# 2013 Bulgarian IPhO Team Selection Test

## Theoretical Exam

**Problem 4.** A layer of tap water is poured into a wide and shallow dielectric vessel. The thickness of the layer is $h = 1.00\,\mathrm{cm}$. The probes of a multimeter are vertically submerged at a distance $l = 20.0\,\mathrm{cm}$ from each other until they touch the bottom of the vessel. The multimeter measures a resistance of $R = 500\,\mathrm{k\Omega}$. Modelling the water as a weakly conducting medium, find a formula for the resistivity of water $\rho$ and calculate its value.

**Problem 5.** A square frame of side $a$ and resistance $R$ is placed at a distance $d$ ($d \gg a$) away from an infinite conducting wire carrying a current $I$. The wire lies in the plane of the frame and is parallel to two of its sides. The frame starts to move away from the wire with a velocity $v$ (in the plane of the frame and perpendicular to the wire). Find a formula for the total heat $Q$ dissipated at the frame until it is infinitely far from the wire. Calculate $Q$ for $a = 2\,\mathrm{cm}$, $R = 0.01\,\Omega$, $d = 20\,\mathrm{cm}$, $I = 10\,\mathrm{A}$, $v = 5\,\mathrm{cm/s}$.

**Problem 6.** A monochromator consists of:
- An isosceles glass prism of base $b = 10.0\,\mathrm{cm}$ and an angle $\theta = 50°$ opposite the base.
- A thin entrance slit.
- An identical exit slit.
- A lens at the entrance which gives rise to a parallel beam incident on the prism.
- An identical lens which focusses the dispersed light onto the exit slit. The lenses are of diameter $D = 10.0\,\mathrm{cm}$ and focal length $f = 50.0\,\mathrm{cm}$.

The glass of the prism has a refractive index $n = 1.73$. Its dispersion at wavelength 550 nm is $\frac{\mathrm{d}n}{\mathrm{d}\lambda} = 1.35 \times 10^5\,\mathrm{m}^{-1}$. Inside the prism light travels parallel to the base. Using the Rayleigh criterion, find the theoretical upper limit for the spectral resolution of the monochromator $R = \lambda/\Delta\lambda$ (due to diffraction). Calculate $R$.

**Constants:**

| | | |
|---|---|---|
| Acceleration due to gravity | $g$ | $9.81\,\mathrm{m/s^2}$ |
| Vacuum permeability | $\mu_0$ | $4\pi \times 10^{-7}\,\mathrm{N/A^2}$ |

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

# Experimental Exam

## Problem 1. Ruler vibrations.

*Equipment:*
Ruler (50 cm), another ruler (shorter), clamp, wooden block, 3 old coins (Bulgarian, issue 1992, one is 5 leva, the other two are 1 lev), stopwatch, tape measure, Scotch tape, scissors, graph paper.

*Data:*

| | | |
|---|---|---|
| Mass of the ruler | $m_L$ | 51.0 g |
| Thickness of the ruler | $h$ | 3.00 mm |
| Mass of the 5 leva coin | $m_5$ | 6.00 g |
| Mass of a 1 lev coin | $h$ | 4.00 g |

You will need to complete five tasks.

(a) Find the density of the plastic $\rho$ that the ruler is made from. The ruler's cross section can be approximated as a parallelogram. **(1.5 pt)**

Clamp one end of the ruler so that the clamped part is horizontal and the free part is $L_0 = 47.0\,\mathrm{cm}$ long. Load the ruler at its free end using different sets of coins, taking care that the centre of mass of the coins is exactly at the end of the ruler. Measure the additional deflection of the ruler $s$ due to the coins. This deflection is given by

$$s = \frac{4FL_0^3}{Ebh},$$

where $F$ is the force at the end of the ruler which causes the deflection, $L_0$ is the length of the ruler, $b$ is its width, $h$ is its length, and $E$ is the Young modulus of the plastic. This formula applies for a rectangular cross section, but it is accurate enough in the case of our ruler as well.

(b) Plot a graph of the deflection $s$ against the mass of the coins $m$. Using the graph, find the Young modulus of the plastic $E$. **(3.0 pt)**

Study the dependence of the oscillation period $T$ of the free end of the ruler (without loading it with coins) on the free length $L$. This dependence is described by the formula

$$T = \frac{CL^2}{h}\sqrt{\frac{\rho}{E}},$$

where $L$ is the free length, $h$ is the thickness of the ruler, and $C$ is some unknown constant.

(c) Plot a linearised graph in the appropriate variables. Using the graph, find $C$. Use the values of $\rho$ and $E$ from the previous parts of the problem. **(4.5 pt)**

Clamp the ruler at one end so that it is vertical, with the part that sticks out being $L_0 = 47.0\,\mathrm{cm}$ long. Attach different sets of coins at its free end, taking care that the centre of mass of the coins is exactly at the end of the ruler. Study the dependence of the oscillation period $T$ of the free end of the ruler on the total mass of the attached coins $m$.

(d) Plot your data in a way that will you to predict the period $T_{20}$ for $m = 20\,\mathrm{g}$ by extrapolating. **(4.0 pt)**

(e) Find the critical mass $M$ at which the equilibrium of the vertical ruler becomes unstable and the ruler stops oscillating. **(2.0 pt)**

Call the examiner in case of any technical difficulties.

*Each problem is worth 15 points.*
*Time: 5 hours.*