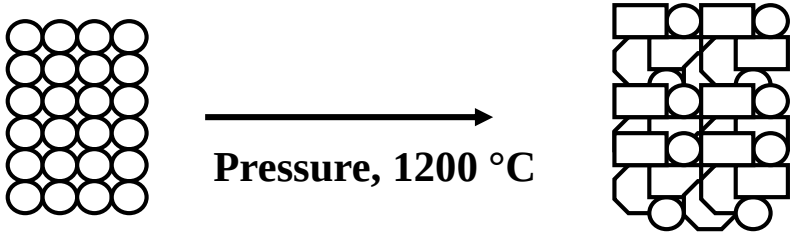
6.9 The High-Pressure Sodium Lamp (HPS)

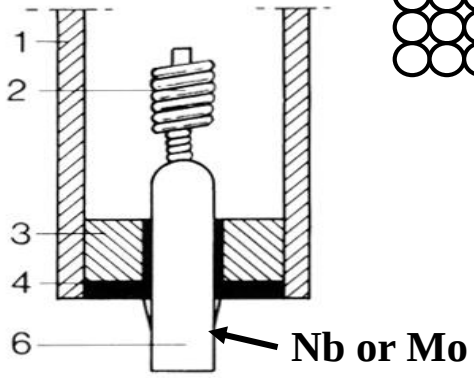
Problem: Na reacts at high temperatures with the quartz glass wall

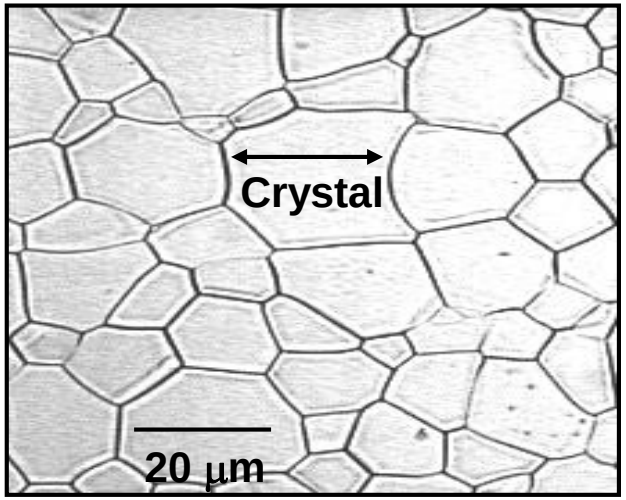
$4\ Na + SiO_2 \rightarrow 2\ Na_2O + Si$

Solution: Transparent, high temperature resistant material, which does not react with Na

Al_2O_3-ceramics (corundum): MgO, CaO, B_2O_3-Additives (DSA = Densely Sintered Alumina)

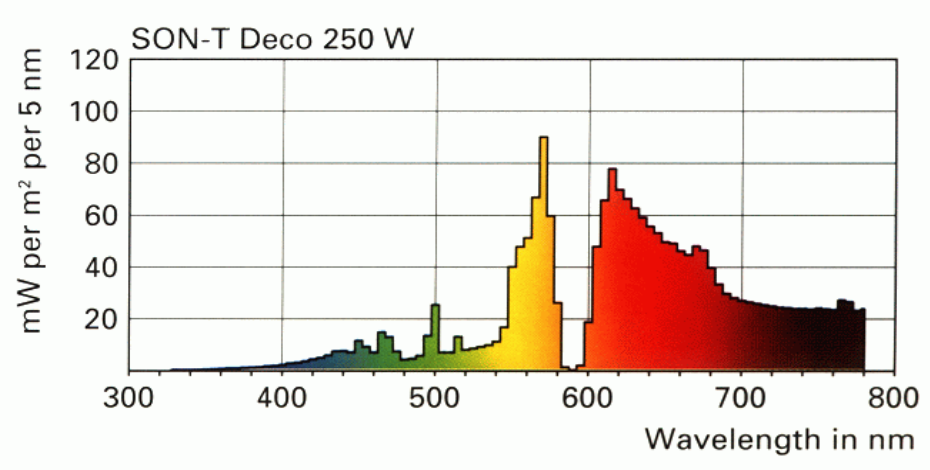






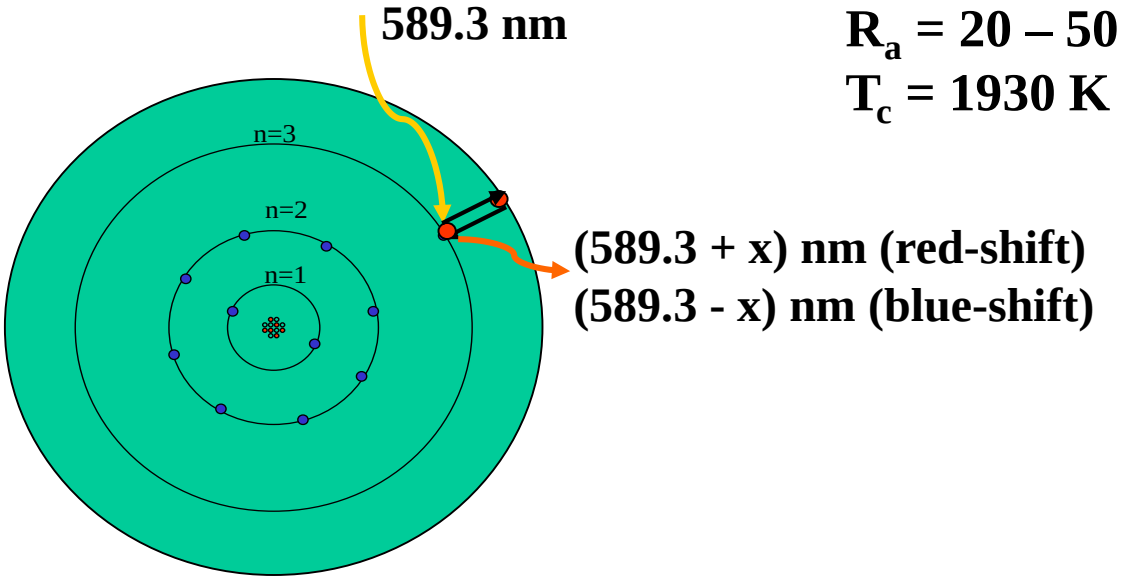
Polycrystalline structure

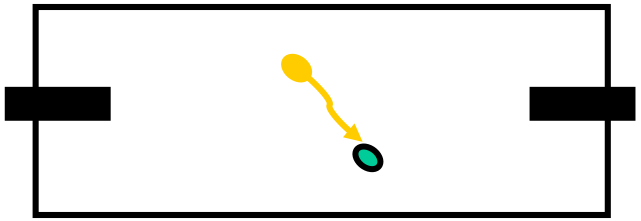
6.9 The High-Pressure Sodium Lamp (HPS)



Widening of the Na-line and self-absorption leads to a spectral hole in the emission spectrum at around 589.3 nm

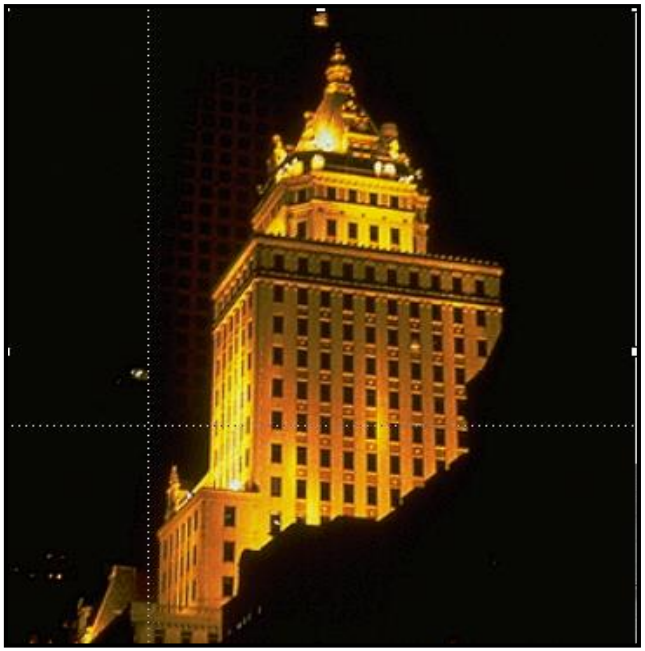
p_{Na} = 150 mbar (saturated)
p_{Hg} = 1000 mbar (buffer gas)
p_{Xe} = 100 mbar (start gas)
η = 90 - 120 lm/W
R_a = 20 – 50 (pressure dependent)
T_c = 1930 K



