

## Question 10: Nuclear Physics

(a) Define binding energy of a nucleus.

解析过程 / Solution

The minimum energy required to separate all the nucleons in a nucleus to infinity.

(b)(i) Reaction:  $4 {}^1_1\text{H} \rightarrow {}^4_2\text{He} + 2 {}^0_1\text{X}$ . Name particle X.

解析过程 / Solution

Positron.

(b)(ii) Show binding energy of He is  $4.54 \times 10^{-12}$  J. (Mass defect = 0.030377 u).

解析过程 / Solution

$$E = \Delta mc^2$$

$$E = (0.030377 \times 1.66 \times 10^{-27}) \times (3 \times 10^8)^2$$

$$E = 4.538 \times 10^{-12} \text{ J} \approx 4.54 \times 10^{-12} \text{ J}$$

(c)(i) Luminosity  $L = 7.98 \times 10^{27}$  W, distance  $d = 8.15 \times 10^{16}$  m. Calculate radiant flux intensity  $F$ .

解析过程 / Solution

$$F = \frac{L}{4\pi d^2} = \frac{7.98 \times 10^{27}}{4\pi \times (8.15 \times 10^{16})^2} \approx 9.56 \times 10^{-8} \text{ W m}^{-2}$$

(c)(ii) Determine the rate of decrease of mass of hydrogen in the star.

解析过程 / Solution

Number of reactions per second:

$$n = \frac{L}{E} = \frac{7.98 \times 10^{27}}{4.538 \times 10^{-12}} = 1.758 \times 10^{39} \text{ s}^{-1}$$

Mass of 4 Hydrogen atoms consumed per reaction:

$$m = 4 \times 1.66 \times 10^{-27} = 6.64 \times 10^{-27} \text{ kg}$$

Rate of mass decrease:

$$\text{rate} = n \times m = 1.758 \times 10^{39} \times 6.64 \times 10^{-27} = 1.17 \times 10^{13} \text{ kg s}^{-1}$$

# CIE Physics (9702/42/M/J/26)

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## Question 1: Circular Motion

(a) With reference to velocity and acceleration, describe uniform circular motion.

### 解析过程 / Solution

- **Velocity:** Has constant magnitude (speed) but constantly changes direction.
- **Acceleration:** Is perpendicular to velocity, directed towards the centre of the circle.

(b) An aircraft is travelling in a horizontal circle of radius 7200 m at a speed of  $180 \text{ m s}^{-1}$ . In order to move in a circle, the aircraft has to tilt its wings so that the lift force from the wings is not vertical.

(i) With reference to the forces acting on the aircraft, explain why the circular motion requires the lift force to be tilted.

### 解析过程 / Solution

A resultant centripetal force is required towards the centre of the circle. The horizontal component of the lift provides this centripetal force, while the vertical component balances the weight.

(ii) Calculate the centripetal acceleration of the aircraft.

### 解析过程 / Solution

$$a = \frac{v^2}{r} = \frac{180^2}{7200} = 4.5 \text{ m s}^{-2}$$

Acceleration =  $4.5 \text{ m s}^{-2}$

(iii) Determine the angle  $\theta$  at which the aircraft is tilted. Explain your reasoning.

### 解析过程 / Solution

Vertical equilibrium:  $L \cos \theta = mg$

Horizontal centripetal force:  $L \sin \theta = ma$

Dividing the two equations gives:

$$\tan \theta = \frac{a}{g} = \frac{4.5}{9.81} \Rightarrow \theta = \tan^{-1} \left( \frac{4.5}{9.81} \right) = 24.6^\circ$$

$$\theta = 24.6^\circ$$

## Question 2: Gravitational Fields

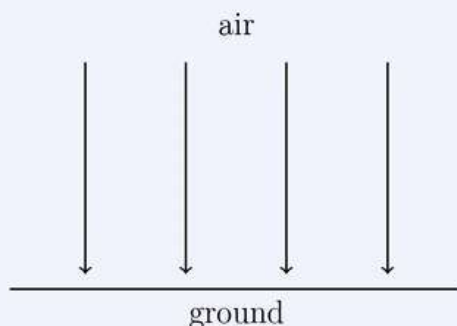
(a)(i) Define gravitational field at a point.

### 解析过程 / Solution

Force per unit mass acting on a small test mass placed at that point.

(ii) Draw four field lines to represent the gravitational field of the Earth in the air above the ground.

### 解析过程 / Solution



(b)(i) By considering the gravitational field strength at the Earth's surface ( $R = 6.37 \times 10^6$  m), calculate a value for the mass of the Earth.

