# 33rd Singapore Physics Olympiad Theory Paper

**Organised by**

Institute of Physics

**In conjunction with**
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## Instructions to Candidates

1. This is a **three and half** hour paper.

2. This paper consists of **NINE (9)** questions printed on NINETEEN (19) pages. The last page is a general information sheet.

3. Attempt all questions.

4. Write your answers in the space provided in the question booklet.

5. You may request working paper from the invigilators.

6. You may not refer to any books or documents relevant to the competition.

NAME: ________________________________________ (As in registration list)

SCHOOL: ________________________________________

1. A cylindrical rod has a radius of 1.0 cm and length 1.0 m. It is made up of two sections, each of length 0.5 m. The material of one section is zinc and that of the other section is copper. The end of the rod made of zinc is pivoted to a fixed point $O$. The rod is first held so that it is horizontal and then released. Determine the angular velocity of the rod when it is in the vertical position.

[Densities : zinc : 7135 kg m $^{-1}$ ; copper : 8940 kg m $^{-1}$ ] [10 marks]

2. (a) A student is sitting on a swing which is swinging back and forth with a constant angular amplitude of $45°$. The length of the swing is 5m. A loudspeaker, placed at a short distance away from the swing, produces a sound with a constant frequency of 400Hz. What are the maximum and minimum frequency of the sound heard by the student?
(Speed of sound waves = 330 m/s) [5 marks]

(b) A compound microscope contains two thin lenses of focal length 6.0 mm and 40.0 mm, respectively. The lenses are separated by a distance of 200 mm. The final image is formed 250 mm from the eye lens. Calculate

(i) The distance of the object from the objective lens

(ii) The magnifying power of the microscope. [5 marks]

3. One end of a thin conducting rod of length $\ell$ is pivoted to a fixed point. The rod has a resistance of $R$ and its two ends of the rod are connected to a resistor with resistance $R_0$ The rod is rotating with a constant angular velocity $\omega$ in a uniform magnetic field of flux density $B$. This direction of magnetic field is normal to the plane of rotation of the rod.

(a) What is the emf induced in the rod?

(b) Determine the electric power developed in the resistor.

(c) Describe, with evidence, the origin of the electric power developed in the resistor.

[10 marks]

4. A free electron collides with a hydrogen atom which is in the ground state. After the collision, the hydrogen atom is excited and during the process of de-excitation, two photons are emitted. The wavelength of one of the photons emitted is 656.3 nm. The electron, after the collision, has de Broglie wavelength of 1.915 nm.

   (a) What is the wavelength of the other photon emitted during the de-excitation?

   (b) What is the speed of the free electron before collision? [10 marks]

5. (a) An airplane flying horizontally with a constant speed of 540 km h $^{-1}$ at a height of 1200 m fires a projectile horizontally in its direction of motion at a speed of $u$ ms $^{-1}$ relative to the plane. At this instant, a vehicle is at a point on the ground $d$ km horizontally from the airplane. The vehicle is moving with a constant speed of 40 ms $^{-1}$ on a horizontal road in the direction of motion of the plane. What must be the minimum value of $d$ so that the projectile will hit the vehicle? If, at the instant when the projectile is fired, the value of $d$ is 5 times its minimum value, what is the speed of the projectile when it hits the vehicle? [7 marks]

(b) A satellite is orbiting the Earth 400 km above the equator. Its sense of revolution follows the rotation of the Earth. When the satellite is vertically above a point $P$ on the equator, it will take a photo of the region around $P$. How many photos can the satellite take in 24 hours? [5 marks]

6. (a) A charged insulating sphere of radius $R$ has a uniform positive charge density $\rho$ throughout its entire volume. A very narrow tunnel is drilled along the sphere's diameter. A charged particle of mass $m$ carrying a charge $-q$ is placed at one end of the tunnel and released. Describe the subsequent motion of the charged particle. What is the speed of the particle when it passes through the centre of the sphere?

