Nepal Physics Olympiad

(pre-selection Test IPHO -49)

February 17, 2018, Saturday

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

Marks for each part of the question are given in the right margin.

You are advised to answer the question which you can easily do first and then come back to attempt seemingly difficult ones.

Numerical answers should be written rounded to appropriate significant figures. Do not forget to state proper units.

Originality in approach will be rewarded.

You are advised to draw figures and sketches with proper labeling wherever necessary.

Values of some physical constant you may need while solving the problems:

Acceleration due to gravity (g) = 10.0 m s^{-2}

Latent heat of fusion of water (L_f) = 3.34×10^5 J kg^{-1}

Latent heat of vaporization of water (L_v) = 2.26×10^6 J kg^{-1}

Molar gas constant (R) = 8.31 J mol^{-1} K^{-1}

Ratio of heat capacities for mono-atomic gas (γ) = 1.67

Permittivity of the free space (ε_0) = 8.85×10^{-12} C^2 N^{-1} m^{-2}

Electronic charge (e) = 1.60×10^{-19} C

Short questions

Q1. A) A particle moves along a parabola $y = ax^2$ with velocity **v** whose modulus is constant. Find the acceleration of the particle at the point x=0. (2.5)

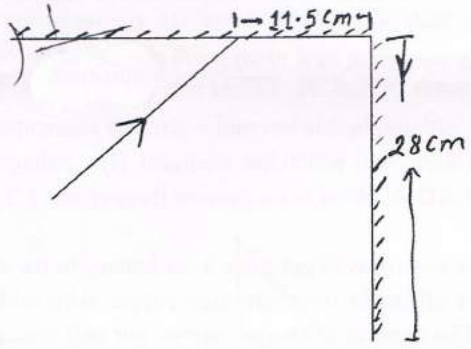
B) A car is travelling on a level road with uniform speed v_o. At some instant the brakes are applied such that the wheels of the car do not roll but only skid. Calculate the minimum stopping distance of the car in terms of v_o, acceleration due to gravity g and coefficient of kinetic friction μ_k between the tires and the road.

By what factor would the minimum stopping distance change if i) the coefficient of kinetic friction were doubled, ii) the initial speed were doubled and iii) both coefficient of kinetic friction and the initial speed were doubled? (2.5)

Q2. A) The temperature of the wall of a vessel containing a gas at a temperature T, is T_{wall}. In which case is the pressure exerted by the gas on the vessel wall higher: when the vessel walls are colder than the gas ($T_{wall} < T$) or when they are warmer than the gas ($T_{wall} > T$)? Explain (2.5)

B) A vessel from which air is rapidly being pumped out contains a small amount of water at 0°C. The intensive evaporation causes a gradual freezing of the water. What fraction of the original mass of water can be converted into ice by this method? (2.5)

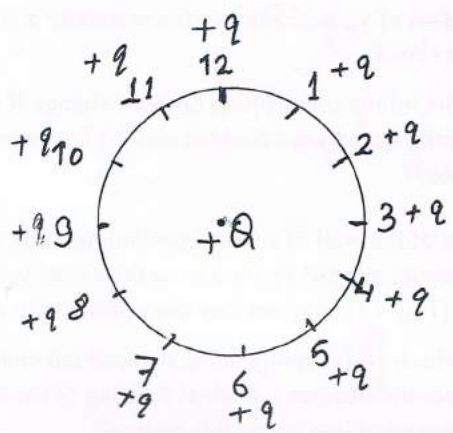
Q3. A) Two plane mirrors intersect at right angles. A laser beam strikes the first of them at a point 11.5 cm from their point of intersection as shown in the Fig. below. For what angle of incidence at the first mirror will this ray strike the midpoint of the second mirror (which is 28 cm long) after reflection from the first mirror? (2.5)



B) The real image of a distant object is formed at 20 cm from the pole of a curved mirror. State the focal length of the mirror.

The curved mirror is filled with water (μ=1.33) and illuminated through a pin hole in a cardboard. Find the position of the cardboard from the mirror so that a sharp image of the pin hole is formed on the cardboard itself. (2.5)

Q4. A) Twelve equal charges each +q, are situated in a circle of radius R and they are equally spaced.