### 解析过程 / Solution

$$mg = \frac{GMm}{R^2} \Rightarrow g = \frac{GM}{R^2} \Rightarrow M = \frac{gR^2}{G}$$

$$M = \frac{9.81 \times (6.37 \times 10^6)^2}{6.67 \times 10^{-11}} = 5.97 \times 10^{24} \text{ kg}$$

(ii) Determine the gravitational potential at the Earth's surface.

**解析过程 / Solution**

$$\phi = -\frac{GM}{R} = -gR = -9.81 \times 6.37 \times 10^6 = -6.25 \times 10^7 \text{ J kg}^{-1}$$

(iii) A satellite of mass 96.0 kg is in circular orbit at a height of  $1.93 \times 10^6$  m above the Earth's surface. Determine its gravitational potential energy.

**解析过程 / Solution**

$$r = R + h = 6.37 \times 10^6 + 1.93 \times 10^6 = 8.30 \times 10^6 \text{ m}$$

$$E_p = m\phi = -\frac{GMm}{r} = 96.0 \times \left( -\frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24}}{8.30 \times 10^6} \right) = -4.60 \times 10^9 \text{ J}$$

**Question 3: Thermal Physics**

(a) Define specific heat capacity.

**解析过程 / Solution**

The energy required to raise the temperature of unit mass (1 kg) of a substance by 1 K (or 1°C).

(b) A sample of ideal gas contains  $6.00 \times 10^{23}$  molecules, each of mass  $6.64 \times 10^{-27}$  kg. Initial  $P = 1.01 \times 10^5$  Pa,  $V_1 = 0.0243 \text{ m}^3$ ,  $U_1 = 3676 \text{ J}$ ,  $T_1 = 296 \text{ K}$ . It is cooled at constant pressure to 80% of initial volume.

(i) Show that the magnitude of the work done on the gas is 491 J.

**解析过程 / Solution**

$$\Delta V = V_1 - V_2 = 0.0243 - (0.8 \times 0.0243) = 0.00486 \text{ m}^3$$

$$W = p\Delta V = 1.01 \times 10^5 \times 0.00486 = 490.86 \text{ J} \approx 491 \text{ J}$$

(ii) Explain whether the work done on the gas is positive or negative.

**解析过程 / Solution**

Positive. The volume decreases, meaning the gas is compressed, so work is done *on* the gas.

(iii) Explain why the increase in internal energy of the gas is -735 J.

### 解析过程 / Solution

For an ideal gas, internal energy  $U \propto T$ . At constant pressure,  $V \propto T$  (Charles's law), therefore  $U \propto V$ .

$$\Delta U = 3676 \times (0.80 - 1) = -735.2 \text{ J} \approx -735 \text{ J}$$

(iv) Determine the thermal energy  $Q$  transferred to the gas.

### 解析过程 / Solution

First Law of Thermodynamics:  $\Delta U = Q + W$

$$Q = \Delta U - W = -735 - 491 = -1226 \text{ J}$$

(v) Calculate a value for the specific heat capacity  $c$  of the gas.

### 解析过程 / Solution

Mass  $m = 6.00 \times 10^{23} \times 6.64 \times 10^{-27} = 3.984 \times 10^{-3} \text{ kg}$ .

$\Delta T = 296 \times (0.80 - 1) = -59.2 \text{ K}$ .

$$c = \frac{Q}{m\Delta T} = \frac{-1226}{3.984 \times 10^{-3} \times (-59.2)} = 5200 \text{ J kg}^{-1}\text{K}^{-1}$$

(c) The gas is now heated at constant volume back to 296 K. Explain whether the specific heat capacity for this change is less than, the same as, or greater than the answer in (b)(v).

### 解析过程 / Solution

**Less than.** Heating at constant volume means no work is done ( $W = 0$ ), so all thermal energy supplied goes entirely into increasing internal energy ( $Q = \Delta U$ ). Heating at constant pressure means the gas expands and does work on its surroundings, requiring extra thermal energy to do this work ( $Q = \Delta U + W$ ). For the same  $\Delta T$ , less thermal energy is required at constant volume, hence specific heat capacity is lower ( $C_v < C_p$ ).

## Question 4: Kinetic Theory of Gases

(a) State the two assumptions of the kinetic theory of gases that relate to collisions of particles.

**解析过程 / Solution**

1. Collisions are perfectly elastic.
2. The time of collision is negligible compared to the time between collisions.

(b) A single particle of mass  $m$  is moving at speed  $u$  in a cubic box of side length  $L$ . Determine an expression for:

- (i) Change in momentum during each collision.

