Incoherent Light Sources

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

July 09th, 2024

Prof. Dr. Thomas Jüstel

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	
Task 1:	10 Points
Task 2:	10 Points
Task 3:	10 Points
Task 4:	10 Points
Task 5:	10 Points
Task 6:	10 Points
Task 7:	10 Points
Task 8:	10 Points
Task 9:	10 Points
Task 10:	10 Points

Mark	
1.0	95 – 100 Points
1.3	90 – 94 Points
1.7	85 – 89 Points
2.0	80 – 84 Points
2.3	75 – 79 Points
2.7	70 – 74 Points
3.0	65 – 69 Points
3.3	60 – 64 Points
3.7	55 – 59 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 importance of blue light for the realization of white light sources! Which technical solutions are known to you to generate blue light? (3 Points)

c) Please define the terms “light outcoupling” and explain its importance for the wall plug efficiency of electrical light sources! (2 Points)

d) Please explain the process of chemiluminescence as result of the oxidation of white phosphor P_4 (comment: this process is the origin of the term phosphorescence)! (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 eye sensitivity curves for photopic and scotopic vision and name two reasons for the shape of these curves! (4 Points)

c) Please explain the term “colour temperature” and its determination! (2 Points)

d) Please explain why the resolution of the human eye depends on the colour and why black and white images are perceived by humas with the highest resolution! (2 Points)

Task 3 **(10 Points)**

Incandescent and halogen lamps

a) Please sketch schematically the spectrum of a black body radiator at a temperature of 2700 and of 4000 K! Please also subdivide the x-axis into the spectral ranges UV, VIS, and NIR! (2 Points)

b) 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 sensitivity of the human eye (555 nm)! (2 Points)

c) Mention two properties of the ideal material for the filament of incandescent and halogen lamps? Which is thus the best material? (3 Point)

d) Please explain the 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 = ρ l/A with ρ = specific resistance)! Please also name a technical measure in order to enhance the lifetime of incandescent lamps! (3 Points)

Task 4 **(10 Points)**

Quantitative Terms for Lighting Technology

a) Please explain the following terms used in lighting technology! (1 Points each)

- Wall plug efficiency
- Luminous flux
- Luminous efficacy
- Illuminance

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, tubular)	36 W	30%		300		
Warm-white LED	5 W	50%		280		

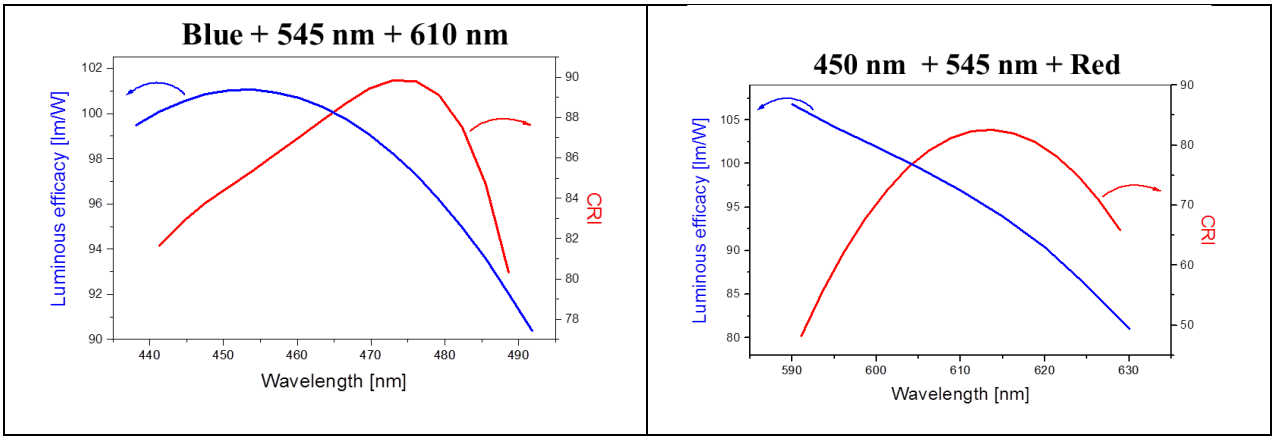
Task 5 **(10 Points)**

Low-pressure gas discharge lamps

a) Please name two reasons why Na or Hg are mostly used as emitter in low-pressure discharge lamps! (2 Points)

b) Please sketch the electrode of a fluorescent lamp and explain the purpose of the coating! (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 the glass tubes of fluorescent lamps are precoated by α-Al_2O_3 or Y_2O_3! (2 Points)

Task 6 **(10 Points)**

Inorganic luminescent materials

a) Explain the working principle of an arbitrary luminescent material by a simple sketch! (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 term sensitization and give an example for a material that uses an sensitizer! (2 Points)

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

Task 7 **(10 Points)**

Luminescence mechanisms

a) Please explain the term s^2-ion and give an example for a technical relevant ion! (2 Points)

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

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

cross-relaxation (CR)

excited state absorption (ESA)

energy-transfer up-conversion (ETU)

photoionization (PI)

d) Please explain by term afterglow and propose a mechanistic model by a simple sketch! (2 Points)