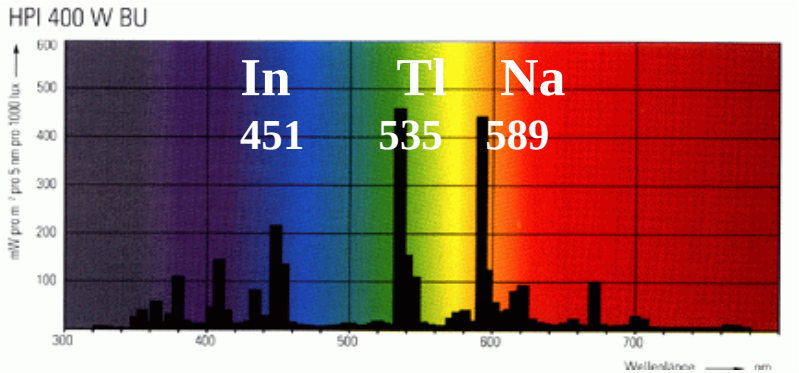


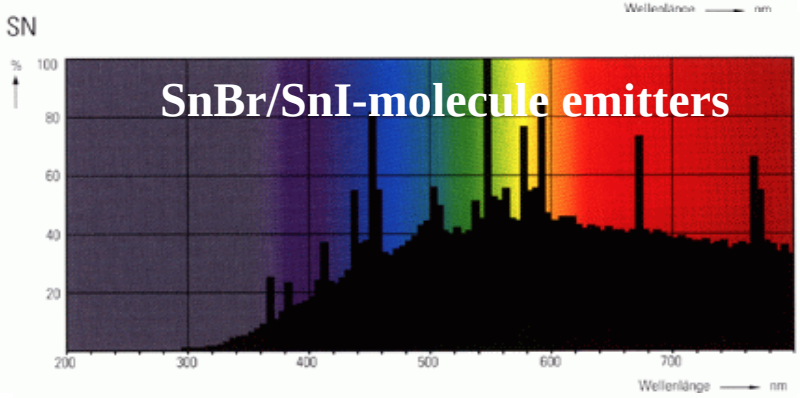
6.10 Application of HPS Lamps

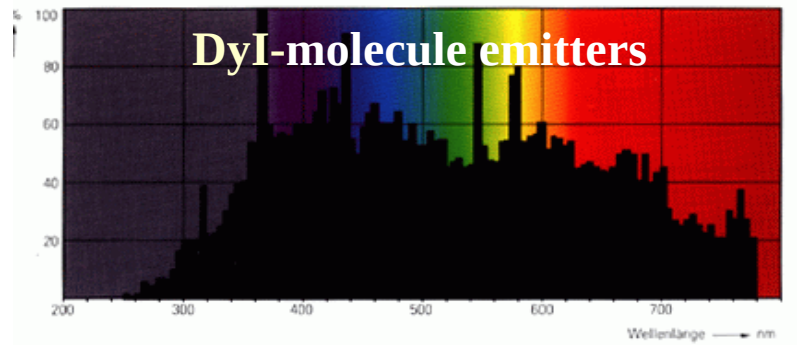
Architectural and street lighting



6.11 Metal-Halide High-Pressure Lamps

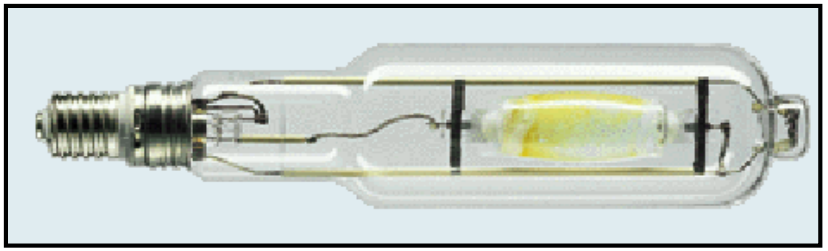


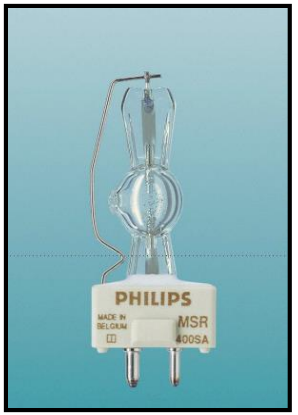


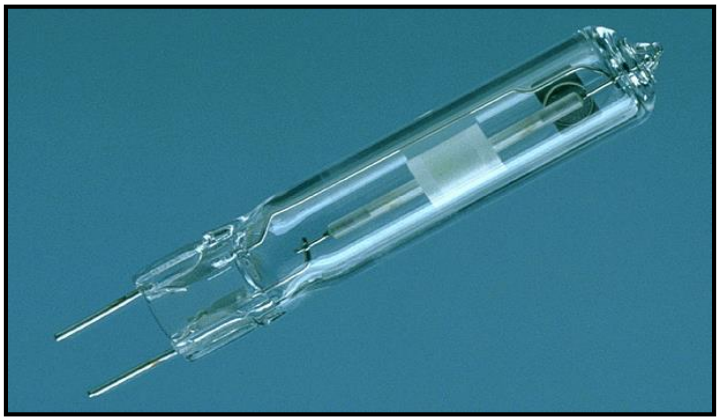


Filling: NaI - TlI - InI
$SnBr_2$ - SnI_2
NaI - DyI_3 (Studio-Stage-TV)
NaI - ScI_3 (automobile headlight)

