2012 Joseph Henry Physics Competition

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**Instructions:** The competition lasts for two hours, please try to solve as many problems as you can. All questions carry equal weight. You do not have to solve all problems to win the competition! Good luck!

1. Three identical balls of mass $m$ are attached to the ends and to the middle point of a massless rod of length $l$. At $t = 0$ the rod is placed vertically on a table, and then is starts falling. Ignoring the friction between the bottom ball and the table, determine the velocity of the middle ball at the moment when it touches the table.

2. A solid insulating ball of radius $R$ with dielectric constant $\varepsilon_1$ is surrounded by liquid with dielectric constant $\varepsilon_2$. A point charge $q$ is placed in the center of the ball. Evaluate the charge density $\sigma$ induced on the surface of the ball.

3. A pendulum with length $l$ has a ball with mass $m$ and positive charge $q$. A negative charge $Q$ is placed directly below the pivot of the pendulum at a distance $h > l$ from it. Find the frequency of small oscillations of the pendulum.

4. Consider an infinite set of identical resistors depicted in the attached figure. Determine the resistance between points A and B.

![Diagram](attachment:diagram.png)

5. How would our world be different if Planck’s constant was larger by 10 orders of magnitude? Do not write more that 2–3 sentences.

6. A neutron has a mass of roughly 939 MeV/c². If a neutron is placed on an infinitely hard table,
   (a) explain qualitatively, why the neutron will not rest on the surface.
   (b) roughly estimate how far above the table the neutron is most likely to be found. Recall that $\hbar = 10^{-34}$ J·s, $c = 3 \cdot 10^8$ m/s, 1eV = $1.6 \cdot 10^{-19}$ J.
7.

(a) Consider two identical balls, one is lying on the floor, and the other one is hanging from the ceiling on a string. Originally the balls have the same temperature, then equal amounts of heat are added to both systems. Assuming that the balls do not exchange heat with air, floor or the string, determine whether the final temperatures are the same. Justify your answer.

(b) Consider a metal pipe depicted in the attached figure. What happens to the size of the hole when the temperature of the pipe is increased?

8. Consider two metal plates ending in the pool filled with insulating liquid, which has density \( \rho \) and dielectric constant \( \varepsilon \). When voltage \( V \) is applied to this capacitor, the liquid between the metal plates goes up by \( h \) centimeters. Determine the value of \( h \).

9. The wires depicted in figures (a) and (b) carry current \( I \).

(a) Determine the magnitude and direction of magnetic field at the point \( O \) in figure (a).

(b) Determine the magnitude and direction of magnetic field at the point \( O \) in figure (b).

(c) A metal ring breaks when the current going through it becomes equal to \( I_0 \). Find the value of current which breaks a similar ring made of the material sustaining stress, which is 10 times bigger.
10. The sketch below shows two blocks that fit together leaving a space of length $d$ open at the bottom. An explosive charge is placed in the outer block as shown. It extends out to a distance slightly less than $d$. The inner block slams into the outer block at relativistic speed. A person not familiar with special relativity complains about the following paradox:

"An observer in the rest frame of the outer block sees that the inner block is length contracted and so the charge should not explode."

"An observer in the rest frame of the inner block sees that the outer block is length contracted and so the inner block should easily reach the charge and cause it to explode."

The person complains that by observing whether or not the charge explodes, one can determine which observer is really moving which is not a concept that exists in special relativity.

(a) Does the charge explode or not?

(b) Resolve the false paradox, i.e., explain your conclusion (a) from the point of view of each observer, referring only to her/his frame. Do not write more that 2–3 sentences.