Incoherent Light Sources

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

September 17th, 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		**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 distinguish between thermal and non-thermal radiation sources! (2 Points)

c) Please explain the expression „chemoluminescence“ and illustrate it by the reaction of white Phosphor P_4 with molecular Oxygen! (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		
Irradiance		
Luminous flux		
Illuminance		
Wall plug efficiency		

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 cannot be constructed from a material scientist point of view? (1 Point)

e) Please sketch the chemical transport reaction in halogen lamps! (2 Points)

Task 4 **(10 Points)**

Quality figures of light sources

a) Please define the term “Luminous efficacy”! (1 Point)

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, in which common light sources are sorted by their energy efficiency! 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/$W_{el.}$]**
Incandescent lamp	100 W	5%		200		
Halogen lamp	50 W	10%		250		
Low-pressure Hg discharge lamp (fluorescent lamp, tubular)	36 W	30%		300		
Low-pressure Na discharge lamp	200 W	40%		500		
Warm-white LED	5 W	50%		280		
Cold-white LED	5 W	80%		350		

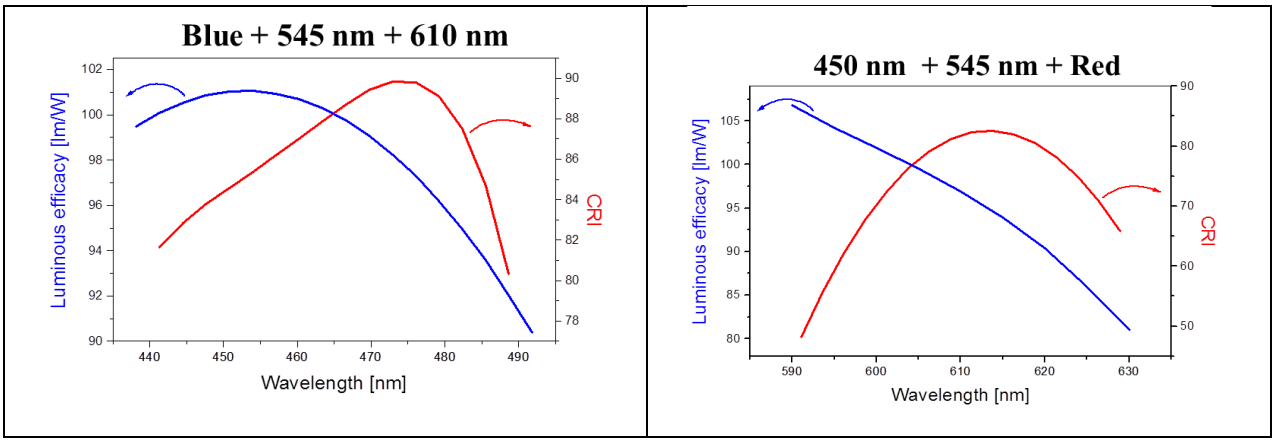
Task 5 **(10 Points)**

Low-pressure gas discharge lamps

a) Please name two reasons why Na or Hg are mostly used as primary emitter in low-pressure discharge lamps! (2 Points) (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 typical activator ions, which are used in luminescent materials for low-pressure Hg discharge lamps! (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 the importance of lanthanide ions as activators in many phosphors for light sources and for full color displays! (2 Points)

Task 7 **(10 Points)**

Luminescence mechanisms

a) Please explain the term up-conversion by a self-chosen example! (2 Points)

b) Please name the dominant luminescence mechanism causing the photoluminescence of the following activators ions! (each 1 Point)

Ti^{3+}

Mn^{4+}

Ce^{3+}

Eu^{3+}

Eu^{2+}

WO_4^{2-}

Sn^{2+}

Bi^{3+}

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, color rendering, and wall plug efficacy! (3 Points)

c) Please mention two measures to enhance the wall plug efficiency of LEDs! (2 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 for the dominance 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)

