Centre Number

Student Number

NSW Education Standards Authority

2024 **HIGHER SCHOOL CERTIFICATE EXAMINATION**

Physics

General Instructions

- Reading time – 5 minutes
- Working time – 3 hours
- Write using black pen
- Draw diagrams using pencil
- Calculators approved by NESA may be used
- A data sheet, formulae sheet and Periodic Table are provided at the back of this paper
- Write your Centre Number and Student Number at the top of this page

Total marks: 100

Section I – 20 marks (pages 2–13)

- Attempt Questions 1–20
- Allow about 35 minutes for this section

Section II – 80 marks (pages 17–40)

- Attempt Questions 21–33
- Allow about 2 hours and 25 minutes for this section

Section I

20 marks
Attempt Questions 1–20
Allow about 35 minutes for this section

Use the multiple-choice answer sheet for Questions 1–20.

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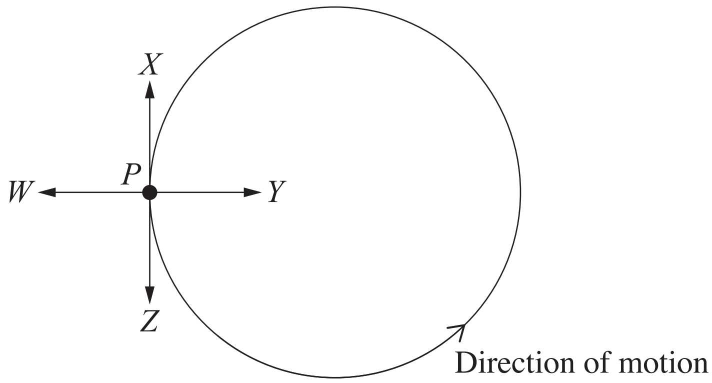
1 The diagram shows an object, *P*, undergoing uniform circular motion.



Which arrow shows the direction of the net force acting on *P*?

A. *W*

B. *X*

C. *Y*

D. *Z*

2 Which of the following provides evidence for the model of light proposed by Huygens?

A. Emission spectra

B. Diffraction of light

C. Black body radiation

D. The photoelectric effect

3 Which of the following is a fundamental particle in the Standard Model of matter?

A. Hadron

B. Neutron

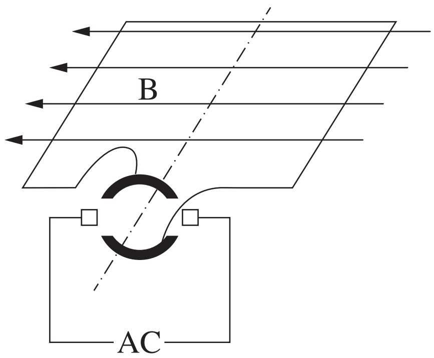
C. Photon

D. Proton

4 A conducting coil is mounted on an axle and placed in a uniform magnetic field. The diagram shows different ways of connecting the coil to a power source.

Which setup allows the conducting coil to rotate continuously?

A.



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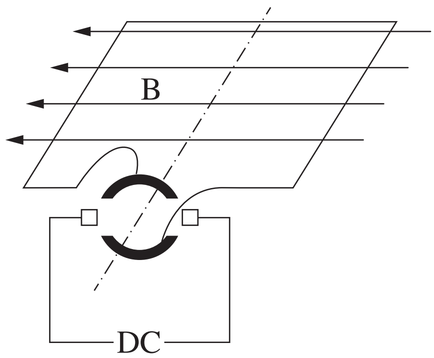

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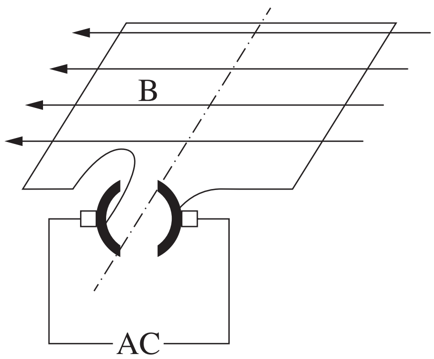

