2021 Bulgarian IPhO Team Selection Test

Short Exam 1

Problem. Spider web. Consider a hexagonal spider web. It has six radial threads, each of relaxed length $l_0 = 45\,\text{cm}$, radius $r = 0.01\,\text{mm}$, and Young modulus $E = 2\times10^8\,\text{Pa}$. The threads are given tension $F_0 = 6\,\text{mN}$ after being attached to some nearby surface. Four concentric hexagonal threads are woven around the radial threads equidistantly (Figure 1). These are initially relaxed. Each of the threads breaks when its strain $\varepsilon = \Delta l/l$ reaches $\varepsilon_{\text{max}} = 0.2$. The spider web can be considered massless.

(a) A fly sticks to the centre of the web with velocity $v = 2\,\text{m/s}$ perpendicular to the web. What is the maximum mass M_{max} of the fly so that the web does not break? **(1.5 pt)**

(b) A fly of mass $m = 0.1\,\text{g}$ sticks to the centre of the web. Find the period T of its small oscillations perpendicular to the web. **(1.5 pt)**

(c) Consider the same web as before, but without tension in any of the threads. The web is carefully taken off its supporting surfaces. It is then loaded at its outermost vertices using six radial forces of equal magnitude. At what magnitude F_{max} does the web break? Where will it break? **(2.0 pt)**

Hint: An elastic material is loaded in some direction using force F. The cross section of the material perpendicular to that direction is S. The relaxed length of the material in that direction is l and its extension is Δl. Hooke's law states that

$$\frac{F}{S} = E\frac{\Delta l}{l},$$

where E is the Young modulus of the material.

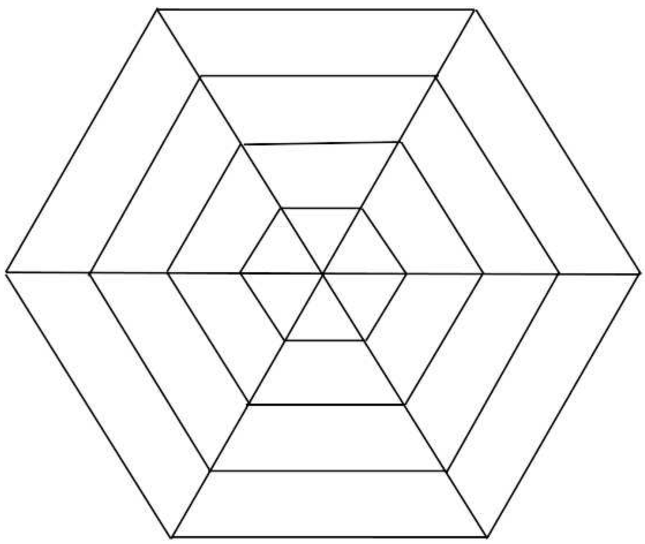

Figure 1

Short Exam 2

Problem. Discharge. Even though air is an insulator, it has a finite resistivity that depends on pressure, temperature, and humidity. This is why charged bodies in air gradually lose their charge through currents directed towards other conductors, including the ground. In this problem we study dry air under standard temperature and pressure. Its resistivity is $\rho = 1.0 \times 10^{14}\,\Omega\text{m}$.

A metal ball with charge $q = 1.0\,\text{nC}$ is suspended in air at a height of $h = 0.10\,\text{m}$ above the ground. The ground can be considered as an infinite conducting plane.

(a) Find the maximum current density $j_{\max}$ (in A/m^2) flowing through the ground.

(b) Find the total current I that flows through the ground.

(c) Find the time $T_{1/2}$ taken for the ball to lose half of its initial charge.

The dielectric constant of air is $\varepsilon = 1$.

Short Exam 3

Problem. Tea in a vacuum flask. A liter of tea at temperature $90\,^\circ\text{C}$ is poured into a vacuum flask (a vessel with an imperfect vaccum between its inner and outer walls). The outer surface of the flask is $S = 600\,\text{cm}^2$. The pressure in the volume between the walls is $P_0 \approx 5 \times 10^{-6}\,\text{atm}$ at room temperature $20\,^\circ\text{C}$. The walls have an emissivity of $\varepsilon = 0.1$ compared to a black body at the same temperature. The specific heat capacity of water is $c = 4.2 \times 10^3\,\text{J}\,\text{kg}^{-1}\,\text{K}^{-1}$. Ignore heat loss through the cap of the flask.

(a) Estimate the total rate of heat loss for the tea due to thermal radiation and thermal conduction between the walls of the flask.

(b) Estimate the time taken for the temperature of the tea to decrease from $90\,^\circ\text{C}$ to $70\,^\circ\text{C}$.

Theoretical Exam

The problems from EuPhO 2021 (held online) were used in place of the usual theoretical exam.

Experimental Exam

The problems from EuPhO 2021 (held online) were used in place of the usual experimental exam.

Constants:

Vacuum permittivity ε_0 $8.85 \times 10^{-12}\,\text{F/m}$