**解析过程 / Solution**

$$\Delta p = mu - (-mu) = 2mu$$

- (ii) Time taken between consecutive collisions with one face.

**解析过程 / Solution**

$$t = \frac{2L}{u}$$

- (iii) Mean force exerted on the particle by one face.

**解析过程 / Solution**

$$\text{Mean force} = \frac{\Delta p}{t} = \frac{2mu}{\frac{2L}{u}} = \frac{mu^2}{L}$$

- (iv) Mean pressure  $p$  exerted over the area of each face. Explain reasoning.

**解析过程 / Solution**

$$p = \frac{F}{A} = \frac{\frac{mu^2}{L}}{L^2} = \frac{mu^2}{L^3}$$

- (c) Explain how the equation in 4(b)(iv) is modified to arrive at  $pV = \frac{1}{3}Nm\langle c^2 \rangle$ .

**解析过程 / Solution**

For  $N$  particles, total pressure is the sum of pressures from all individual particles. Particles move randomly in 3 dimensions. On average,  $\frac{1}{3}$  of the particles move in each direction, so the mean-square speed in one direction is  $u^2 = \frac{1}{3}\langle c^2 \rangle$ . Substituting  $V = L^3$ :

$$p = \frac{Nm(\frac{1}{3}\langle c^2 \rangle)}{V} \implies pV = \frac{1}{3}Nm\langle c^2 \rangle$$

## Question 5: Simple Harmonic Motion

(a) Block mass 27g. Period  $T = 1.7$  s, Energy  $E = 13\mu\text{J}$ . (i) Show angular frequency is  $3.7 \text{ rad s}^{-1}$ .

解析过程 / Solution

$$\omega = \frac{2\pi}{T} = \frac{2\pi}{1.7} \approx 3.7 \text{ rad s}^{-1}$$

(ii) State what is meant by amplitude.

解析过程 / Solution

Maximum displacement of the block from its equilibrium position.

(iii) Calculate amplitude.

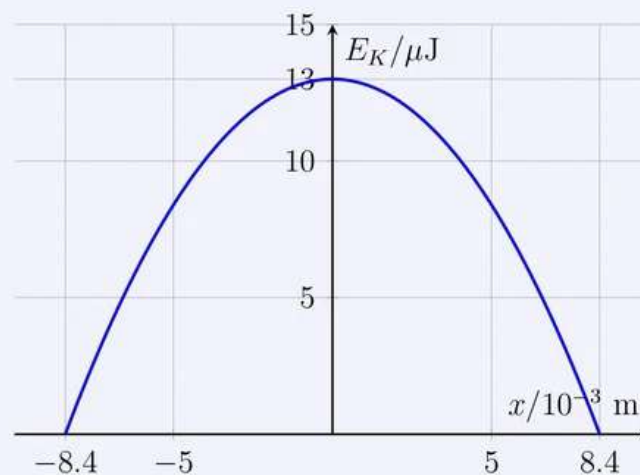
解析过程 / Solution

$$E = \frac{1}{2}m\omega^2 A^2$$

$$A = \sqrt{\frac{2E}{m\omega^2}} = \sqrt{\frac{2 \times 13 \times 10^{-6}}{0.027 \times 3.7^2}} = 8.4 \times 10^{-3} \text{ m}$$

(b) Sketch the variation of kinetic energy  $E_K$  with displacement  $x$ .

解析过程 / Solution



## Question 6: Electric Potentials and Capacitance

(a) Define electric potential at a point.

### 解析过程 / Solution

Work done per unit positive charge to bring a small test charge from infinity to the point.

(b)(i) State an expression for magnitude  $V_0$  of electric potential at the surface of a sphere of radius  $R$  and charge  $+Q$ .

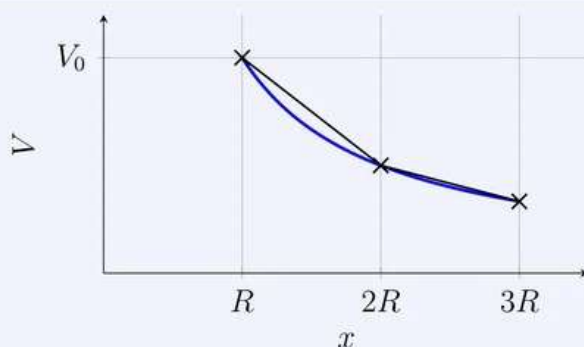
### 解析过程 / Solution

$$V_0 = \frac{Q}{4\pi\epsilon_0 R}$$

where  $\epsilon_0$  is the permittivity of free space.

