2007 Bulgarian IPhO Team Selection Test

Short Exam 2

Problem. A monochromatic ($\lambda = 500\,\text{nm}$) point source S illuminates a rectangular mirror O which rotates at a frequency of $\nu = 16\,\text{Hz}$. The distance between the source and the mirror is $L = 100\,\text{m}$. The reflected light is sent to a detector D of negligible size located close to the mirror. The mirror rotates about an axis that lies in the plane of the mirror and is perpendicular to the plane in which the reflected ray moves. You can assume that the source, the detector, and the mirror are collinear. Accounting for diffraction, find the duration Δt of the light pulse registered by the detector. What is the width a of the mirror that minimises Δt? What is the value of Δt then? The height of the mirror is much larger than a.

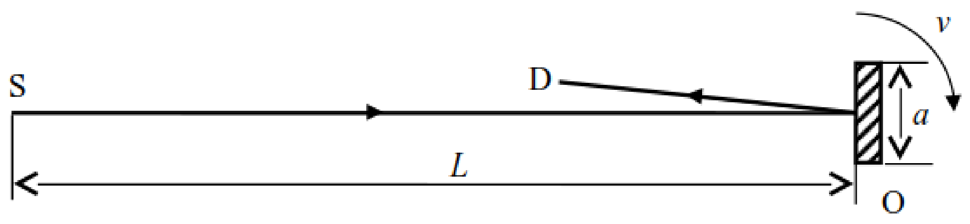

Figure 1

The problem is worth 5 points.
Time: 60 minutes.

Theoretical Exam

Problem 4. Figure 2 shows the I-V curve of a bulb. This bulb is connected in parallel with a resistance $R = 2.00\,\Omega$ to a source of EMF $E = 15\,\mathrm{V}$ and internal resistance $r = 3.00\,\Omega$. Using the I-V curve, find the power P dissipated in the bulb. Estimate the accuracy ΔP of your result.

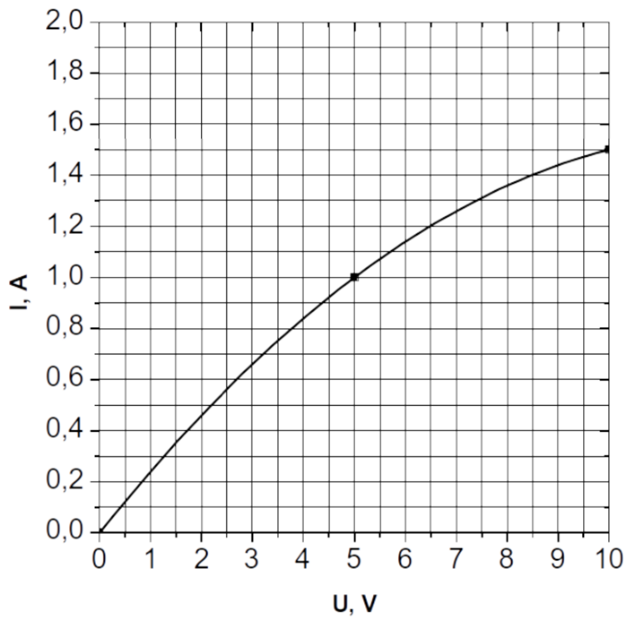

Figure 2

Problem 5. A coil of inductance $L = 2.0\,\mu\mathrm{H}$ and internal resistance $r = 1.0\,\Omega$ is connected in parallel to a resistance $R = 2.0\,\Omega$. These have been connected to a constant voltage source $E = 3.0\,\mathrm{V}$ for a long time. At time $t = 0$ the source is removed from the rest of the circuit. Find the time dependence of the current through the coil $I(t)$. Find the total heat Q dissipated in the coil until the current ceases to flow.

Problem 6. A parallel beam of monochromatic light of wavelength $\lambda = 589.0\,\mathrm{nm}$ is normally incident on a grating of period $d = 2.5\,\mu\mathrm{m}$ and $N = 10000$ slits. Find the angular width of the diffraction maximum of order $m = 2$. Derive the relevant formula and calculate the numerical value in arcminutes.

Constants:

Each problem is worth 3 points.
Time: 5 hours.

Experimental Exam

Problem 1. The speed of sound in air.

Equipment:
Tone generator, two loudspeakers, microphone with a jack (female XLR connector), rectifier, resistance, two-channel oscilloscope, wire connectors, wires, screwdriver, self-retracting tape measure, tape, graph paper.

(a) Connect the setup to the microphone jack. The jack has three pins called base (−), middle (+), and top (signal). The middle and top pins are shorted. Carefully examine the jack. Using the wire connectors and the wires, connect the jack and the resistance in series with the rectifier. Also connect the oscilloscope to the microphone so as to measure the voltage across it. Sketch the circuit. Supply a voltage of 3 V to the microphone and test it. **(1.5 pt)**

Note: To avoid damaging the microphone when turning it on, follow these instructions:
- Before connecting the microphone to the rectifier, set the voltage to zero using the potentiometers.
- First, turn on the rectifier.
- Then connect the wires to the rectifier's terminals, being mindful of the polarity.
- **Slowly** increase the voltage to 3 V.

Note: To avoid damaging the microphone when turning it off, do not turn off the rectifier while the microphone is connected. First turn down the voltage to zero, detach the wires and only then turn off the rectifier.

(b) Connect the two loudspeakers to the tone generator. Put the microphone very close to one of the loudspeakers. Vary the frequency of the tone generator in the range [2 kHz, 20 kHz]. Write down the frequency at which the voltage across the microphone is largest. Work with this frequency from now on. **(1 pt)**

Design a setup for observing two source interference. The distance d between the loudspeakers should be around 30 cm to 50 cm. The distance L between the line through the loudspeakers and the line along which you will move the microphone should be around 1 m. Put the loudspeakers and the microphone on separate tables. Remove all objects that could reflect the sound waves. Be mindful of where you stand during the measurements.

(c) Move the microphone around and measure the coordinates x_k of at least 6 consecutive minima around the central maximum. Use a voltage low enough so that the loudspeakers emit monochromatic waves (without any harmonics). Write down the value of this voltage. Write down the values of x_k in a table. Use those to find an accurate value for the coordinate of the central maximum x_0. **(3 pt)**

(d) Derive an exact formula for the optical path difference Δ of the interfering sound waves. Express Δ in terms of L, d, x, and x_0. **(1 pt)**

(e) Plot a graph of the optical path difference Δ for the measured minima against some number that corresponds to the physical condition for observing such minima. **(1 pt)**

(f) Find the wavelength of the sound waves λ. **(1 pt)**

(g) Calculate the speed of sound in air c for your experimental setup. **(0.5 pt)**

(h) Estimate the error in your value for c. **(1 pt)**

This problem is worth 10 points.
Time: 2 hours.