National Physics Olympiad, Nepal, 2009

(Pre-selection test, 2009)

Saturday, 21st February, 2009
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 $\varepsilon_0 = 8.854\text{X}10^{-12}\ C^2/Nm^2$
Gravitational constant $G=6.673\text{X}10^{-11}\ Nm^2/kg^2$
Magnitude of charge of an electron $e = 1.602\text{X}10^{-19}\ C$
Mass of electron $m_e = 9.110\text{X}10^{-31}\ kg$
Mass of proton $m_p = 1.673\text{X}10^{-27}\ kg$

Question 1

(A) (i) Does the power needed to raise a box onto a platform depend on how fast it is raised? Explain. (1+1.5)

(ii) Satellites are held in orbit by the force of our planet's gravitational attraction. A satellite in a small-radius orbit moves at a higher speed than a satellite in an orbit of large radius. Based on this information, explain how you can conclude that the Earth's gravitational attraction decreases with increasing distance from the planet. (2.5)

(B) (i) Why do frozen water pipes burst? Would a mercury thermometer break if the temperature went below the freezing temperature of mercury? Why or why not? (2.5)

(ii) A gas of temperature T is enclosed in a container whose walls are initially at temperature T_1. When does the gas exert a higher pressure onto the walls of the container: when $T_1<T$ or when $T_1>T$? (2.5)

(C) (i) A thin plano-convex lens with its plane side towards the object forms an image of a point object on its axis. Is the image location changed if the convex side of the lens is facing the object without changing the object distance? Explain your answer with ray diagrams. (2.5)

(ii) The distance between the screen and the light source is of 120 cm on an optical bench. Moving a lens between them, sharp images can be obtained at two positions, and the ratio of the sizes of these two images is 1:9. What is the focal length of the lens? (2.5)

(D) (i) Why no two electric lines of force can intersect each other? (2.5)

(ii) Find the ratio of the electrostatic and gravitational forces between an electron and a proton separated by a distance r. (2.5)

(E) (i) On increasing the temperature, the electrical conductivity of a metallic conductor increases, decreases or remains unchanged? Explain. (2.5)

(ii) Is it possible that connecting a battery of voltage U to side I of the box shown in figure, a voltmeter connected to side II reads a voltage of U/2, while connecting the battery to side II, the voltmeter at side I reads voltage U? Consider the box contains only combination of resistors. Explain. (0.5+2.0)



Question 2

(A) Molly the ant falls from a height *h* above a conveyor belt which is moving at a constant, velocity *v*, and she bounces off at an angle θ to the horizontal. Molly has a mass *m* and the coefficient of kinetic friction between Molly and the belt is μ.

a. Find an expression for the velocity with which Molly hits the conveyor belt.

b. Draw a diagram showing all the forces acting on Molly during her collision with the conveyor belt. Indicate on your diagram the relative sizes of the forces in the vertical direction.

c. Write down expressions for the horizontal and vertical components of change in Molly's momentum during the collision time (Δt) in terms of forces on your diagram.

d. Find expressions for Molly's final velocity in the horizontal and vertical directions.

e. If the average size of the normal force that Molly experiences during the collision is equal to $2mg$, find an expression for the time the collision takes, Δt. (15)

(B) Smugglers start off in a ship from a straight shore, in a direction perpendicular to the shore, and move at constant speed *v*. The police on a motor boat at a distance *d* from the smugglers along the same side of the shore start chasing them at the same time. The police always move in the direction of the smugglers at a constant speed and catches up with the criminals at distance *d* from the shore. How many times is the speed of the police greater than that of the smugglers? (10)

Question 3

(A) While running a 70-kg student generates thermal energy at a rate of 1200 W. To maintain a constant body temperature of 37^0 C, this energy must be removed by perspiration or other mechanisms. If these mechanisms failed and the heat could not flow out of the student's body, for what amount of time could a student run before irreversible body damage occurs? (Protein structures in the body are irreversibly damaged if body temperature rises to 44^0 C or above. The specific heat capacity of a typical human body is 3480 J/kg-K.). (12.5)

(B) The plane side of a thin plano-convex lens is silvered. Will it act as a convex or concave mirror? Justify your answer by drawing a ray diagram. The material of lens has refractive index 1.5. What is the radius of curvature of the curved surface of lens if the focal length of the mirror is 40 cm? (12.5)

Question 4

(A) Twelve capacitors, each having a capacitance C, are connected to form a cube. Find the equivalent capacitance between the diagonally opposite corners. (10)

(B) The resistivity of a semiconductor can be modified by adding different amounts of impurities. A rod of semiconducting material of length L and cross-sectional area A lies along the x-axis between x=0 and x=L. Its resistivity varies along the rod according to $\rho(x) = \rho_0 \exp(-x/L)$. The end of the rod at x=0 is at potential V_0 greater than the end at x=L.

a) Find the total resistance of the rod and the current in the rod.

b) Find the electric field magnitude E(x) in the rod as a function of x.

c) Find the electric potential V(x) in the rod as a function of x.

d) Graph the functions $\rho(x)$, E(x), and V(x) for values of x between x=0 and x=L. (15)