[6 marks]

(b) A particle P of mass $m$ moves along a straight line joining two fixed points A and B. The particle is under the action of two forces $F_A$ and $F_B$. $F_A$ acts towards the point A and has magnitude $2\mu m d_A$ where $d_A$ is the distance of the point P from A. $F_B$ acts towards the point B and has magnitude $\mu m d_B$ where $d_B$ is the distance of the point P from B. Given that $\mu$ is a constant, shows that the motion of P is simple harmonic. Deduce an expression for the period of motion. During the oscillation, the particle is instantaneously at rest at the mid-point of AB. What is the amplitude of the oscillation and what is the kinetic energy of the particle when it is at $O$, the point where it experiences zero net force? [6 marks]

7. (a) A container, the volume of which is $8.0\times10^{-3}$ m$^3$, contains an ideal gas at a pressure of $1.14\times10^{5}$ Pa and temperature $T$. The lid of the container is opened, causing the gas to expand adiabatically until its pressure is $1.01\times10^{5}$ Pa. This results in a slight decrease in the mass of the gas in the container. The lid is then closed and the gas in the container is allowed to return to its initial temperature. Under this new equilibrium condition, the pressure of the gas is $1.06\times10^{5}$ Pa.

(i) What will be the volume of the gas left in the container under the initial equilibrium condition; i.e. at pressure $1.14\times10^{5}$ Pa and temperature $T$ ?

(ii) What is the value of $\gamma$, the ratio of the molar heat capacity of the gas at constant pressure to that at constant volume?

(iii) State, with reasons, what is the atomicity of the molecules of the gas?

[6 marks]

(b) One end of a copper rod, with diameter 2.0 cm and length 50.0 cm, is in good thermal contact with a hot bath maintained at $100°C$ while the other end is immersed in a mixture of 200 g ice and 100 g water initially maintained at $0°C$ inside a container whose thermal capacity is negligible. Both the copper rod and the container are well-lagged. How long does it take for the temperature of the mixture to rise from $0°C$ to $20°C$?

[Thermal conductivity of copper $= 400\ \mathrm{W\ m^{-2}\ K^{-1}}$;
Specific heat capacity of water $= 4200\ \mathrm{J\ kg^{-1}\ K^{-1}}$
Latent heat of fusion of water $= 3.34 \times 10^{5}\ \mathrm{J\ kg^{-1}}$] [6 marks]

8. (a) Two identical sound sources A and B which emit sound waves with frequency 256Hz are initially side by side together with a stationary observer. Source A remains stationary with respect to the observer, while source B accelerates from rest with a constant acceleration of 0.5 $ms^{-2}$ until it reaches a point P. After this, B continues to move with a constant velocity that it attains at the point P. When this happens, the observer finds that the frequency of sound coming source B differs from that from source A by 8 Hz. What is the distance of the point P from the observer? [Speed of sound waves in air = 330 $ms^{-1}$] [5 marks]

(b)

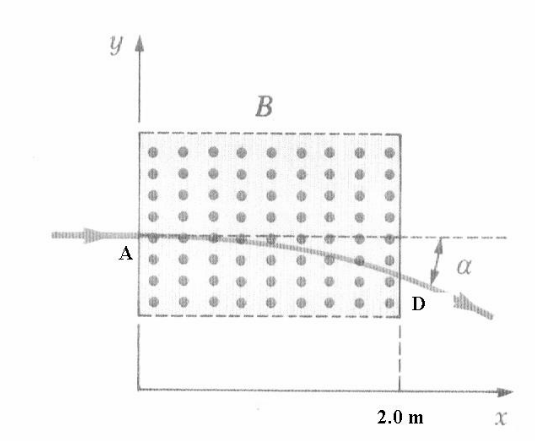


Fig. 1

A beam of proton with kinetic energy 10 MeV is travelling in the positive $x-$direction. It enters a magnetic field of magnitude 1.5 T and the direction of the magnetic field is in the positive $z-$direction. The magnetic field extends from $x=0$ to $x=2.0$ m as shown in Fig. 1. Determine the angle $\alpha$ between the initial velocity vector of the proton beam and the velocity vector after the beam emerges from the magnetic field. [7 marks]

9. (a) Light with wavelength 122 nm is incident on the surface of a metal. The electrons, which are **emitted with maximum kinetic energy**, enters a magnetic field the direction of which is normal to the velocity vectors of these electrons. The flux density of the magnetic field is $5\times10^{-5}$ T. These electrons are found to describe a circular path of radius 15.8 cm in the magnetic field. What is the work function of the metal? [5 marks]

(b) Muons are particles which are created in the upper atmosphere via cosmic interactions. These particles travel vertically downward to the surface of the Earth at a speed of $0.995c$ where $c$ represents the speed of light in vacuum. When muons are at rest, they have a half-life of $1.56\mu s$. A muon counter is placed at the top of a mountain 2000 m high. The counter records 568 muons in 1 hour.