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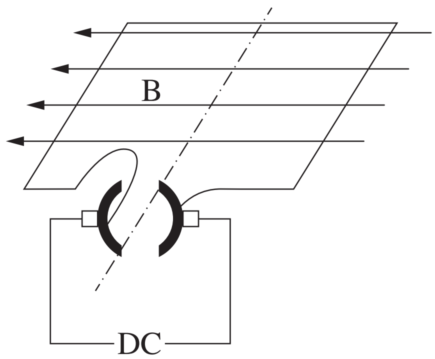
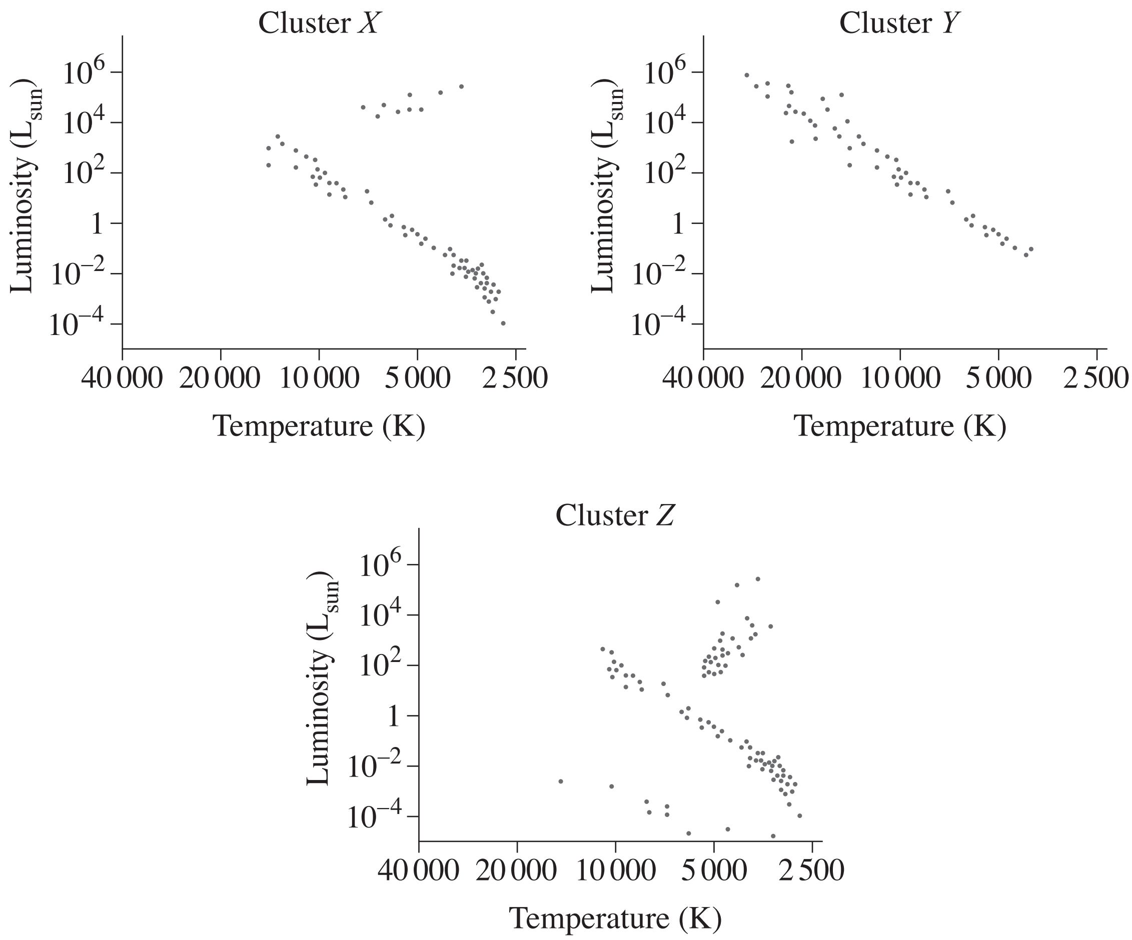


5 A star cluster is a group of stars that form at the same time. Hertzsprung–Russell diagrams for three star clusters, *X*, *Y* and *Z* are shown.



Which row of the table correctly shows the three star clusters from youngest to oldest?

	Youngest ⟶		*Oldest*
A.	*Y*	*X*	*Z*
B.	*Y*	*Z*	*X*
C.	*Z*	*X*	*Y*
D.	*Z*	*Y*	*X*

6 The photoelectric effect is mathematically modelled by the following relationship:

$$K_{\text{max}} = hf - \phi$$

In this model, the symbol ϕ represents the amount of energy

A. supplied by a photon to an electron.

B. retained by an electron after being hit.

C. required to release an electron from a material.

D. left over after a collision of a photon with an electron.

7 A pure sample of polonium-210 undergoes alpha emission to produce the stable isotope lead-206.

The half-life of polonium-210 is 138 days.

At the end of 276 days, what is the ratio of polonium-210 atoms to lead-206 atoms in the sample?

A. 1 : 4

B. 1 : 3

C. 1 : 2

D. 1 : 1

8 An ideal transformer produces an output of 6 volts when an input of 240 volts is applied.

What change would be needed to produce an output of 12 volts, using the same input voltage?