(b)(ii) Sketch variation of electric potential  $V$  at distance  $x$  between  $x = R$  and  $x = 3R$ .

### 解析过程 / Solution



(c) Van de Graaff generator dome radius 11.9 cm, potential  $-4.80 \times 10^4$  V. (i) Calculate charge on the surface.

### 解析过程 / Solution

$$V = \frac{Q}{4\pi\epsilon_0 R} \implies Q = 4\pi\epsilon_0 R V$$

$$Q = \frac{0.119 \times (-4.80 \times 10^4)}{8.99 \times 10^9} \approx -6.35 \times 10^{-7} \text{ C}$$

(ii) Explain why the dome acts as a capacitor.

### 解析过程 / Solution

It stores charge at a particular electric potential.

(iii) Calculate capacitance.

**解析过程 / Solution**

$$C = 4\pi\epsilon_0 R = 4\pi \times 8.85 \times 10^{-12} \times 0.119 = 1.32 \times 10^{-11} \text{ F}$$

(iv) Determine energy stored.

**解析过程 / Solution**

$$E = \frac{1}{2}CV^2 = \frac{1}{2} \times 1.32 \times 10^{-11} \times (-4.80 \times 10^4)^2 \approx 1.52 \times 10^{-2} \text{ J}$$

**Question 7: Hall Effect**

(a)(i) Identify the faces between which Hall voltage is induced.

**解析过程 / Solution**

WPSZ and XQRY.

(a)(ii) Meanings of  $n$ ,  $q$  and  $t$  in  $V_H = \frac{BI}{nqt}$ .

**解析过程 / Solution**

- **n**: Number density of free charge carriers.
- **q**: Charge of a single charge carrier (elementary charge  $e$ ).
- **t**: Thickness of the slice in the direction of the magnetic field.

(b)(i) Explain the origin of the Hall voltage.

**解析过程 / Solution**

Charge carriers moving in a magnetic field experience a magnetic force. This force acts perpendicular to both their velocity and the magnetic field. Charge carriers accumulate on one face, creating an electric field/potential difference.

(b)(ii) Identify which face is at higher potential and explain.

**解析过程 / Solution**

**WPSZ is at the higher potential.**

Assuming charge carriers are electrons (negative). Using Fleming's left-hand rule, the magnetic force pushes these electrons towards the back face (XQRY). Face XQRY becomes negative, leaving the front face (WPSZ) positive, which is at a higher potential.

## Question 8: Alternating Current and Rectification

(a)(i) Name of component for rectification.

**解析过程 / Solution**

Diode.

(a)(ii) Name of component for smoothing.

**解析过程 / Solution**

Capacitor.

(b)(i) Determine peak value of  $V_{IN}$ .

**解析过程 / Solution**

3.6 V (Read from the amplitude of the sinusoidal graph).

(b)(ii) Determine period of  $V_{IN}$ .

**解析过程 / Solution**

0.04 s (Time for one complete cycle).

(c) Determine three other conclusions drawn from the graphs.

### 解析过程 / Solution

1. The output voltage is always positive, indicating half-wave rectification.
2. The peak output voltage is slightly less than the peak input voltage, due to the forward voltage drop across the diode.
3. The output voltage has a small ripple, showing the smoothing capacitor is effective.

## Question 9: Quantum Physics

- (a) State what is meant by de Broglie wavelength.

### 解析过程 / Solution

The wavelength associated with a moving particle, given by  $\lambda = \frac{h}{p}$ .

- (b) Complete Table to identify experimental evidence.

### 解析过程 / Solution

|                     | Wave nature                | Particle nature               |
|---------------------|----------------------------|-------------------------------|
| <b>Matter</b>       | Electron diffraction       | $\alpha$ -particle scattering |
| <b>EM radiation</b> | Interference / diffraction | Photoelectric effect          |

- (c) Electron accelerated by p.d. of 3.5 kV. (i) Calculate speed.

### 解析过程 / Solution

$$eV = \frac{1}{2}mv^2$$

$$v = \sqrt{\frac{2eV}{m}} = \sqrt{\frac{2 \times 1.6 \times 10^{-19} \times 3500}{9.11 \times 10^{-31}}} = 3.5 \times 10^7 \text{ m s}^{-1}$$

- (ii) Calculate de Broglie wavelength.

### 解析过程 / Solution

$$\lambda = \frac{h}{p} = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 3.5 \times 10^7} = 2.1 \times 10^{-11} \text{ m}$$