Goal: High η & color rendering

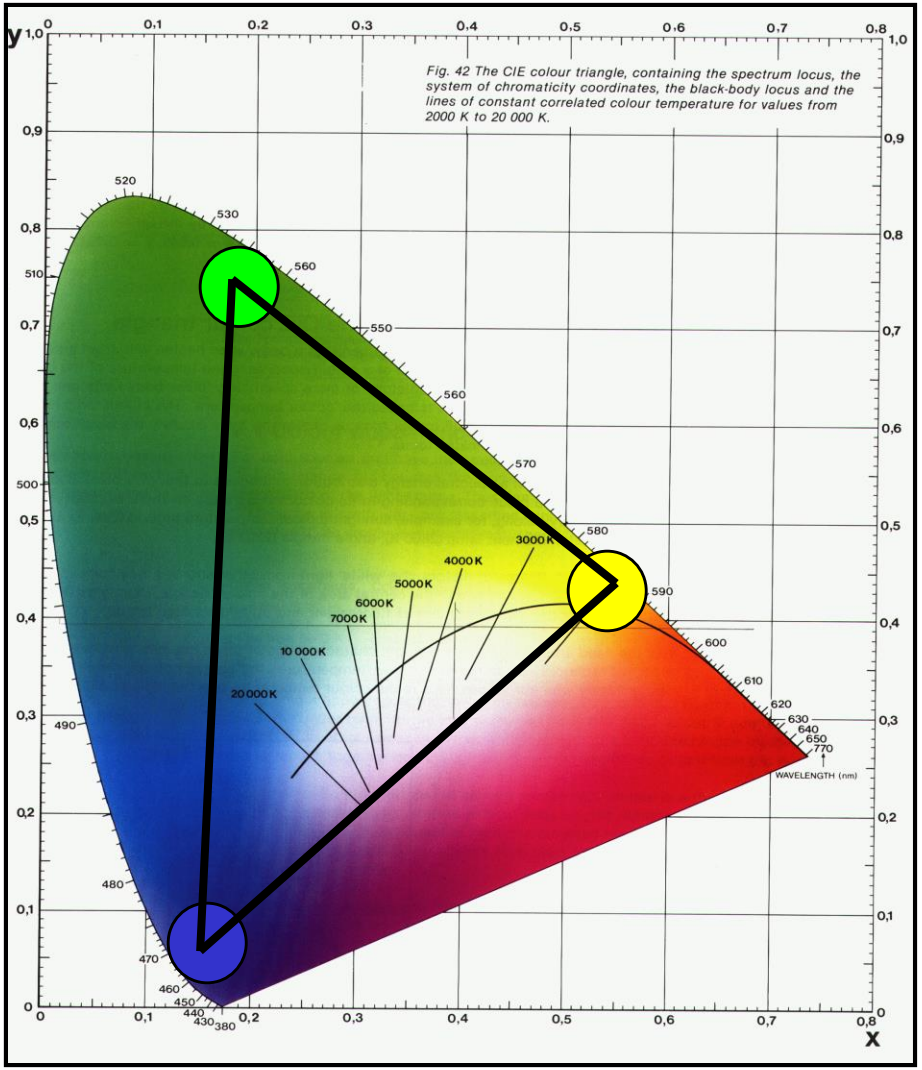






6.11 Metal-Halide High-Pressure Lamps

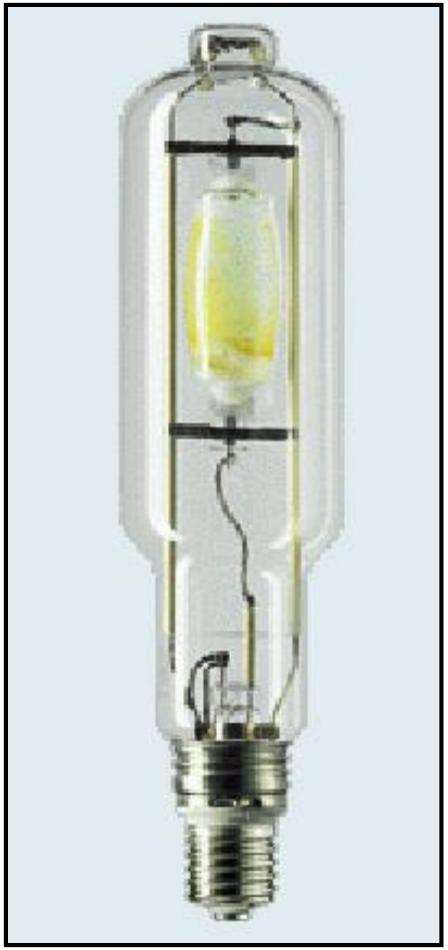
HPI (High Pressure Iodide) lamps



451 nm (In)

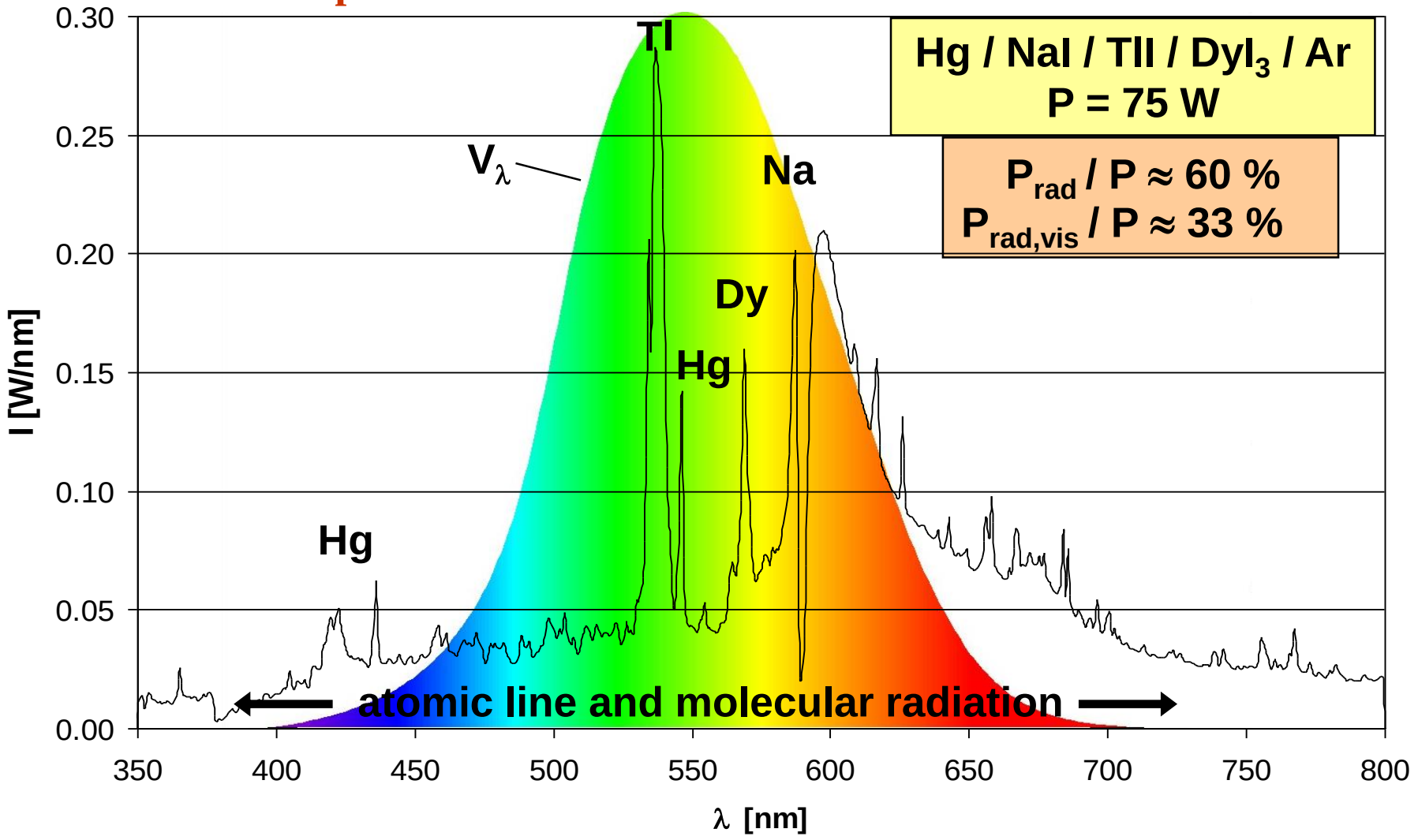
535 nm (Tl)

589 nm (Na)



6.11 Metal-Halide High-Pressure Lamps

Spectrum of a MH lamp



6.11 Metal-Halide High-Pressure Lamps

Filling of metal halide lamps

Lamp starting (starting gas)

Noble gases: Ar or Xe (xenon lamps) → Penning effect

Radioactive substances: ^{85}Kr, ^{147}Pm, ThO_2

Operating voltage

- **Hg**
- **Trend towards the substitution of Hg (environmental aspect) → Zn**

Light emission

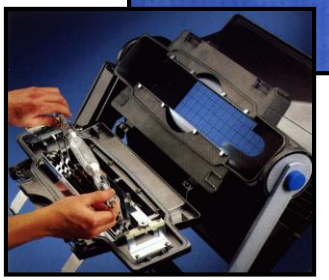
- **Hg**
- **Metal halides MeX_n (Me = Na, In, Tl, Sc, Sn, Dy, ...)**

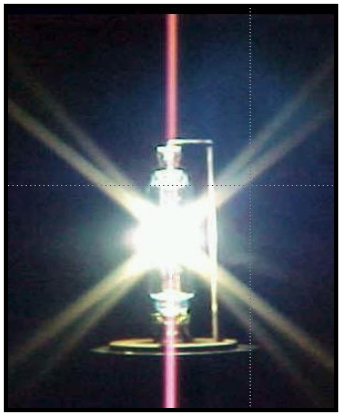
6.12 Photometric Data in Comparison

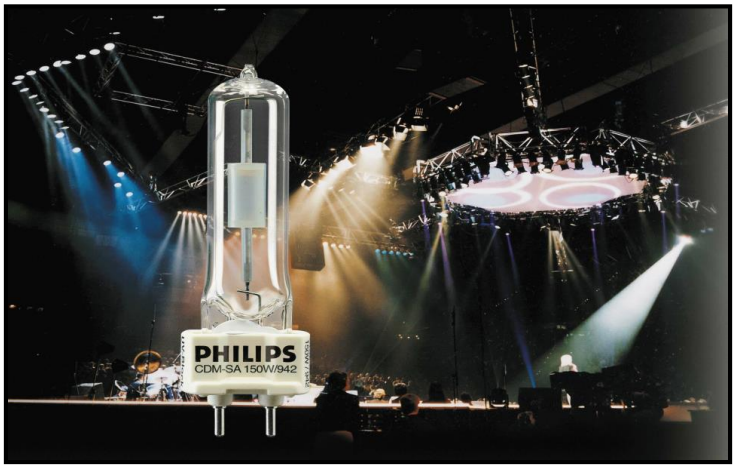
	Improvement	η (lm/W)	R_a	Color temperature T_c [K]
High Pressure Hg		60	20	6000
	+ phosphor	60	50	3800
High Pressure Na		60 - 130	20	2000
	Xe-pressure↑	80 - 150	20	2000
	Na-pressure↑	60 - 90	60	2200
Metal Halide	HPI (NaI-TlI-InI)	70 - 80	70	3800 - 4200
	$SnBr_2$-SnI_2	70	90	
	NaI-DyI_3	75 - 80	90	3800 - 5600
	NaI-ScI_3	80 - 90	75	3600 - 4200

