Incoherent Light Sources

M. Sc. Chemical Engineering / Photonics

July 11th, 2019

Prof. Dr. T. Jüstel

Name: _____

Enrolment number: _____

Day 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 light sources used for general lighting. Please also figure the steps of the light generation pathway! (6 Points)

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

c) Please explain the expression „cathodoluminescence“! In which devices is such process of importance? (2 Points)

Task 2 **(10 Points)**

Terms related to lighting technology

Please define the following photometric and radiometric quantities and mention the respective physical units! (1 Point each)

Term	**Definition**	**Unit**
Radiant flux		
Luminous flux		
Irradiance		
Illuminance		
Luminous efficacy		

Task 3 **(10 Points)**

Incandescent and halogen lamps

a) Please mention suitable technical components for the construction of an incandescent or halogen lamp! (0.5 Points each)

Wire material	Gas filling	Glass type

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 (λ_{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 eye sensitivity of humans (555 nm)! (2 Points)

d) Please explain why such an incandescent lamp is not feasible from a material scientist point of view? (1 Point)

e) Please name two technical measures in order to enhance the lifetime and/or luminous efficacy of an incandescent lamp! (2 Points)

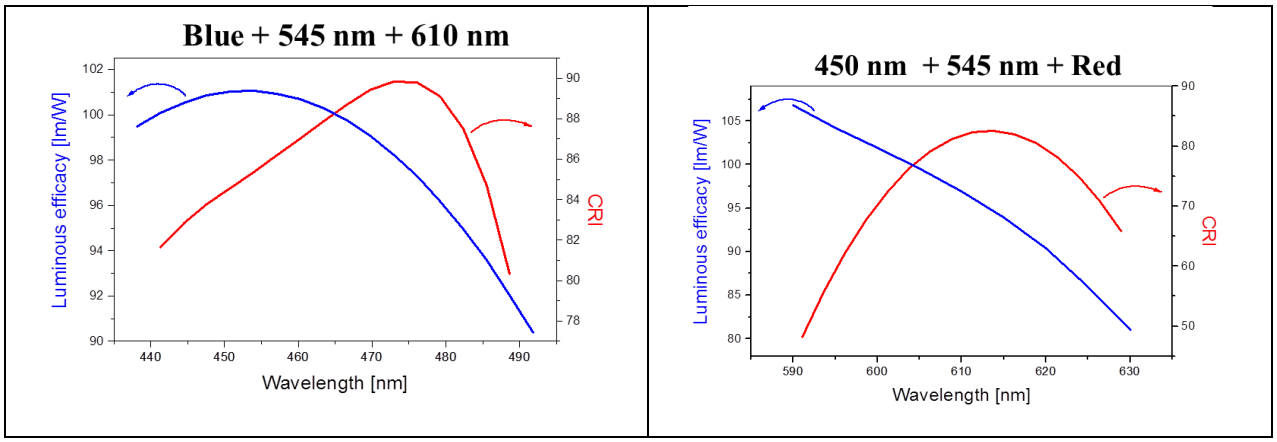
Task 4 **(10 Points)**

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 and 15% at 185 nm 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 in a linear fluorescent lamp! (4 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)

Task 5 **(10 Points)**

High-pressure gas discharge lamps

a) Please explain the origin of the spectral shift of a low-pressure Hg discharge with increasing pressure? (3 Points)

b) Please calculate the wall plug efficiency (energy efficiency) $\eta_{el.}$ of a low-pressure Hg discharge lamp if the driver efficiency η_{driver} is 90% is and the discharge efficiency $\eta_{discharge}$ is 30%! What is the luminous efficacy if the lamp spectrum relates to a lumen equivalent of 250 $lm/W_{optical}$? (2 Points)

c) Please name two application areas of high-pressure lamps and explain the advantage of such lamps over low-pressure lamps! (3 Points)

d) Please mention two technical measures to enhance the color rendering index of a high-pressure Hg discharge lamp! (2 Points)

Task 6 **(10 Points)**

Inorganic luminescent materials

Luminescent materials are activated by impurity ions, which yield certain emission color and decay curves. Please fill up the following table! (0.5 Points each)

Ion	**Electron configuration**	**Most relevant optical transition**	**Emission color**	**Time scale of the respective optical transition***
Pr^{3+}				
Ce^{3+}				
Eu^{2+}				
Tb^{3+}				
Eu^{3+}				

* nanoseconds, µ-seconds, milliseconds, or seconds

Task 7 **(10 Points)**

Luminescence mechanisms

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

b) Please name four reasons for the wide use of trivalent lanthanide ions in laser crystals and luminescent materials! (4 Points)

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

down-conversion

excited state absorption

up-conversion

energy transfer up-conversion

Task 8 **(10 Points)**

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 these nitrides and phosphides. Please also compare the two solid solutions with each other! (3 Points)

b) Explain the success of III-V semiconductor LEDs with respect to lifetime, temperature resistance, spectral consistency, and efficacy! (4 Points)

c) Please mention a measure to enhance the wall plug efficiency of LEDs! (1 Points)

d) Please explain the term multi quantum well and comment on its importance for inorganic LEDs! (2 Points)

Task 9 **(10 Points)**

Organic Light Emitting Diodes (OLEDs)

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

b) Explain the reason for the use of a hole blocking layer in modern OLEDs! (2 Points)

c) Give two reasons for the use of Ir^{3+} complexes in OLEDs? (2 Points)

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

e) Briefly describe the technical process to manufacture OLEDs! Compare this process to the manufacturing process of polymer LEDs (PLEDs)! (2 Points)

Task 10 **(10 Points)**

UV Radiation Sources

a) Which chemical reactions are triggered by UV radiation in the tropo-, strato- and ionosphere? (3 Points)

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

c) What is the temperature of a black body radiator with peak emission at 265 nm (Wien's displacement law: λ_{max}= 2880 / T [µm*K])? What kind of celestial object will emit such a spectrum? (2 Points)

d) Calculate the energy efficiency (wall-plug efficiency) $\eta_{el.}$ of an UV radiation source based on a Xe excimer discharge (172 nm, discharge efficiency = 70%, driver efficiency 90%) and an UV-C phosphor (265 nm, Quantum Efficiency QE = 90%)! (2 Points)

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