National Physics Olympiad, Nepal, 2008

(Pre-selection test, 2008)

Saturday, 1st March, 2008
Time: 3 hours + 15 minutes
Full marks: 100

Answer all questions, giving appropriate reasons for your answer in each.

Marks 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. Final answer is not the only important step. Every correct step in your solution carries marks for that step. Originality in approach will be rewarded. You are advised to draw figures and sketches with proper labeling where necessary.

Data Sheet

Permittivity of free space $\varepsilon_0 = 8.85X10^{-12}\ C^2/Nm^2$

Question 1

(A) (i) A ball is attached to one end of a piece of string. You hold the other end of the string and whirl the ball in a horizontal circle around your hand. If the ball moves at a constant speed, is its linear momentum (**p**) constant? Is its angular momentum (**L**) constant? (2.5)

(ii) Is it possible for a planet to have the same value of gravitational field intensity at its surface as that on earth and yet have a greater (or smaller) escape speed? (2.5)

(B) (i) The inside of an oven including the air is at a temperature of 200^0 C. You may put your hand in the oven momentarily without injury but if you touch anything inside, you will get injured. Explain. (2.5)

(ii) You take a block of ice at 0^0 C and add heat to it at a steady rate. After 20 minutes, the block of ice has been converted completely to steam at 100^0 C. What is its phase in 10 minutes after the start of heating? (2.5)

(C) (i) If you were driving a car, what type of side-view mirror would you prefer to use for observing traffic behind you? (2.5)

(ii) A street appears darker when wet than when dry. Explain. (2.5)

(D) (i) A negatively charged ebonite rod attracts a suspended ball of straw. Can we infer that the ball is positively charged? (2.5)

(ii) A charged particle is free to move in an electric field. Will it always move along a line of force? (2.5)

(E) (i) Is Ohm's law true for all conductors? Explain. (2.5)

(ii) Same potential difference is applied across the ends of two wires of same material. What will be the ratio of currents in them if they have (a) same cross-sectional area, but lengths in ratio 2:1, and; (b) same length but cross-sectional area in the ratio 2:1? (2.5)

Question 2

(A) In any collision the sum of the momenta of all the bodies involved should be the same immediately before and after the collision. In an elastic collision the same is true for the sum of the kinetic energies of the bodies.

(a) Consider a small blob of mass *m* moving with a velocity *v* colliding normally with a perfectly rigid wall. Assume the collision is elastic. What is the final velocity of the blob?

There is a box with a very large number of these blobs (comparable to the number of molecules in a gas at STP) all moving with different speeds in different directions so that the total average momentum is initially zero. The box is held firmly in place. Assume that all collisions with the wall and between the blobs are elastic.

(b) What happens to the (i) total kinetic energy, and, (ii) total momentum of all the blobs?

If there were a small hole in one side of the box that some blobs could escape through and the initial distribution of velocities of the blobs were the same as before. After some time has elapsed,
(c) what happens to the (i) total kinetic energy, and, (ii) total momentum of the blobs left in the box? (12.5)

(B) A box sits on a sled which is being towed along by a donkey. The donkey starts from rest and begins to move forward slowly, accelerating steadily and pulling on the sled with a constant force.
a. Draw a free body diagram showing all the forces acting on the box.

The box has a mass of 12 kg, and the sled has a mass of 20kg. Both the box and sled accelerate together at a rate of 2.0 ms^{-2}. The coefficient of static friction between the box and the sled is 0.50 and the coefficient of kinetic friction between the sled and the ground is 0.20.
b. What is the frictional force acting on the box?

c. How much force must the donkey apply to the sled to maintain this acceleration?

The donkey breaks into a run, increasing his acceleration.
d. What is the maximum acceleration of the donkey, and hence the sled, that is possible before the box begins to slide off? (12.5)

Question 3

(A) Newton's law of cooling says that the rate of cooling of an object is proportional to the temperature difference between the object and its environment; hence a cup of tea cools off faster in a cold room than in a warm room. The equation that describes the temperature as a function of time is:
$T_{tea}(t) - T_{room} = (T_{tea}(0) - T_{room}) \exp(-kt)$
where $T_{tea}(t)$ is the temperature of the tea at any time t, T_{room} is the temperature of the room, $T_{tea}(0)$ is the initial temperature of the tea at $t = 0$ and k is a constant.
a. What are the units of the constant k?

A particular cup of tea is made in a room at 15^{o}C. The temperature of the tea is measured as a function of time and the results are shown in the table below.

t (minutes)	10	20	30	40	50	60	70	80
T_{tea} (^{o}C)	65	49	38	30	25	22	20	18

b. (i) Explain why natural logarithm of $(T_{tea}(t) - T_{room})$ versus t graph will give a straight line.
(ii) Transform the above data according to b(i) in a suitable table.

(c) Plot the data on the graph paper provided to obtain a straight line graph and find the constant k. Show all your work.

d. What was the temperature of the tea at time t=0? (12.5)

(B) A beam of light converges to a point P. A lens is placed in the path of the convergent beam 12 cm from P. At what point does the beam converge if the lens is (i) a convex lens of focal length 20 cm, (ii) a concave lens of focal length 16 cm. (12.5)

Question 4

(A) An electric lamp of resistance R_0 = 2 Ω working at a nominal voltage U_0 = 4.5 V is connected to a battery of electromotive force E = 6 V and negligible internal resistance.

i). The nominal voltage of the lamp is ensured as the lamp is connected potentiometrically to the battery using a rheostat with resistance *R*. What should be the resistance *R* and what is the maximum electric current I_{max}, flowing in the rheostat, if the efficiency of the system must not be smaller than $\eta_0 = 0.6$?

ii). What is the maximum possible efficiency η of the system and how the lamp can be connected to the rheostat in this case? (12.5)

(B) Some cell walls in the human body have a layer of negative charge on the inside surface and a layer of positive charge of equal magnitude on the outside surface. Assume that the cell is spherical and suppose that the surface charge densities are $\pm 5X10^{-4}$ C/m^2 , the cell wall is $5X10^{-9}$ m thick, and the cell wall material has a dielectric constant of K=5.4.

(a) Find the vale of (|**E**|) in the wall between the two charge layers.

(b) Find the potential difference between the inside and the outside of the cell. Which is at higher potential?

(c) A typical cell in the human body has volume 10^{-16} m^3. Estimate the total electric-field energy stored in the wall of a cell of this size. (12.5)