6.13 Applications of MH Lamps

HPI	**Street lighting**
(NaI-TlI-InI)	**Architectural lighting**
	Sports field lighting
Tin	**Older type of lamp**
	is replaced by MH
$NaI-DyI_3$	**Sports field lighting**
$NaI-ScI_3$	**Shop lighting**
	Studio-stage-TV (SSTV)
	Automotive headlights
$NaI-ScI_3$ + Hg + Xe (blue)	

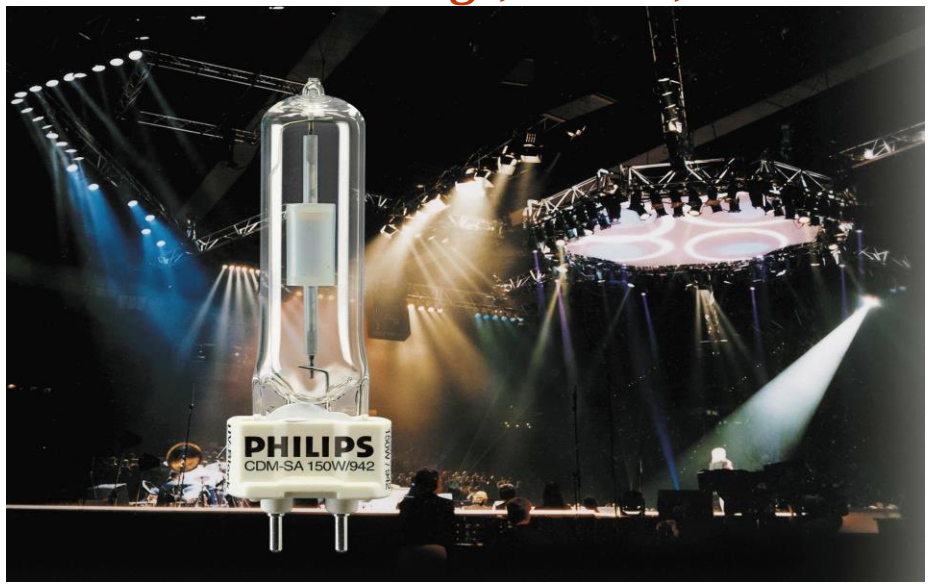




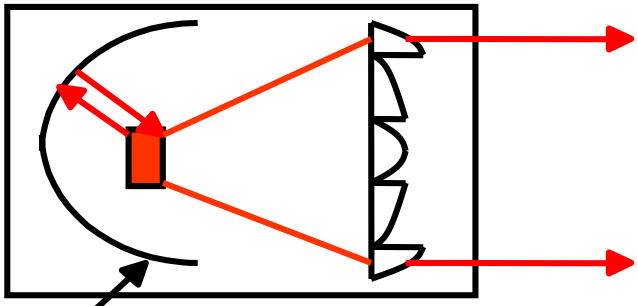


6.13 Applications of MH Lamps

SSTV market = Stage, Studio, and Television



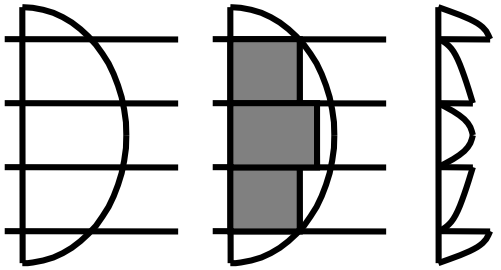
Reflector

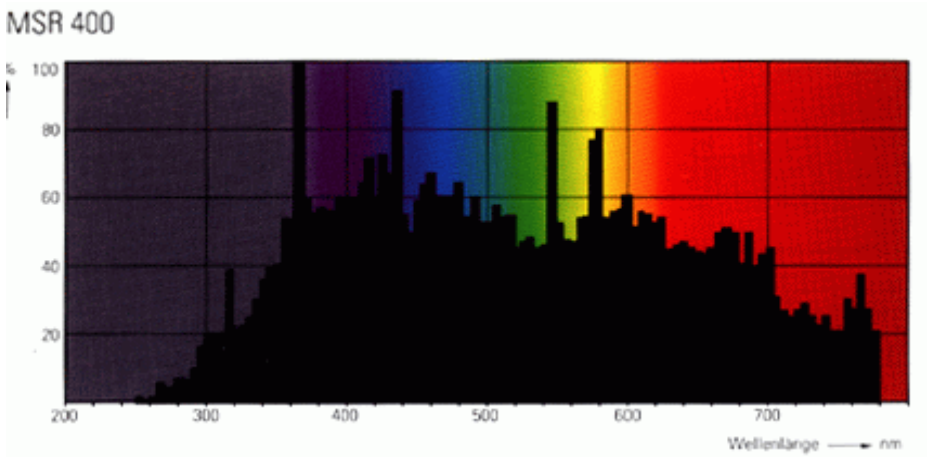


Spherical mirror

f

Fresnel-lens





6.13 Applications of MH Lamps

In the „beamer“

Warum Projektion ?

- Vorteile:
  - sehr große Bilder
  - kleines Volumen und Gewicht

Rückwärts-Projektion

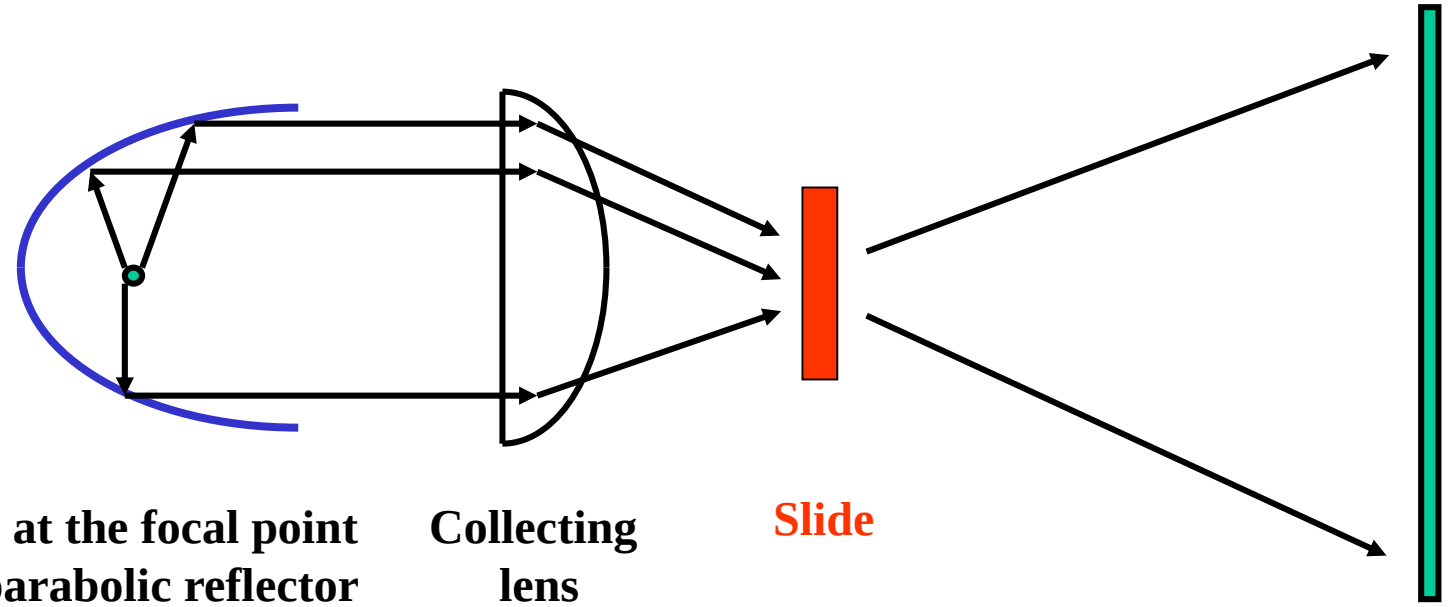
Professionelle Präsentationen

Heimkino

6.13 Applications of MH Lamps

Construction of a beamer

A projector is actually a slide projector (diascope)!



