Nepal Physical Society

15th Nepal Physics Olympiad (NePhO)- 2022

[Pre-Selection Test for IPhO-2023]

NePhO-2022 December 10, 2022
Duration: 3 H 15 m Maximum Marks:100

INSTRUCTIONS

- This question paper consists of Six (6) pages.
- There are altogether Eleven (11) questions. Section A contains Five (5) short questions and Section B contains Six (6) long questions. Most of them are divided into sub-questions.
- All questions are compulsory. Answer to each question should begin on a new page.
- Permitted materials: a non-programmable, non-graphical calculator, blue and black pens, lead pencils, an eraser, and a ruler.
- A suitable diagram in each question is desirable and ensure that your diagrams are clear and labelled.
- All numerical answers must have correct units and with proper significant figures.
- Marks will not be deducted for incorrect answers but deducted for improper significant figures.

SUGGESTED TIME (3 Hrs. 15 minutes)

Reading Questions and prepare for exam:	15m
Section A: Short Questions Answers types:	36m
Section B: Long Questions Answers types:	144m
Total time:	195m

TABLE OF INFORMATION

Speed of light in vacuum (c)	=	$3.00 \times 10^{8}\ \text{m s}^{-1}$
Planck's constant (h)	=	$6.63 \times 10^{-34}\ \text{J s}$
Universal constant of Gravitation (G)	=	$6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2}$
Magnitude of the electron charge (e)	=	$1.60 \times 10^{-19}\ \text{C}$
Permittivity constant (ε_0)	=	$8.85 \times 10^{-12}\ \text{F m}^{-1}$
Universal Gas Constant (R)	=	$8.314\ \text{J K}^{-1}\ \text{mol}^{-1}$
Avogadro's number (N_A)	=	$6.023 \times 10^{23}\ \text{mol}^{-1}$
Coefficient of volume expansion of Hg	=	$18.0\times10^{-5}\ \text{K}^{-1}$
Sp. heat capacity of water	=	$4200\ \text{J kg}^{-1}\ \text{K}^{-1}$
Sp. heat capacity of Al	=	$910\ \text{J kg}^{-1}\ \text{K}^{-1}$
Refractive index of glass	=	1.52
Refractive index of water	=	1.33
Refractive index of oil	=	1.43
Atomic mass m_H	=	1.007825 u
Atomic mass m_{Cu}	=	$63.55\ \text{g mol}^{-1}$
Atomic mass m_n	=	1.008665 u
Mass of electron m_e	=	$9.11\times10^{-31}\ \text{kg}$
Mass of proton m_p	=	$1.67\times10^{-27}\ \text{kg}$

Section A: Short Questions

QN1. (A) A raindrop with mass m falls vertically near the earth's surface with terminal velocity v. If it experiences a retarding force αv due to the air, where α is a constant, find an expression for the raindrop's kinetic energy in this situation. [2.5]

(B) Obtain an expression for the kinetic energy of a coin of mass m rolling without slipping along a horizontal path with velocity v. In the same scenario, if the coin's diameter doubles but its mass remains the same, what will happen to its kinetic energy? [2.5]

QN2. (A) Obtain volume occupied by 1.0 mol of each for ideal oxygen and hydrogen gases at standard temperature and pressure (STP), defined as T = 273.15 K and P = 101.3 kPa? [2.5]

(B) A physicist pours coffee of mass 0.300 kg at a temperature of 70.0 ^{o}C into an aluminum cup of mass 0.300 kg at a temperature of 10.0 ^{o}C. (i) Calculate the equilibrium temperature of the coffee and the cup. (ii) Compare the equilibrium temperature with the average temperature of coffee and the cup. Why the equilibrium temperature you calculated is not equal to the average temperature? Explain. (Assume that the coffee has the same specific heat as water and that there is no heat exchange with the surroundings.) [2.5]

QN3. (A) A concave mirror has a radius of curvature of 10.0 cm. (i) What is its focal length? (ii) If the mirror is immersed in oil, what is its focal length? [2.5]

(B) A submarine periscope uses two totally reflecting 45^{o}-45^{o}-90^{o} prisms with total internal reflection on the sides adjacent to the 45^{o} angles. Explain why the periscope will no longer work if there is a leak and the bottom prism is submerged in water. [2.5]