Task 8 **(10 Points)**

Inorganic Light Emitting Diodes (LEDs)

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

Material	Electronic band gap
AlN	6.2 eV
GaN	3.5 eV
InN	2.0 eV

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

c) Please mention two physical processes which determine the wall plug efficiency of inorganic LEDs! (2 Points)

d) Please name two physical processes for the cooling of LEDs and discuss the advantage of the flip-chip design for high-power LEDs! (3 Points)

Task 9 **(10 Points)**

Organic Light Emitting Diodes (OLEDs)

a) Describe the process of manufacturing of OLEDs and PLEDs. Please also explain the causes for the different manufacturing processes! (3 Points)

b) Explain the causes for the dominance of Ir^{3+} complexes in OLEDs? (3 Points)

c) Sketch the light generation chain in a typical OLED! (4 Points)

Task 10 **(10 Points)**

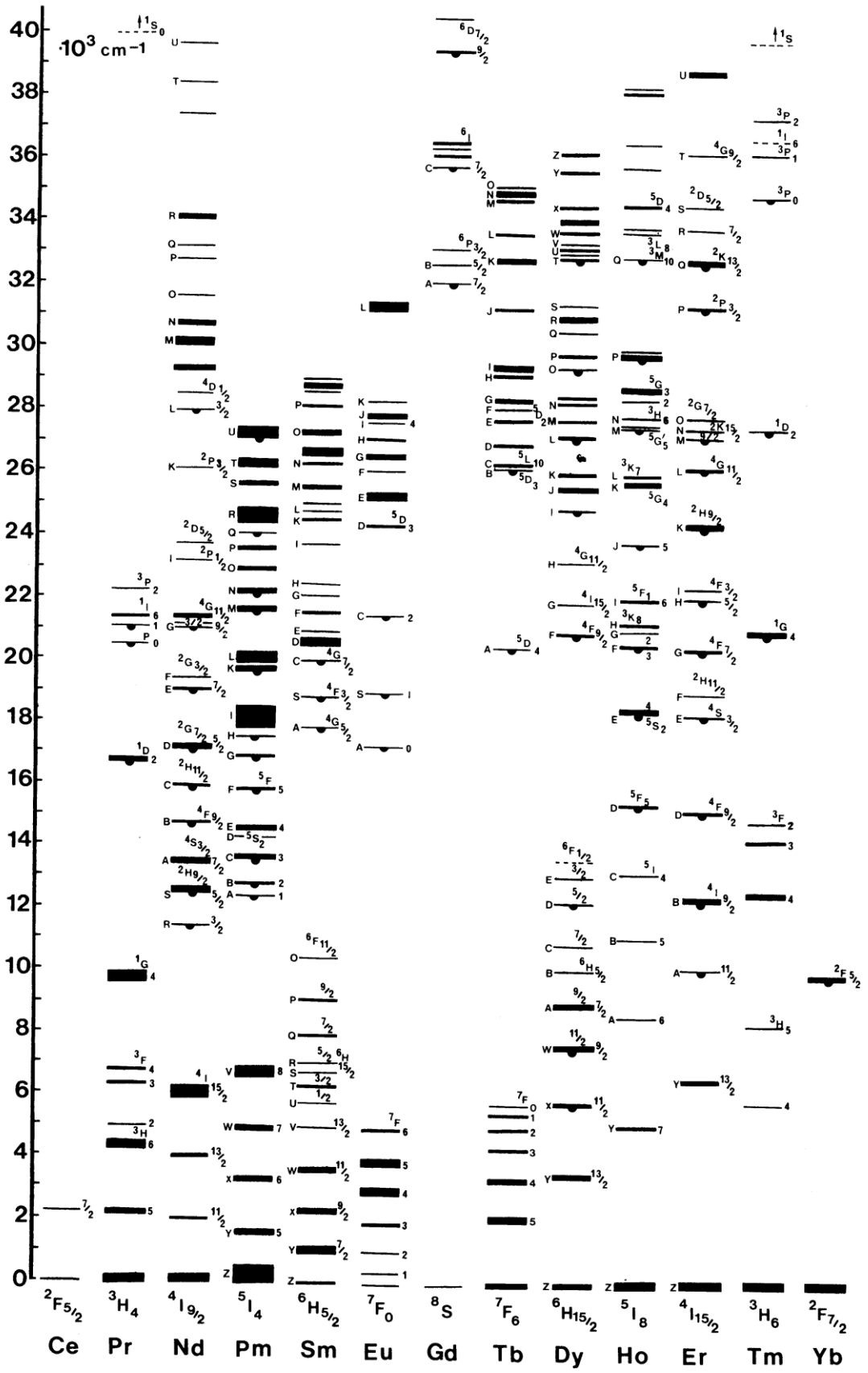
UV Radiation Sources

a) Please name four types of artificial UV radiation sources! (4 Points)

b) Please name three technically relevant photochemical reactions and propose a suitable UV radiation source for each of them! (3 Points)

c) Calculate the wall-plug efficiency ε of an electrical UV radiation source comprising a discharge vessel with a Hg low-pressure discharge (discharge efficiency $\varepsilon_{discharge}$ = 70%, 15% 185 nm and 85% 254 nm), a high frequency driver (ε_{driver} = 90%), and an UV-B phosphor (La,Bi)B_3O_6:Gd, 311 nm, QE = 90%)! (3 Points)