Lamp at the focal point in a parabolic reflector

Collecting lens

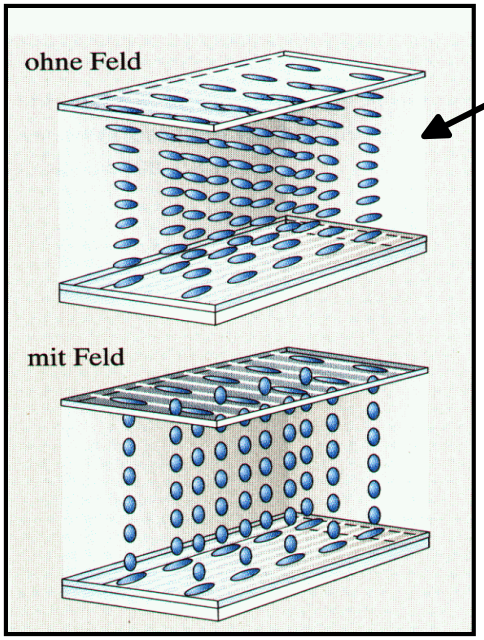
Slide

Projection screen

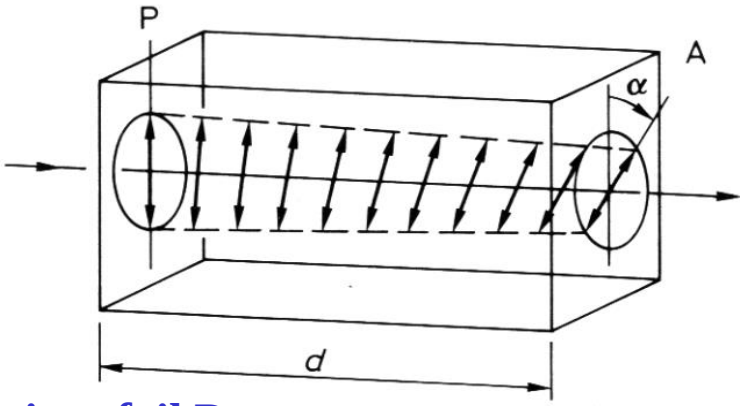
In a beamer the slide is replaced by a small LCD screen or by a DMD (Digital Mirror Device)

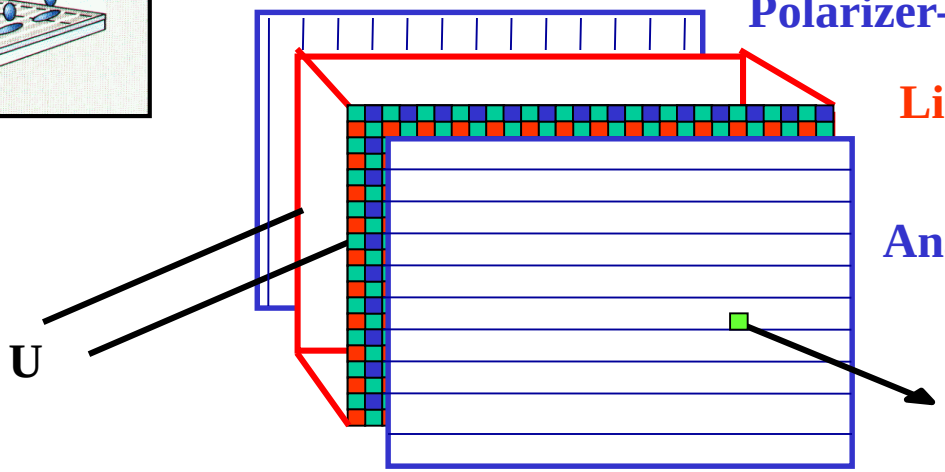
6.13 Applications of MH Lamps

Operating principle of a LCD (Liquid Crystal Display)



LCDs are based on liquid crystals, which rotate the polarization plane of polarised light by a rotational angle α





Polarizer-foil P

Liquid crystal cell (with ITO)

Analyzer foil (perpendicular to P)

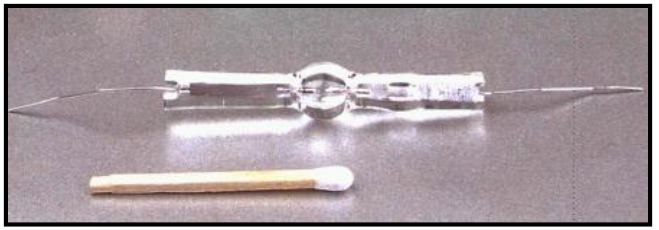
Pixel on for U = 0

Pixel off for U > 0

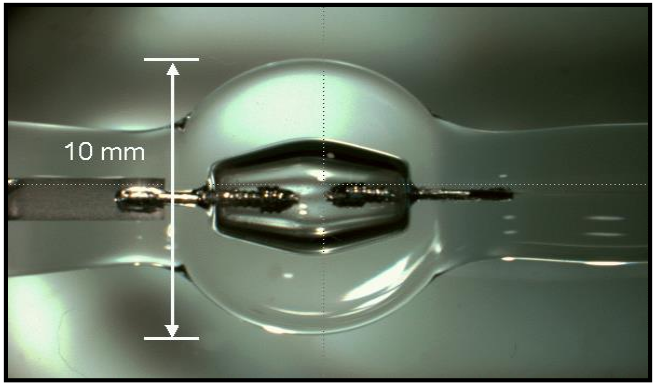
6.14 UHP-Lamps

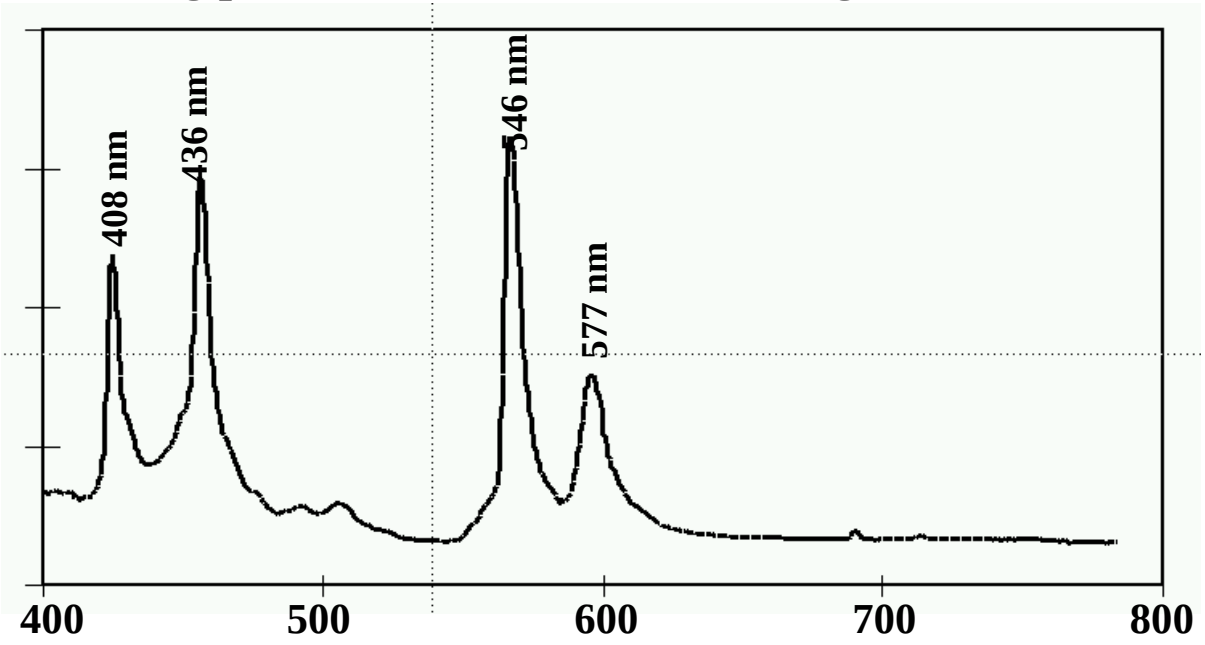
Requirements for light sources for projectors

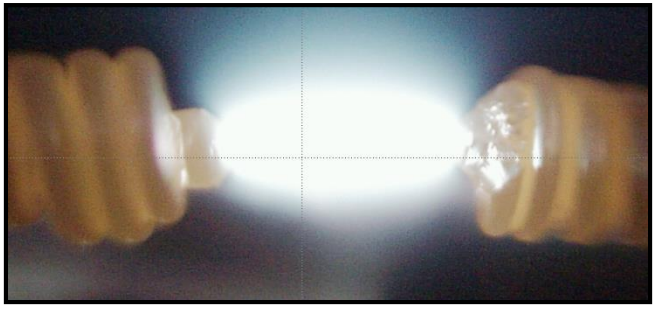
- If possible punctual ⇒ A lot of light from a small volume
- High luminance (light density) ⇒ High Hg-pressure



UHP = Ultra High Pressure (Performance)
⇒ Approx. 200 bar Hg, electrode separation ~ 1 mm
⇒ Strong pressure-broadened lines of Hg

