Photonics Exercise 1
Ray Optics

Group 1
Antti Mäki
Chris Edwards
Eino Tyrvanen
Kirill Eliutin
Oskari Leiviskä
Sandra Dorfer
Yerkezhan Baltasheva

24.01.2023

Contents

If you have any questions, please contact Eliutin Kirill <kirill.eliutin@aalto.fi>. After you finished, please also send the answers to Kirill! Thanks.

Exercise 1: Geometric optics

Explain in your own words:

(a) Why in the lecturer's 'water-fiber' experiment shown during the lecture, does the laser light bend and follow the arc of the water flowing out of the bottle? Does 100% of the light follow the water's path, and explain why/why not? Does this effect also occur for ultraviolet light?


(b) Why does a rooftop covered with sheet iron scatter visible light waves but reflect radiowaves?

Exercise 2: Maxwell's equations and plane waves

(a) Derive non-homogeneous electromagnetic wave equations (both **E** and **H**) for space with nonzero current density **J** and charge ρ. Assume the medium to be isotropic and homogeneous.

(b) Now, consider a plane wave propagating in a lossless non-magnetic ($\mu = \mu_0$) homogeneous medium. Calculate the relative permittivity for the material, when $k = 4.139 \times 10^{-5}$ rad/m and $\omega = 6.283 \times 10^3$ rad/s. What material the medium could be, based on the permittivity? Find the table with permittivity of different materials at
https://electronicsreference.com/references/relative-permittivity/
(Hint: start with Faraday's law: $\nabla \times E = \mu \frac{\delta H}{\delta t}$, and Ampere's law: $\nabla \times H = J + \varepsilon \frac{\delta E}{\delta t}, J = \sigma E$)

Exercise 3: Wave-particle duality

(a) Particle properties

I. From the previous exercise we concluded that light acts as a wave, now we take a look at its other properties. We examine the photoelectric effect(1): in this experiment, we shine a light onto a metal surface and measure the current produced by the electrons ejected from the material. The collector plate where the electrons are heading, is charged negatively to find out how much kinetic energy the electrons hold, by seeing how much repelling voltage they are able to overcome. When physicists first performed the experiment, the results(Fig. 2) were surprising:

1. The measured current depended on light intensity, but also had a dependence on frequency such that below a minimum threshold no current was measured
2. Even with low intensity of light, a delay in the start of the current was expected, but the start of the current was immediate
3. The kinetic energy of the electrons did not depend on the intensity of the light, but rather had a linear dependency on the frequency of the light.

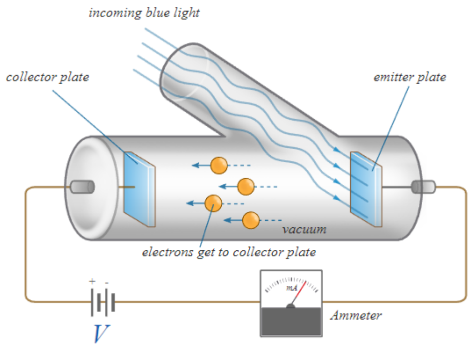

Figure 1: Photoelectric effects

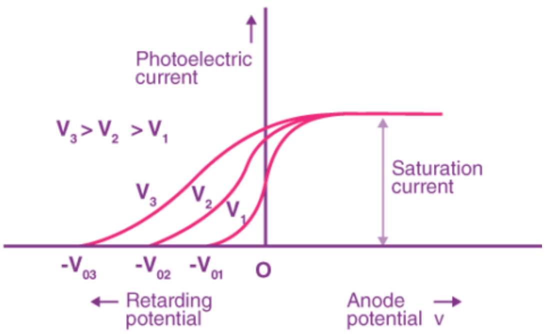

Figure 2: Photoelectric current

Explain how these results contradict the model of light acting only as a wave, and introduce the notion of a wave particle duality. Include the formula $E = hf$, for a photon.
(The answer does not have to be long, as long as you answer the essence of the question, it is fine)

II. For a given metal surface, the energy required to expel an electron is 10 eV. Calculate the maximum wavelength of light capable of emitting photoelectrons.

(b) Choose if the property/experiment can be described by the wave or particle theory, or both

property / experiment	**wave**	**particle**	**both**
spread of light			
energy absorption & consumption			
light diffraction			
single/double slit experiment			
photo effect			
heat radiation			
interference of light			

Exercise 4: Identifying elements with spectrometry

Spectrometry is a technique which allows us to conduct research by measuring a spectral pattern of reflected, emitted or transmitted light. For example, by looking at the emission patterns of some object, we can conclude which elements it consists of. Usually spectrometer's main component is a diffraction grating - a plate with a very frequent grid of very thin transparent slits, the light passing through experiences diffraction, and light of different wavelengths travels in different angles after passing through the grating. To calculate, at which angles would be the peaks for different wavelengths, the following relationship can be used:

$$n\lambda = d \sin\theta,$$

where n is the number of the peak (every wavelength is diffracted to several consecutive peaks), d is the period of the grating (typically in the range of micrometers), θ is the angle between the ray and the normal of the grating, λ is the wavelength of the light.