I) What is the net force (magnitude and direction) on a charge +Q at the center of the circle?
II) We remove the charge +q , which is located at position 3. What will be the force (magnitude and direction) on the charge +Q at the center of the circle? (2.5)

B) During its first orbital period, a spherical satellite of radius 1.5 m picks up charge from the dilute ionized gas of earth's ionosphere, with its potential changing by -3.50 V.
a) How much charge has been collected?
b)If the charge is entirely electrons, how many were collected? (2.5)

Q5. A) A 12.6 V car battery with negligible internal resistance connected to a series combination of a 3.2 Ω resistor and a thermistor which has a current (I) – voltage (V) relation $V= \alpha I + \beta I^2$ with $\alpha = 3.8\ \Omega$ and $\beta = 1.3\ \Omega/A$. What is the current through the 3.2 Ω resistor? (2.5)

B) How long does it take electrons to get from a car battery to the starting motor? Assume the current is 285 A and the electrons travel through copper wire with cross-sectional area 0.17 cm^2 and length 0.43 m. The number of charge carriers per unit volume is $8.49\times10^{28}\ m^{-3}$. (2.5)

Long questions

Q6. A) The angle θ through which a disc drive turns is given by $\theta(t) = a + bt - ct^3$, where a, b and c are constants. t is time in seconds and θ is in radians. When t=0, $\theta= \pi/4$ rad and the angular velocity Is 2.00 rad/s and when t= 1.5 sec , the angular acceleration is 1.25 rad/s^2 . i) Find a, b and c, together with their units. Ii) What is the angular acceleration when $\theta= \pi/4$ rad? Iii) What are θ and the angular velocity when the angular acceleration is 3.5 rad/s^2 ? (7.5)

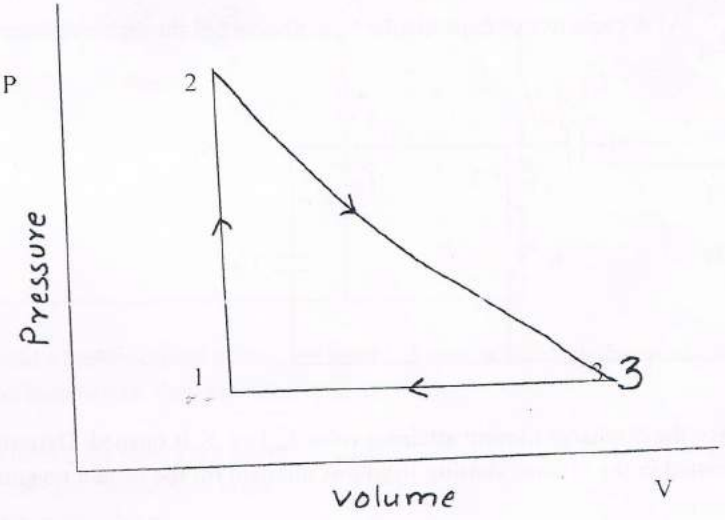
B) A hole is bored in a straight line through the earth from Kathmandu to Cairo, and a ball – bearing is dropped in at the Kathmandu end. Assuming that frictional and air resistance forces are negligible, and that the earth may be taken as a uniform- density sphere of radius 6400 km, how long does it take the ball bearing to arrive in Cairo? (Assume the effect due to rotation of the Earth is negligible) (5)

Q7. A) A horizontal plane supports a plank with a bar of mass m=1.0 kg placed on it and attached by a light elastic non- deformed string of length l_0 = 40 cm to a point in the ceiling. The coefficient of friction between the bar and the plank equal μ= 0.20. The plank is slowly shifted to the right until the bar starts sliding over it. It occurs at the moment when the cord deviates from the vertical by an angle α= 30°. Find the work that has been performed up to that moment by frictional force acting on the bar in the reference frame fixed to the plane. (7.5)

B) A bullet of mass m is fired with a velocity of 50 m/s at an angle θ with the horizontal. At the highest point of its trajectory, it collides head-on with a bob of mass 3m suspended by a weightless string of length 3.33 m and gets embedded in the bob. After the collision, the string moves through an angle 120°. Find,

a) the angle θ
b) the vertical and horizontal coordinates of the initial position of the bob with respect to the point of firing of the bullet. (5)

Q8. A) Fig shows a cycle undergone by 2.0 mol of an ideal monoatomic gas. The temperature at points 1,2 and 3 re T_1= 300 K, T_2= 600 K and T_3 =455 K respectively. For 1 to 2, what are (a) heat Q , the change in internal energy ΔU and Work done W? For 2 to 3 (adiabatic) what are (b) Q , ΔU and W? For 3 to 1 what are (c) Q , ΔU_{int} and W? For the full cycle, what are (d) Q , ΔU and W? The initial pressure at point 1 is 1 atm (1.013×10^5 Pa).(e) What are volume and pressure at point 2 and 3 respectively? (7.5)



(B) A typical student listening attentively to a physics lecture has a heat output of 100 W.

a) How much heat energy does a class of 90 physics students release into the lecture hall over the course of a 50 min lecture?