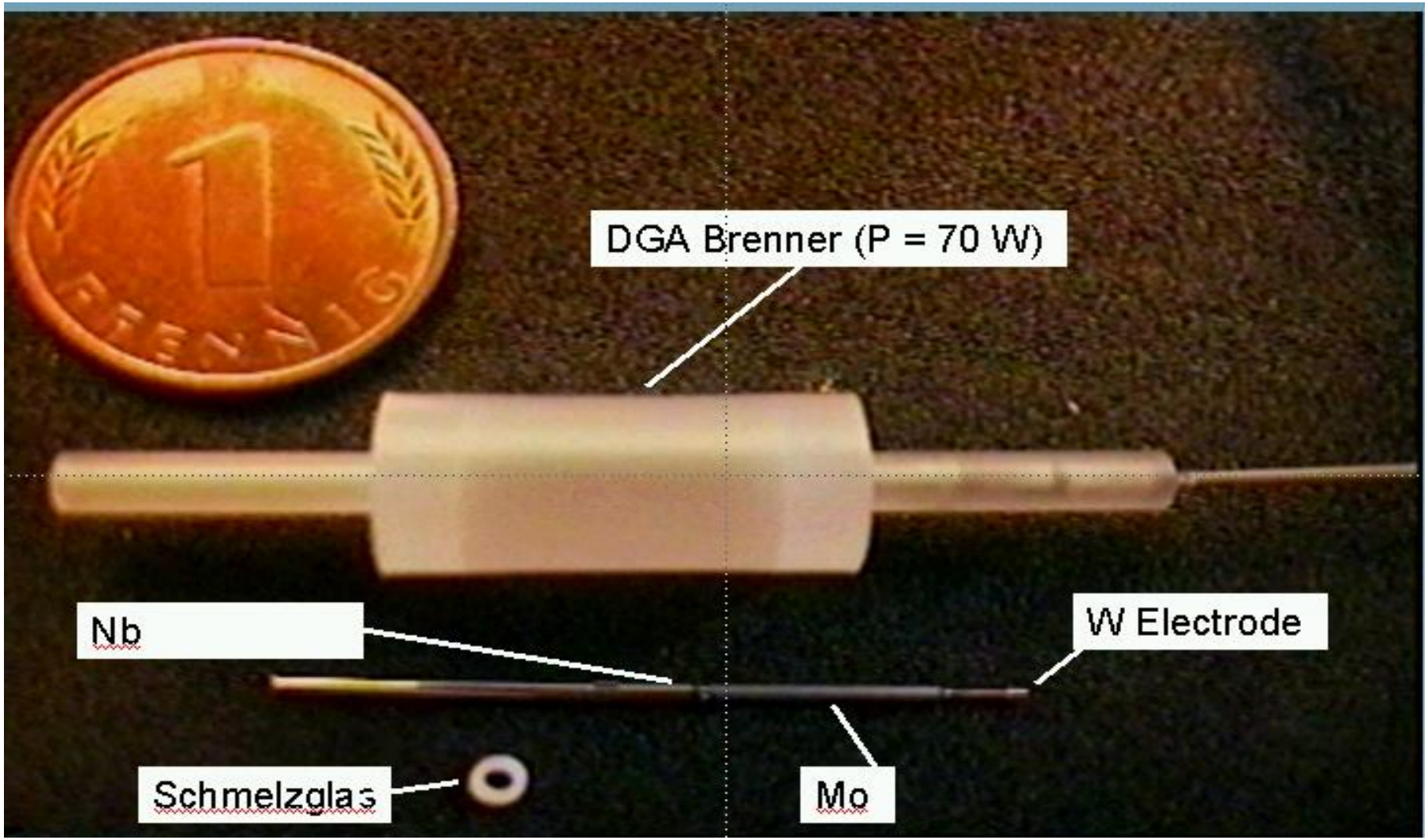






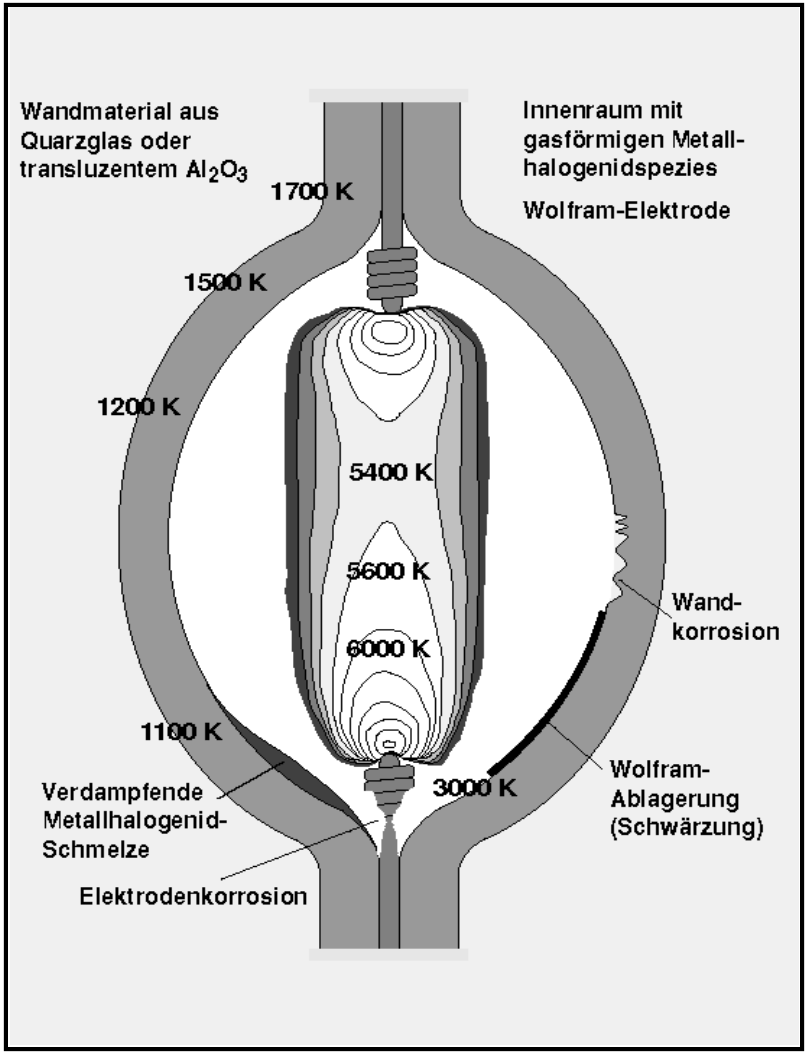
6.14 UHP-Lamps

Components of UHP-Lamps



6.14 UHP-Lamps

Design of UHP-lamps



Description of UHP-lamp by

- **Chemical equations**
  - **Vapor pressure of metal halides**
  - **Disintegration of the metal halides in the plasma**