(i) According to classical concepts, what will be the number of muons counted in 1 hour if the counter is placed at the foot of the mountain? [2 marks]

(ii) In a typical experiment, a counter placed at the foot of the mountain record 422 muons in 1 hour. Why does the result of this experiment differ so much from your result in part (i)? [2 marks]

(iii) What is the "height" of the mountain according to muons? [1 mark]

(iv) While the muons are travelling downward to the earth, another particle also travels in the same direction with speed $0.9995c$. What is the velocity of this particle in the muon's inertial frame? [2 marks]

## GENERAL INFORMATION SHEET

| | |
|---|---|
| Acceleration due to gravity at Earth surface, | $g = 9.80\ \mathrm{m\ s^{-2}} = \lvert\vec{g}\rvert$ |
| Radius of the Earth | $R_E = 6.371\times10^6\ \mathrm{m}$ |
| Universal gas constant, | $R = 8.31\ \mathrm{J\ mol^{-1}\ K^{-1}}$ |
| Vacuum permittivity, | $\varepsilon_0 = 8.85\times10^{-12}\ \mathrm{C^2\ N^{-1}\ m^{-2}}$ |
| Vacuum permeability, | $\mu_0 = 4\pi\times10^{-7}\ \mathrm{T\ m\ A^{-1}}$ |
| Atomic mass unit, | $u = 1.66\times10^{-27}\ \mathrm{kg}$ |
| Speed of light in vacuum, | $c = 3.00\times10^{8}\ \mathrm{m\ s^{-1}}$ |
| Charge of electron, | $e = 1.60\times10^{-19}\ \mathrm{C}$ |
| Planck's constant, | $h = 6.63\times10^{-34}\ \mathrm{J\ s}$ |
| Mass of electron, | $m_e = 9.11\times10^{-31}\ \mathrm{kg} = 0.000549u$ |
| Mass of proton, | $m_p = 1.67\times10^{-27}\ \mathrm{kg} = 1.007u$ |
| Rest mass of alpha particle, | $m_\alpha = 4.003\mathrm{u}$ |
| Boltzmann constant, | $k = 1.38\times10^{-23}\ \mathrm{J\ K^{-1}}$ |
| Avogadro's number, | $N_A = 6.02\times10^{23}\ \mathrm{mol^{-1}}$ |
| Standard atmosphere pressure, | $P_0 = 1.01\times10^{5}\ \mathrm{Pa}$ |
| Density of water, | $\rho_w = 1000\ \mathrm{kg\ m^{-3}}$ |
| Specific heat (capacity) of water, | $c_w = 4.19\times10^{3}\ \mathrm{J\ kg^{-1}\ K^{-1}}$ |
| Latent heat of fusion for water, | $L_f = 3.34\times10^{5}\ \mathrm{J\ kg^{-1}}$ |
| Stefan-Boltzmann constant, | $\sigma = 5.67\times10^{-8}\ \mathrm{W\ m^{-2}\ K^{-4}}$ |
| Sum of N terms in an arithmetic series, | $\sum_{k=0}^{N} a_k + (k-1)d = \frac{N}{2}\left[2a_0 + (N-1)d\right]$ |
| Sum of N terms in a geometric series, | $\sum_{k=0}^{N} r^k = \frac{1-r^N}{1-r} \qquad r<1$ |
| Approximation for square root, for small $x$ | $\sqrt{1+x} \approx 1 + \frac{x}{2}$ |
| Area under the curve of $y = x^n$ for $0 \le x \le x_0$ | $\int_0^{x_0} x^n dx = \frac{1}{n+1} x_0^{n+1}$ |