National Physics Olympiad, Nepal, 2017

(Model questions)

Saturday, 17th February 2017
Time: 3 hours 15 minutes
Full Marks: 100

Attempt all questions. Mark for each question or a part of a question is given in the right margin. You are advised to answer the questions which you can easily do first and then come back to attempt seemingly difficult ones. Originality in approach will be rewarded. You are advised to draw figures and sketches where necessary.

Name:

DOB:

Institution:

Question 1:

(a):

(i) While taking shower, I turned on the shower tap accidentally when the shower head was resting on the floor. The flexible pipe thrashed around like a berserk snake. Explain this behavior. [2]

(ii) A long flexible garden hose is connected to a tap. It is then turned on. Water spurts out faster when the hole emitting the water is partially closed. How would you measure the increased speed of the water? You are supplied only a meter rule. [3]

(b) According to the kinetic theory of gases for a perfect gas: $P = (1/3)\ \rho c^2$; where P is the pressure of the gas, ρ is the density of the gas and c is the root mean square speed of the gas molecules. Find an expression of the rate of leakage of a gas from a small hole, cross-sectional area a, in a cubic container, side l, $l >> a^{1/2}$. [5]

(c) An object lies before a thin symmetric converging lens. Does the image distance increase, decrease or remain the same if we increase (i) the refractive index η of the lens, and (ii) the refractive index η_{med} of the surrounding medium, keeping η_{med} less than η ? [2.5 + 2.5]

(d)(i) Consider a hollow sphere having uniform positive charge distribution at the surface. What is the total force acting on a negative charge at the center of the sphere? [2]

(ii) Electrons in an electric circuit pass through a resistor. The wire on either side of the resistor has the same diameter. a) How does the drift speed of the electrons before entering the resistor compare to the speed after leaving the resistor? Explain your reasoning. b) How does the potential energy for an electron before entering the resistor compare to the potential energy after leaving the resistor? Explain your reasoning. [1.5 + 1.5]

(e) According to the Nepal Bureau of Standards, copper wire used for interior wiring of houses, hotels and industrial plants is permitted to carry no more than a maximum amount of current. The table below shows the maximum current I_{max} for several common sizes of wire with proper insulation. The "wire gauge" is a standard method to describe the diameter of the wire. Note that larger the diameter of the wire, the smaller the wire gauge.

Wire gauge	**Diameter / cm**	**I_{max} / A**
14	0.163	18
12	0.205	25
10	0.259	30
8	0.326	40
6	0.412	60
5	0.519	65
4	0.649	85

(i) What considerations determine the maximum current-carrying capacity of household wiring? [2]

(ii) A total of 4200 W of power is to be supplied through the wires of a house to the household electrical appliances. If the potential difference across the group of appliances is 220 V, determine the gauge of the thinnest permissible wire that can be used. [3]

Question no.2(a). In a space research project two schemes of launching a space probe out of the Solar system are discussed. The first scheme (i) is to launch the probe with a velocity large enough to escape from the Solar system directly. According to the second one (ii), the probe is

to approach one of the outer planets, and with its help change its direction of motion and reach the velocity necessary to escape from the Solar system. Assume that the probe moves under the gravitational field of only the Sun or the planet, depending on whichever field is stronger at that point.
Determine the minimum velocity and its direction relative to the Earth's motion that should be given to the probe on launching according to scheme (i). [12.5]
Data: Velocity of the Earth round the Sun is 30 km/s.

2(b). A triangular prism of mass M is placed one side on a frictionless horizontal plane as shown in Fig. The other two sides are inclined with respect to the plane at angles α_1 and α_2 respectively. Two blocks of masses m_1 and m_2, connected by an inextensible thread, can slide without friction on the surface of the prism. The mass of the pulley, which supports the thread, is negligible.