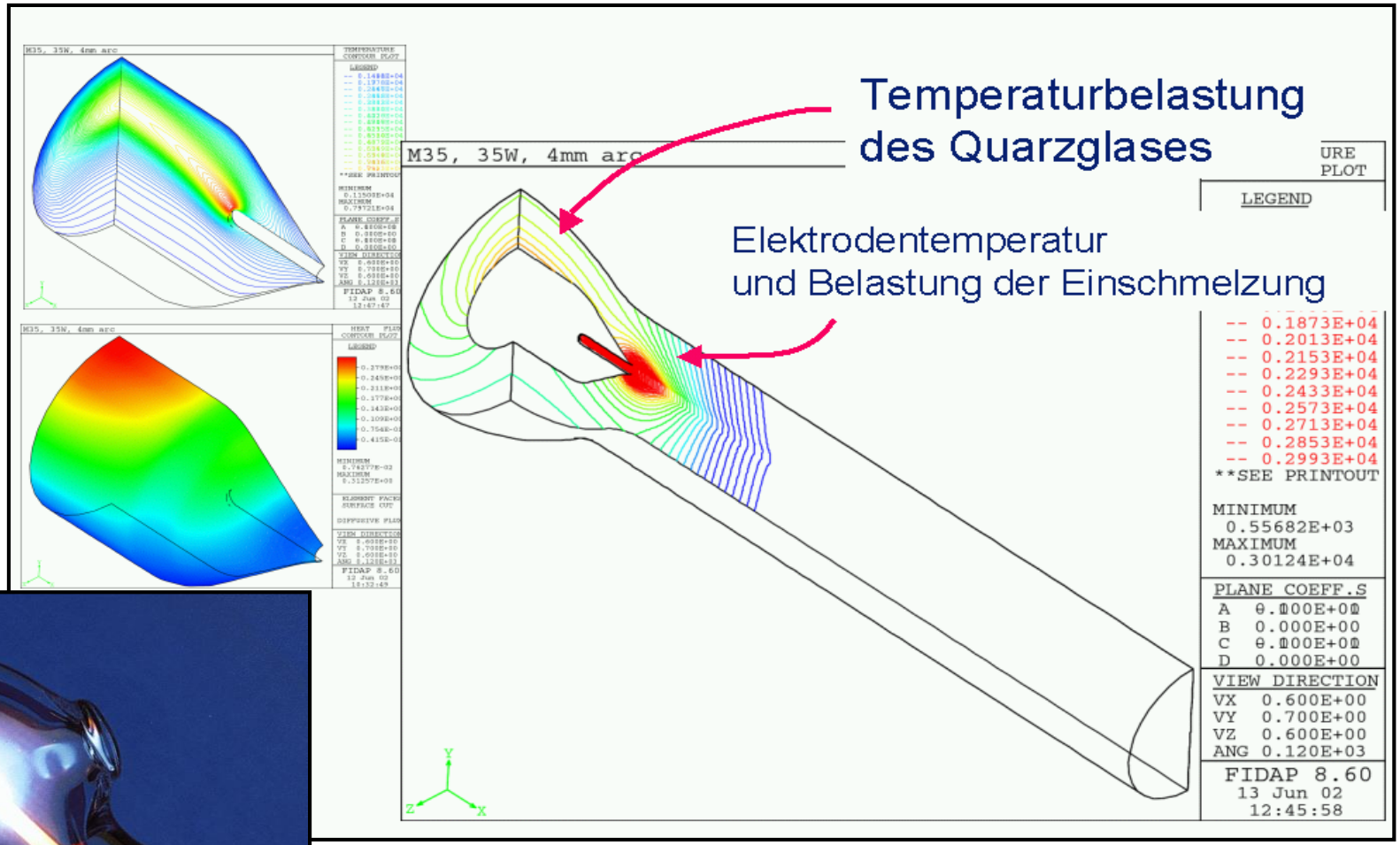
- **Temperature distribution in the plasma**
  - **Energy balance**
  - **Loss via radiation**
  - **Loss due to chemical energy**
  - **Loss due to heat**
    - **Convection (flow)**
    - **Heat conduction**

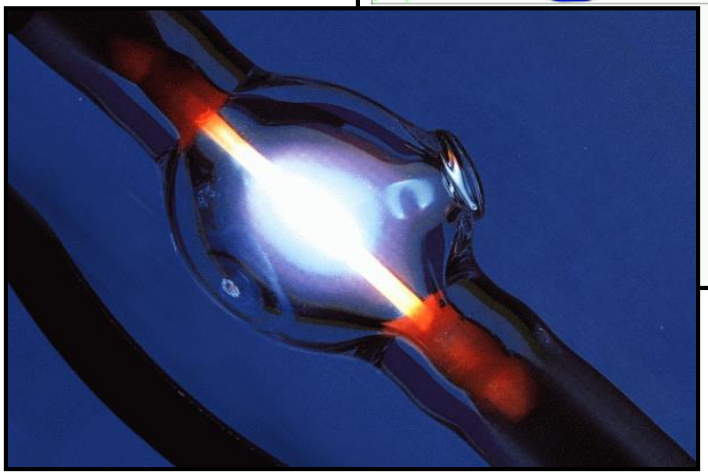
- **Convection equation = Navier-Stokes-Equation**

$$\Rightarrow \quad \frac{\partial^2 h}{\partial x'^2} + \frac{\partial^2 h}{\partial y'^2} = 0 \qquad \text{Potential: } h = z + \frac{u}{\gamma w}$$

- **Energy balance of the electrodes and the wall**

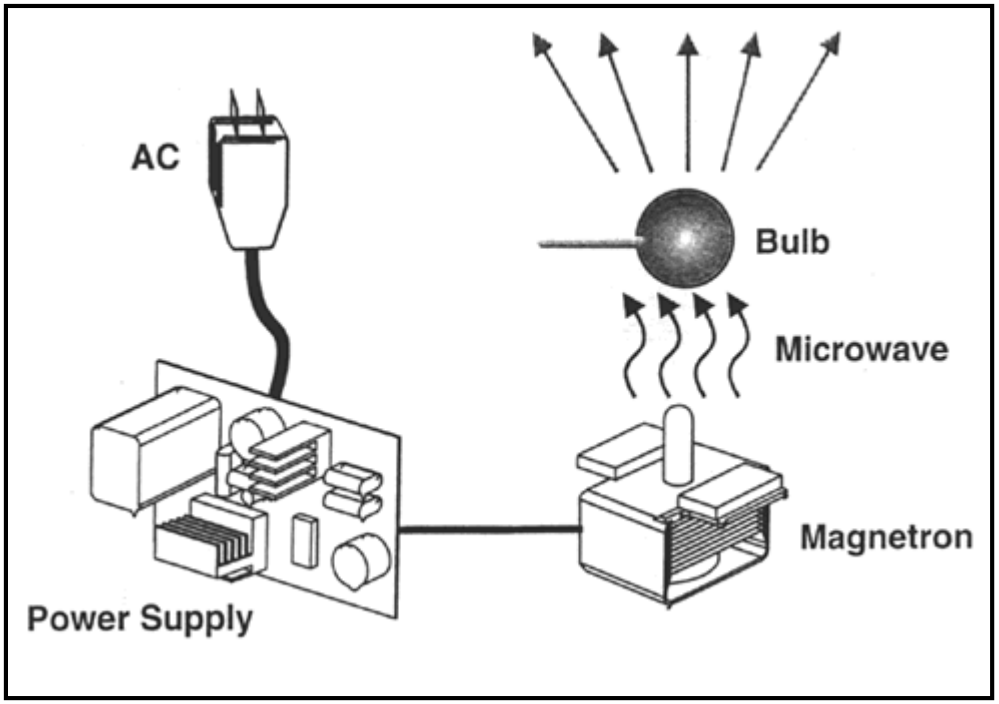
6.14 UHP-Lamps

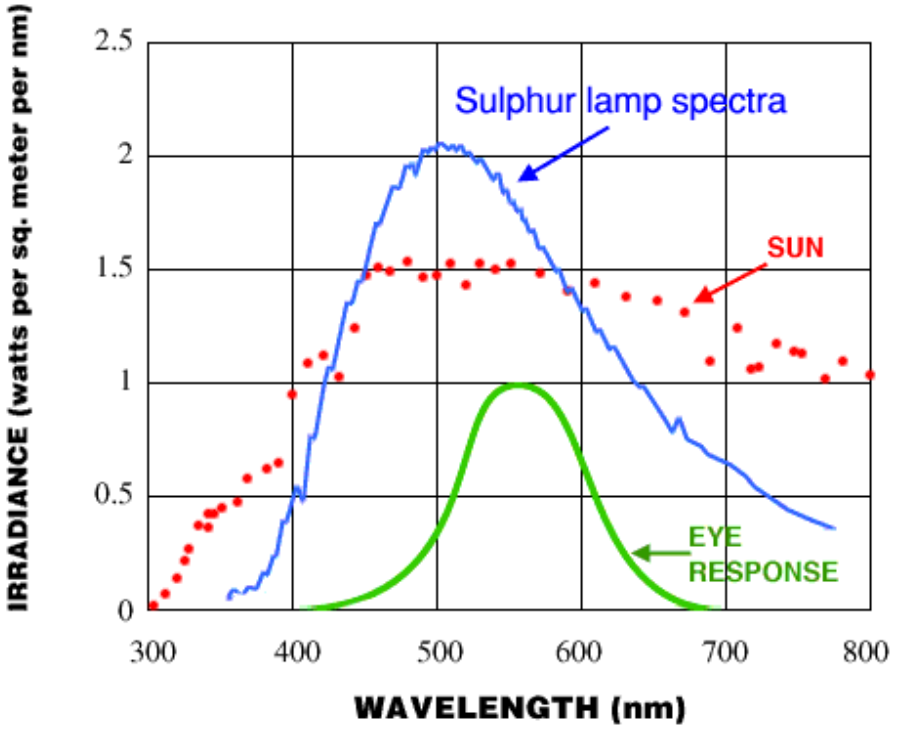




6.15 New Developments

Sulfur lamp: In 1990 the first discharge lamp based on a molecular sulfur discharge (S_4 – S_8) was develop