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



Appendix: Periodic Table of the Elements

hydrogen 1 **H** 1.0079																		helium 2 **He** 4.0026
lithium 3 **Li** 6.941	beryllium 4 **Be** 9.0122												boron 5 **B** 10.811	carbon 6 **C** 12.011	nitrogen 7 **N** 14.007	oxygen 8 **O** 15.999	fluorine 9 **F** 18.998	neon 10 **Ne** 20.180
sodium 11 **Na** 22.990	magnesium 12 **Mg** 24.305												aluminium 13 **Al** 26.982	silicon 14 **Si** 28.086	phosphorus 15 **P** 30.974	sulfur 16 **S** 32.065	chlorine 17 **Cl** 35.453	argon 18 **Ar** 39.948
potassium 19 **K** 39.098	calcium 20 **Ca** 40.078		scandium 21 **Sc** 44.956	titanium 22 **Ti** 47.867	vanadium 23 **V** 50.942	chromium 24 **Cr** 51.996	manganese 25 **Mn** 54.938	iron 26 **Fe** 55.845	cobalt 27 **Co** 58.933	nickel 28 **Ni** 58.693	copper 29 **Cu** 63.546	zinc 30 **Zn** 65.39	gallium 31 **Ga** 69.723	germanium 32 **Ge** 72.61	arsenic 33 **As** 74.922	selenium 34 **Se** 78.96	bromine 35 **Br** 79.904	krypton 36 **Kr** 83.80
rubidium 37 **Rb** 85.468	strontium 38 **Sr** 87.62		yttrium 39 **Y** 88.906	zirconium 40 **Zr** 91.224	niobium 41 **Nb** 92.906	molybdenum 42 **Mo** 95.94	technetium 43 **Tc** [98]	ruthenium 44 **Ru** 101.07	rhodium 45 **Rh** 102.91	palladium 46 **Pd** 106.42	silver 47 **Ag** 107.87	cadmium 48 **Cd** 112.41	indium 49 **In** 114.82	tin 50 **Sn** 118.71	antimony 51 **Sb** 121.76	tellurium 52 **Te** 127.60	iodine 53 **I** 126.90	xenon 54 **Xe** 131.29
caesium 55 **Cs** 132.91	barium 56 **Ba** 137.33	57-70 *	lutetium 71 **Lu** 174.97	hafnium 72 **Hf** 178.49	tantalum 73 **Ta** 180.95	tungsten 74 **W** 183.84	rhenium 75 **Re** 186.21	osmium 76 **Os** 190.23	iridium 77 **Ir** 192.22	platinum 78 **Pt** 195.08	gold 79 **Au** 196.97	mercury 80 **Hg** 200.59	thallium 81 **Tl** 204.38	lead 82 **Pb** 207.2	bismuth 83 **Bi** 208.98	polonium 84 **Po** [209]	astatine 85 **At** [210]	radon 86 **Rn** [222]
francium 87 **Fr** [223]	radium 88 **Ra** [226]	89-102 **	lawrencium 103 **Lr** [262]	rutherfordium 104 **Rf** [261]	dubnium 105 **Db** [262]	seaborgium 106 **Sg** [266]	bohrium 107 **Bh** [264]	hassium 108 **Hs** [269]	meitnerium 109 **Mt** [268]	ununnilium 110 **Uun** [271]	unununium 111 **Uuu** [272]	ununbium 112 **Uub** [277]		ununquadium 114 **Uuq** [289]				

* Lanthanide series	lanthanum 57 **La** 138.91	cerium 58 **Ce** 140.12	praseodymium 59 **Pr** 140.91	neodymium 60 **Nd** 144.24	promethium 61 **Pm** [145]	samarium 62 **Sm** 150.36	europium 63 **Eu** 151.96	gadolinium 64 **Gd** 157.25	terbium 65 **Tb** 158.93	dysprosium 66 **Dy** 162.50	holmium 67 **Ho** 164.93	erbium 68 **Er** 167.26	thulium 69 **Tm** 168.93	ytterbium 70 **Yb** 173.04
** Actinide series	actinium 89 **Ac** [227]	thorium 90 **Th** 232.04	protactinium 91 **Pa** 231.04	uranium 92 **U** 238.03	neptunium 93 **Np** [237]	plutonium 94 **Pu** [244]	americium 95 **Am** [243]	curium 96 **Cm** [247]	berkelium 97 **Bk** [247]	californium 98 **Cf** [251]	einsteinium 99 **Es** [252]	fermium 100 **Fm** [257]	mendelevium 101 **Md** [258]	nobelium 102 **No** [259]