- Express the acceleration a of the blocks relative to the prism in terms of the acceleration a_0 of the prism.
- Find the acceleration a_0 of the prism in terms of quantities given and the acceleration g due to gravity.
- At what ratio m_1/m_2 the prism will be in equilibrium? [6.5+3+3]

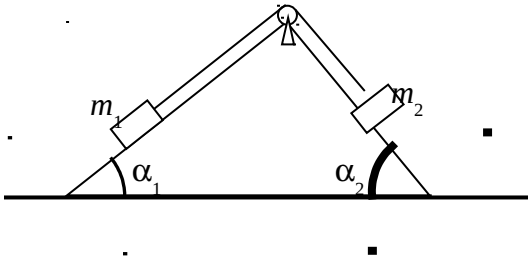

Fig. 1

Question no. 3(a). Water of mass $m2$ is contained in a copper calorimeter of mass $m1$. Their common temperature is $t2$. A piece of ice of mass $m3$ and temperature $t3 < 0^0$C is dropped into the calorimeter.
i) Determine the temperature and masses of water and ice in the equilibrium state for general values of $m1$, $m2$, $m3$, $t2$ and $t3$. Write equilibrium equations for all possible processes which have to be considered. [12]
ii) Find the final temperature and final masses of water and ice for $m1$ = 1.0 kg, $m2$ = 1.*0* kg, $m3$ = 2.*0* kg, $t2 = 10^0$ C, $t3 = -20^0$ C. [3]

Neglect the energy losses, assume the normal barometric pressure. Specific heat of copper is $c1$ = 0.1 kcal/kg-^{0}C, specific heat of water $c2$ = 1 kcal/kg-^{0}C, specific heat of ice $c3$ = 0.492 kcal/kg^{0}C, latent heat of fusion of ice l = 78.7 kcal/kg. Take 1 cal = 4.2 J.

3(b). Consider a plane-parallel transparent plate, where the refractive index, n, varies with distance, z, from the lower surface (see figure). Show that $n_A \sin\alpha = n_B \sin\beta$. The notation is that of the figure. [10]

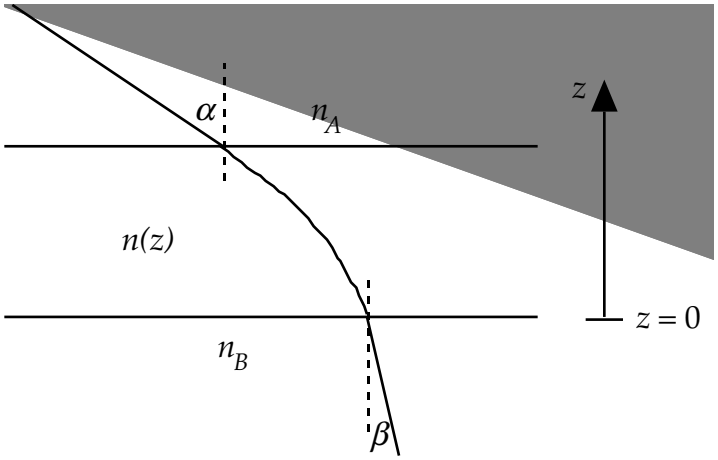

Fig. 2

4(a) Four batteries of EMF $E_1 = 4$ V, $E_2 = 8$ V, $E_3 = 12$ V, and $E_4 = 16$ V, four capacitors with the same capacitance $C_1 = C_2 = C_3 = C_4 = 1$ μF, and four equivalent resistors are connected in the circuit shown in Fig 3. The internal resistance of the batteries is negligible.

- Calculate the total energy W accumulated on the capacitors when a steady state of the system is established. [10]

The points H and B are short connected. Find the charge on the capacitor C_2 in the new steady state. [5]

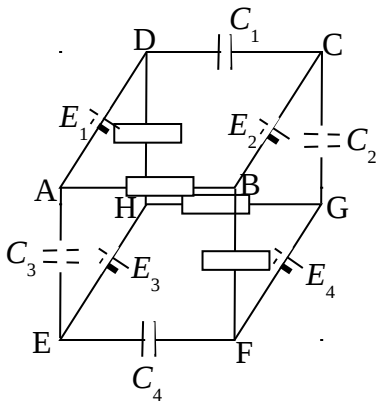

Fig. 3

4(b) From the stand point of electrostatics, the surface of the Earth can be considered to be a good conductor. It carries a certain total charge Q_0 and an average surface charge density σ_0.

(i) Under fair-weather conditions, there is a downward electric field, E_0, at the Earth's surface equal to about 150 V/m. Deduce the magnitude of the Earth's surface charge density and the total charge carried on the Earth's surface. [5]

(ii) The magnitude of the downward electric field decreases with height, and is about 100 V/m at a height of 100 m. Calculate the average amount of net charge per m^3 of the atmosphere between the Earth's surface and 100 m altitude. [5]