The energy coupling into the discharge takes place by means of a microwave generator (magnetron), because electrodes can not be used

6.15 New Developments

Sulfur lamp: To generate a very large luminous flux

Typical operating parameters
Input power: 1.400 W
Ball diameter: approx. 30 mm
Luminous flux: 135000 lm
Color temperature: 5700 K
Starting time: 25 s
Lifetime (lamp): 60.000 h
Lifetime (magnetron): 20.000 h
Light output: 95 lm/W

Light source with extremely high light output, about 140000 lm (~ 40 fluorescent tubes) and (almost) pure-white light (emission band of S_8, …. , S_2 molecules)

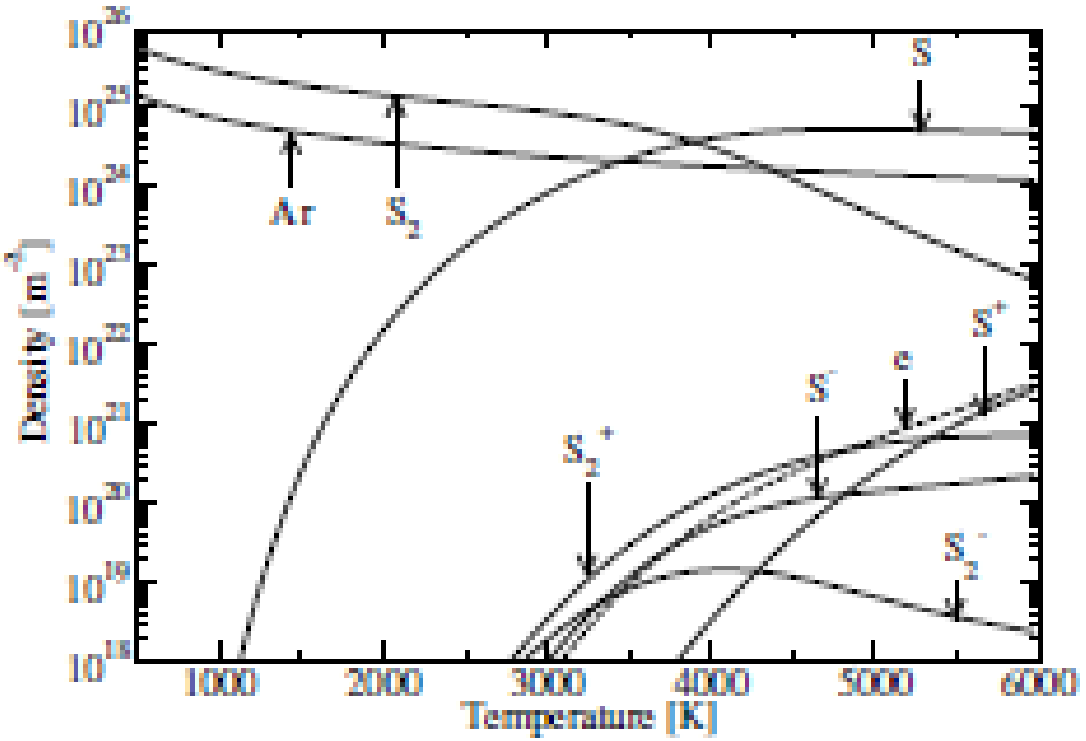
Efficiency: **Similar to fluorescent lights (thus 90 - 100 lm/W)**
Problems: **EMC and lifetime of the microwave generator**

6.15 New Developments

Sulfur lamp: Mechanism of light generation ⇒ Emission from molecules , e.g. S_2

Reaction			Energy [eV]
S_3	$\rightleftharpoons$	$S_3^+ + e$	10.6
S_3^-	$\rightleftharpoons$	$S_3 + e$	2.1
S_3	$\rightleftharpoons$	$S_2 + S$	0.8
S_2	$\rightleftharpoons$	$S_2^+ + e$	9.36
S_2^-	$\rightleftharpoons$	$S_2 + e$	1.67
S_2	$\rightleftharpoons$	$S + S$	4.46
S	$\rightleftharpoons$	$S^+ + e$	10.36
S^-	$\rightleftharpoons$	$S + e$	2.1

Reactants		Products	ΔE[eV]
$S_2 + X$	$\leftrightarrow$	$2S + X$	4.46
$S_2 + e$	$\leftrightarrow$	$S_2^+ + e + e$	9.36
S_2^-	$\leftrightarrow$	$S_2 + e$	1.8
$S + e$	$\leftrightarrow$	$S^+ + e + e$	10.4
S^-	$\leftrightarrow$	$S + e$	2.0
$Ar + e$	$\leftrightarrow$	$Ar^+ + e + e$	15.76

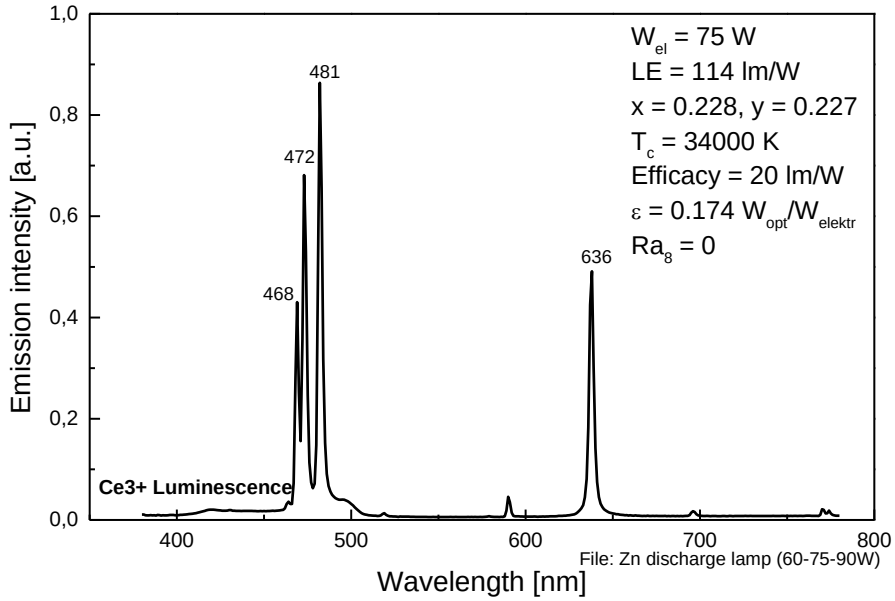


Lit.: C.W. Johnston, Transport and equilibrium in molecular plasmas: The sulfur lamp, Technische Universiteit Eindhoven, 2003

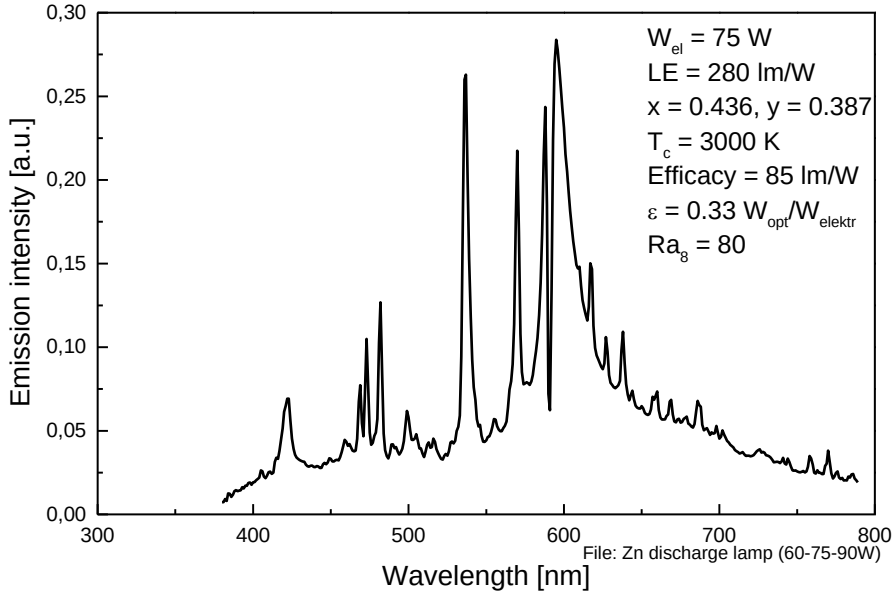
6.15 New Developments

Substitution of Hg by Zn (e.g. in automotive headlight lamps)

Zn/Ar Discharge



Zn/Ar/metal halide Discharge



	Zn-Ar	Zn-Ar-metal halide
η	20 lm/W	85 lm/W
Energy efficiency	17%	33%
R_a	0	80