Assume that all the heat energy in part (a) is transferred to the 3200 m^3 of air in the room. The air has specific heat capacity 1020 J kg^{-1} $K^{-1}$and density 1.20 kg m^{-3}.

(b) If none of the heat escapes and the air conditioning system is off, how much will the temperature of the air in the room rise during the 50 min lecture?

(c) If the class is taking an exam, the heat output per student rises to 280 W. What is the temperature rise during 50 min in this case? (5)

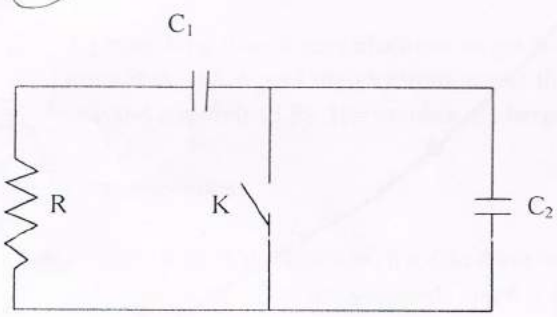
Q9. A) An object is viewed through a converging lens at different object positions. Table below gives the object distance along with the corresponding linear magnification.

Object distance (u) in cm	magnification (m)
15.0	4.01
20.0	1.50
30.0	0.67
40.0	0.43
50.0	0.32
60.0	0.25
70.0	0.21

How would you plot the given data to obtain a straight line. Plot this linear graph to find the focal length of the lens. (7.5)

B) A small fish 40.0 cm below the surface of water in a pond is viewed through a thin equiconvex glass lens (μ=1.5) of radius of curvature 300 cm. If this lens is held 20 cm above the water (μ=1.33) surface, where is the image of the fish seen by the observer? (5)

Q10. A) A capacitor of capacitance C_1 is discharged through a resistor R (refer to the Fig. below)



When the discharge current attains a value I_0, key K is opened. Determine the amount of heat liberated in the resistor starting from this moment till the instant no current flows in the resistor. (7.5)

B) A soap bubble 10 cm in radius with a wall thickness 3.3×10^{-6} cm is charged to a potential difference of 100 V. The bubble burst and falls as a spherical drop. Calculate the potential of the drop. (5)

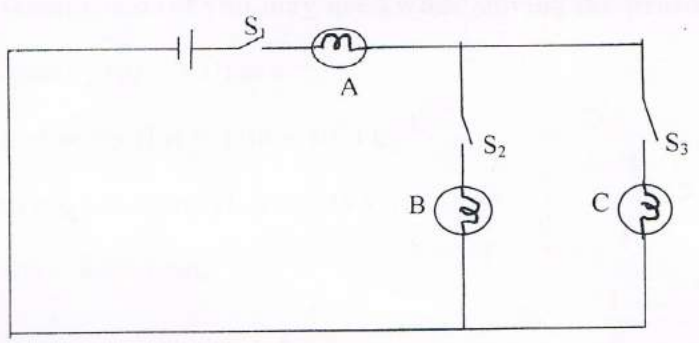
Q11 A) In an experiment on Ohm's law, an ammeter with 10 smallest divisions corresponding to 1mA and voltmeter with 10 smallest divisions per 1 mV, are used by a group of students. A meter scale with smallest division of 1mm is used to measure the length of the wire. The micrometer screw gauge used to measure the diameter of the wire has the following specification:

i) zero of the circular scale is above the base line by 10 division,
ii) number of circular scale division is 100,
iii) pitch of the screw is 1mm.

When current flowing in the circuit is 2.0 mA, the potential difference measured across the resistance wire of length 45.0 cm is found to be 4.2 mV. The mean circular scale reading of the five observations for the diameter is 46 divisions.

a) Calculate the following with their estimated errors:
   i) resistance of the wire,
   ii) corrected diameter of the wire,
   iii) area of cross-section of the wire,
   iv) resistivity of the material of the wire
b) Calculate the percentage error in resistance and resistivity of the wire. (7.5)

(B) The circuit below consists of a battery (with negligible internal resistance), three incandescent light bulbs (A, B and C) each with exactly the same resistance and three switches (S_1, S_2 and S_3). In what follows you may assume that regardless of how much current flows through a given light bulb, its resistance remains unchanged and also the light bulb glows.



In this situation (a,b and c) as described below, we want to know which light bulbs are glowing and which are not and how bright they are relative to each other:

a) switch S_1 is closed, the others are open,
b) switch S_1 and S_2 are closed S_3 is open,
c) all three switches are closed.

Now compare the situations a, b and c. Which bulb is the brightest of all and which is the faintest of all (the bulbs that are off do not count)? Give reasons to your answer. (5)

Good luck