QN4. (A) Suppose a physicist wants to store 1.00 J of electric potential energy in 1.00 m^3 of vacuum space. (i) How large of an electric field is necessary? (ii) If the magnitude of the field is 10 times larger than you obtained in (i), how much energy is stored per cubic meter? [2.5]

(B) Consider Fig. 1. Is it possible to increase the current flowing through R by short-circuiting one of the sources, say $\boldsymbol{\mathcal{E}_2}$ as indicated in the figure? You may neglect the internal resistance of the sources. [2.5]

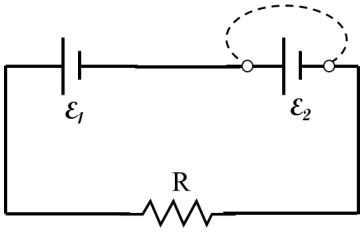


Figure 1: QN4. (B)

QN5. (A) Uranium isotope, $^{238}_{92}U$, has atomic mass 238.05 u. Calculate its (i) mass defect; (ii) binding energy (in MeV); (iii) binding energy per nucleon. Explain the results on the basis of the values obtained. [2.5]

(B) During a photoelectric-effect experiment with light of a certain frequency, a reverse potential difference V is required to reduce the current to zero. Find the expression for the maximum speed of the emitted photoelectrons. Also find the value of the maximum speed of the emitted photoelectrons when the stopping potential is 1.25 V. [2.5]

Section B: Long Questions

QN6. (A) A baby playing on a very heavy smooth uniform sphere of radius 1 m, starts sliding off the top of as shown in figure 2. Draw a free body diagram in this case. Find the angle θ in the figure that corresponding to the point at which the baby detached from the sphere, and also find the baby's velocity at the time of separation. Comment on your answers. [10]

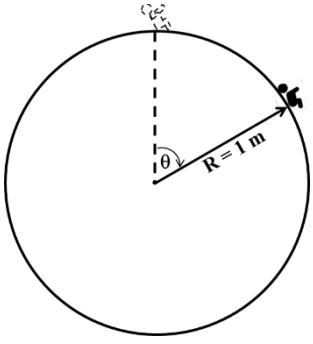


Figure 2: QN6. (A)

(B) A glass flask whose volume is at 1000.00 cm^3 at 0.0 ^oC is completely filled with mercury at this temperature. When the flask and mercury are warmed to 55.0 ^oC, 9.00 cm^3 of mercury overflow. Find the coefficient of the volume expansion of the glass. [5]

QN7. (A) Find the expression for the moment of inertia of (a) a uniform copper disc relative to the symmetry axis perpendicular to the plane of the disc, if its thickness is equal to t and its radius to R; (b) a uniform solid cone relative to its symmetry axis, if the mass of the cone is equal to m and the radius of its base to R. [10]

(B) A vacuum pump can easily attain pressures of the order of 10^{-13} atmosphere in the laboratory. Consider a volume of air and treat the air as an ideal gas. How many molecules are present in a volume of 1.00 cm^3 at a pressure of 9.00 x 10^{-13} atm and temperature of 300.0 K? [5]

QN8. (A) In the figure 3, each capacitance C_1 is 13.8 μF, and each capacitance C_2 is 9.2 μF (a) Compute the equivalent capacitance of the network between terminals a and b. (b) Compute the charge on each of the three capacitors nearest to the terminals a and b when V_{ab} = 420 V. (c) With 420 V across the terminals a and b, compute V_{cd}. [7.5]

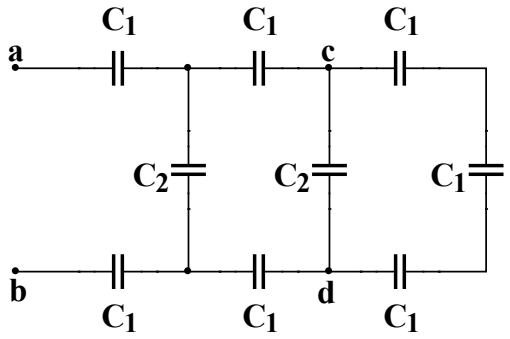


Figure 3: QN8. (A)