Imagine you have an object that emits light, and you are trying to find out, which ones of the first four elements (H, He, Li, Be) are present in the object (can be several of them). For that you use a spectrometer with a diffraction grating of period 2×10^{-6} m and a screen 40 cm away from the grating *(center of the screen is aligned with the center of the grating).*

When you place the object into the spectrometer, you can see that the central area is too bright to distinguish individual peaks, but you can notice that two *consecutive* sets of peaks are quite clearly visible. You measure their distances away from the center of the screen: 18 cm, 18.9 cm, 22.6 cm, 29 cm, 30.8 cm, 34.8 cm, 31.2 cm, 33.3 cm, 43.8 cm, 74.3 cm, 90.7 cm, 220.9 cm. Using the given spectra of the elements (Fig. 3), reason which ones are most likely to be present in the object. *(Note: some of the spectral lines from the element can be too dim and not be visible, but, if you find that some wavelength is present in the image, you can assume that it came from one of the first four elements)*

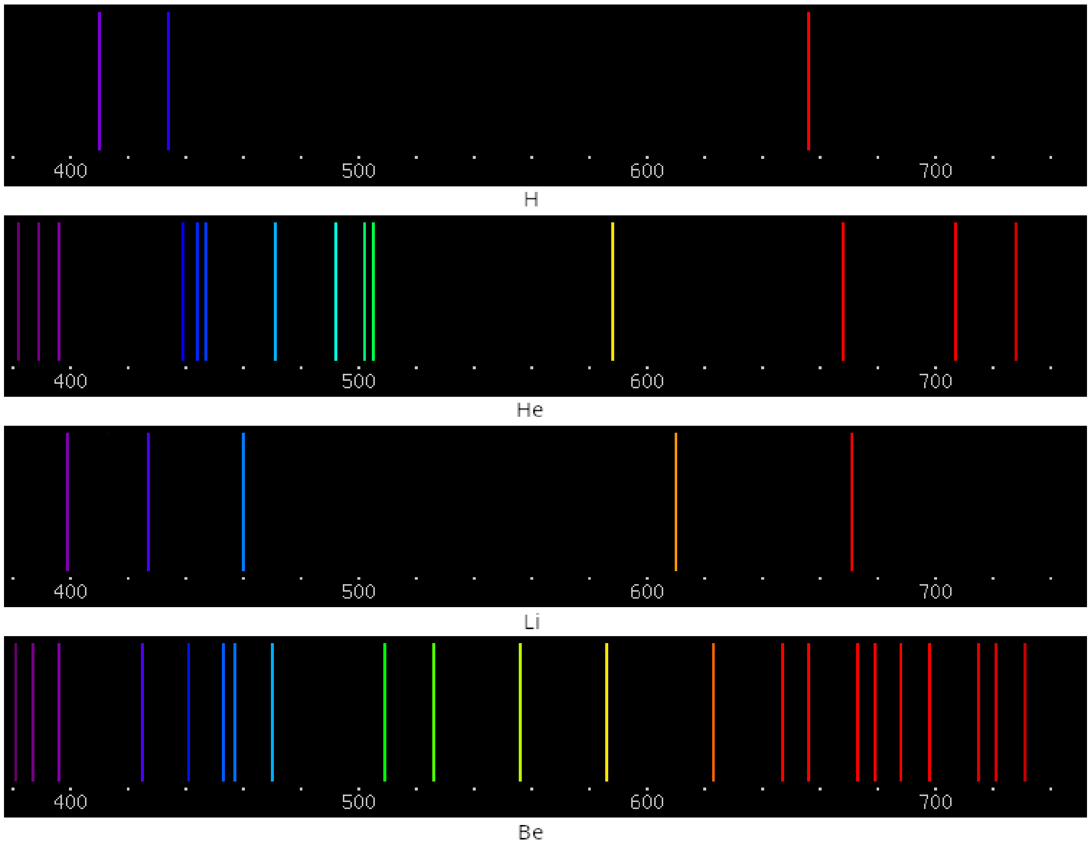

Figure 3: Emission spectra

(Hint: several repetition of the entire spectra don't overlap, so you can consider first half of peaks to be number n, and the second half to be n+1 for the same set of wavelengths)

**