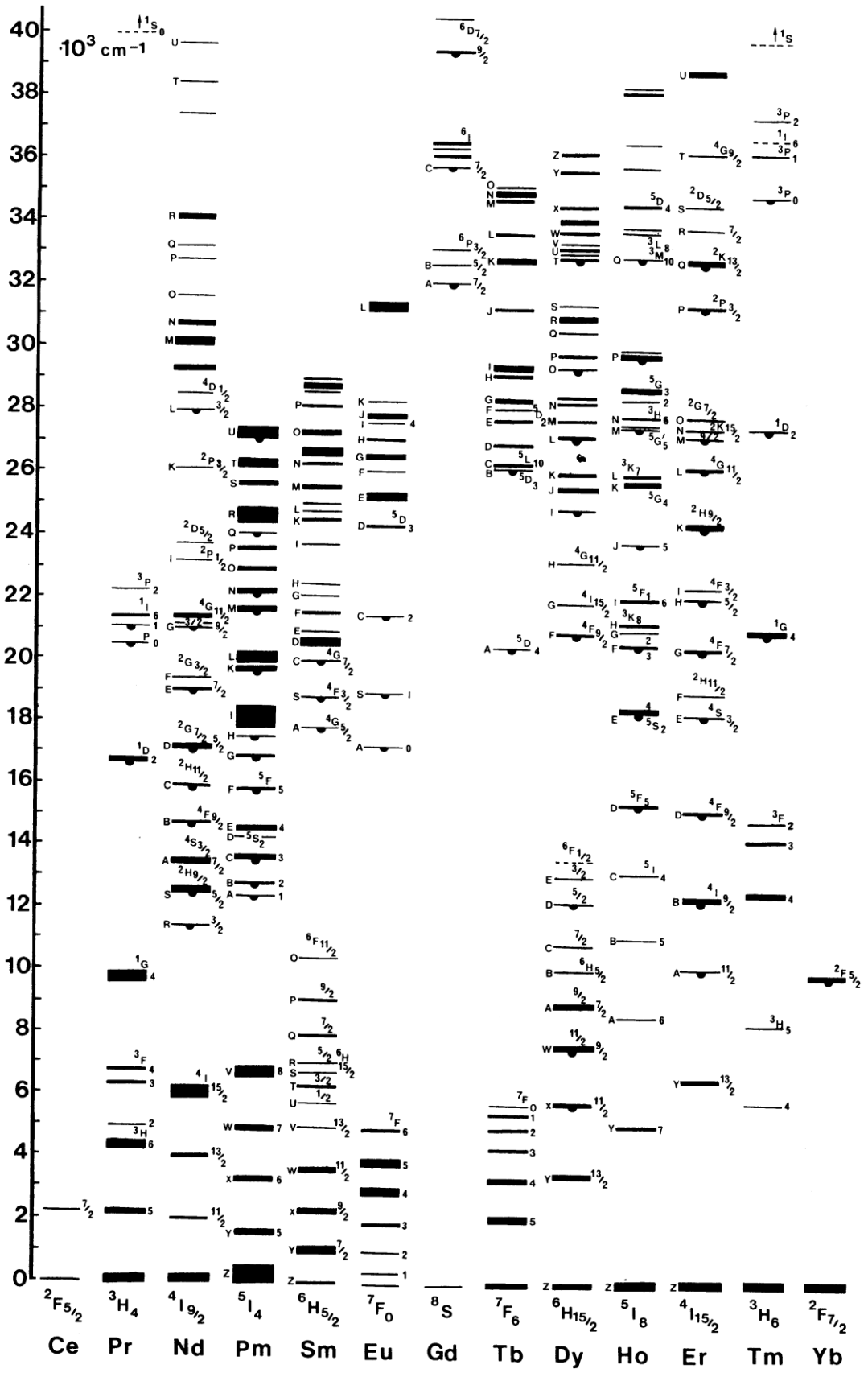
UV Radiation Sources

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

b) Please name four types of artificial UV radiation sources? (4 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]