(B) Compute the interaction force between two copper spheres, each of mass 0.1 g, separated by a distance of 1.0 m, if the total electronic charge on them differs from the total charge of the copper nuclei by 1%. [5]

QN9. (A) Consider two vibrations of equal amplitude and frequency but differing in phase, one along the X-axis,

$$\frac{x}{A} = \sin(\omega t - \alpha) \ldots\ldots\ldots\ldots (1)$$

and the other along the Y-axis

$$\frac{y}{A} = \sin(\omega t - \beta) \ldots\ldots\ldots\ldots (2)$$

(i) Multiply Eq. (1) by $\sin\beta$ and Eq. (2) by $\sin\alpha$, and then subtract one of the resulting equations from another one. (ii) Multiply Eq. (1) by $\cos\beta$ and Eq. (2) by $\cos\alpha$, and then subtract one of the resulting equations from another one. (iii) Square and add the results of parts (i) and (ii). (iv) Now obtain the equation $x^2 + y^2 - 2xy\,cos\theta = A^2 sin^2\theta$ where $\theta = \alpha - \beta$ (v) Use the above results to justify each of the following figures in figure 4 i.e a diagonal straight line for $\theta = 0$ and a circle for $\theta = \frac{\pi}{2}$. In the figure 4, the angle given is the phase difference between two simple harmonic motions of the same frequency and amplitude, one along the X-axis and the other along the Y-axis. The figure thus shows the resultant motion from the superposition of the two perpendicular harmonic motions. [6.5]

Angle (θ)	0	$\frac{\pi}{2}$
Shape		

Figure 4: QN9. (A)

(B) A man runs at a velocity v in a straight line forming an angle θ with the plane of a mirror. Determine the velocity $v_{relative}$ at which he approaches his image, assuming that the object and its image are symmetric relative to the plane of the mirror. [3.5]

QN10. (A) A student has two packets of resistors, one marked as 10 kΩ and the other as 15 kΩ with a tolerance of 5%. And each packet contains 10 pieces of resistors. He measured each resistor individually and tabulated the resistances as follows:

R_1(kΩ)	9.51	9.39	9.41	9.36	9.60	9.52	9.53	9.39	9.62	9.60
R_2(kΩ)	14.98	14.83	14.74	14.90	14.59	14.74	14.73	14.49	14.80	14.85

(i) Determine the values of R_1 and R_2 with their uncertainties.

(ii) Check whether the labeled values on the packets are valid or not.

(iii) Calculate the values of R_1 and R_2 when they are connected in series and also when they are connected in parallel. [7.5]

(B) Another student took a resistance from the same packet of QN10. (A) labeled as 15 kΩ with a tolerance of 5%. He tried to determine the resistance of that resistor by measuring the voltage across it and the corresponding current through it as follows:

Voltage (V)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
Current (mA)	0.032	0.069	0.102	0.130	0.162	0.196	0.230	0.263	0.297	0.350

(i) Plot a graph between current and voltage with error bar.

(ii) Determine the resistance from the graph with uncertainty. [5]

QN11. (A)(i) Show that in the Bohr model, the frequency of revolution of an electron in its circular orbit around a stationary hydrogen nucleus is $\nu = me^4/4\varepsilon_o^2 n^3 h^3$. (ii) In classical physics, the frequency of revolution of the electron is equal to the frequency of the radiation that it emits. Show that when n is very large, the frequency of revolution is indeed equal the radiated frequency calculated from the relation $h\nu = \frac{hc}{\lambda}(= E_i - E_f)$ for a transition from $n_1 = n+1$ to $n_2 = n$. [6.5]

(B) The potential difference between the two plates in the figure 5 is 50.0 V. What will be the speed of a proton released from plate B just before it hits plate A? Assume the system is in vacuum. [3.5]

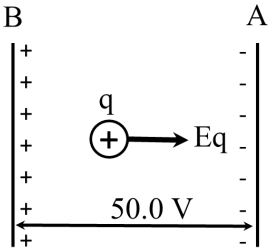


Figure 5: QN11. (B)

**********Good Luck**********