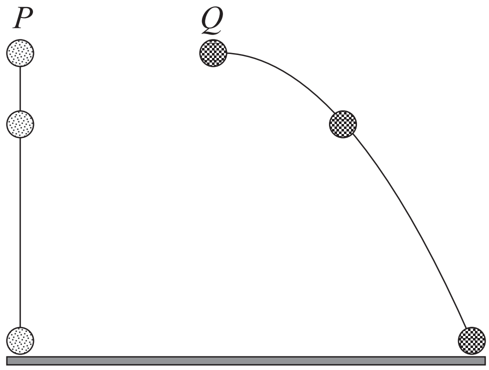
A. Increase the number of turns on the primary coil

B. Decrease the number of turns on the primary coil

C. Increase the resistance connected to the secondary coil

D. Decrease the resistance connected to the secondary coil

9 Object P is dropped from rest, and object Q is launched horizontally from the same height.



Which option correctly compares the projectile motion of P and Q?

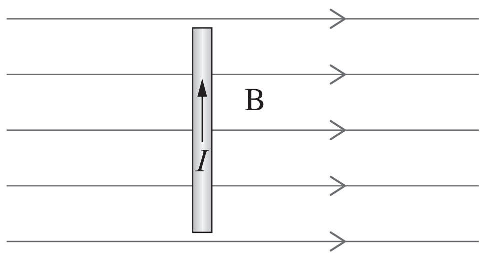
A. The acceleration of P is less than the acceleration of Q.

B. The final velocity of Q is greater than the final velocity of P.

C. The time of flight of Q is greater than the time of flight of P.

D. The initial vertical velocity of P is less than the initial vertical velocity of Q.

10 A rod carrying a current, I, placed in a uniform magnetic field as shown, experiences a force F.



How many degrees must the rod be rotated clockwise so that it experiences a force $\frac{F}{2}$?

A. 30°

B. 45°

C. 60°

D. 90°

11 A satellite is in a circular orbit.

What is the relationship between its orbital velocity, v, and its orbital radius, r?

A. v is directly proportional to the square of r.

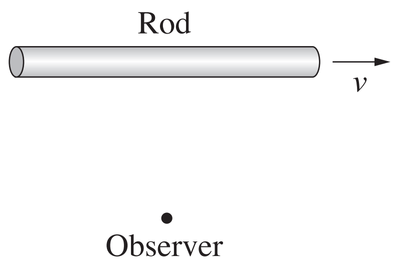
B. v is inversely proportional to the square of r.

C. v is directly proportional to the square root of r.

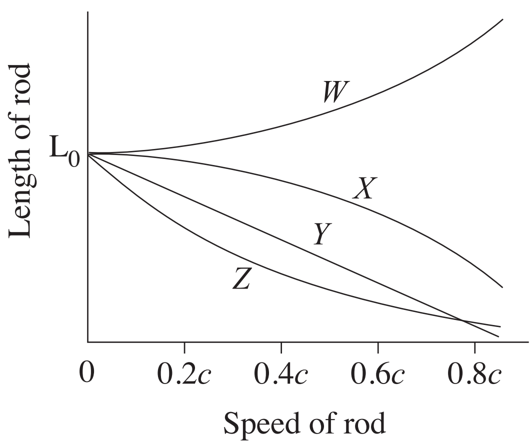
D. v is inversely proportional to the square root of r.

12 A rod has a length, L_0, when measured in its own frame of reference.

The rod travels past a stationary observer at speed, v, as shown in the diagram.



Which option represents the relationship between the speed of the rod, v, and the length of the rod as measured by the stationary observer?



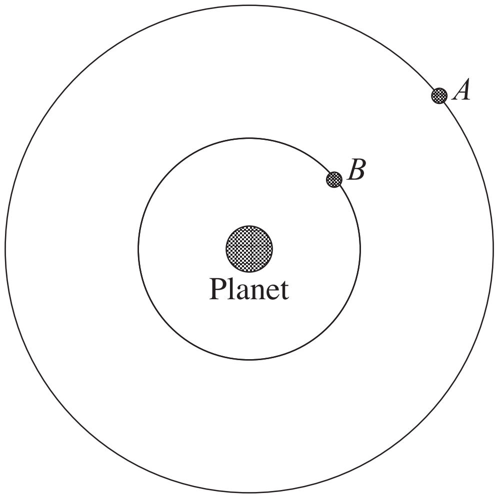
A. W

B. X

C. Y

D. Z

13 The diagram shows two identical satellites, A and B, orbiting a planet.



Which row in the table correctly compares the potential energy, U, and kinetic energy, K, of the satellites?

	Potential energy	*Kinetic energy*
A.	$U_A > U_B$	$K_A < K_B$
B.	$U_A < U_B$	$K_A > K_B$
C.	$U_A > U_B$	$K_A > K_B$
D.	$U_A < U_B$	$K_A < K_B$

14 The velocity of a proton $\left({}^{1}_{1}\mathrm{H}\right)$ is twice the velocity of an alpha particle $\left({}^{4}_{2}\mathrm{He}\right)$. The proton has a de Broglie wavelength of λ.

What is the de Broglie wavelength of the alpha particle?

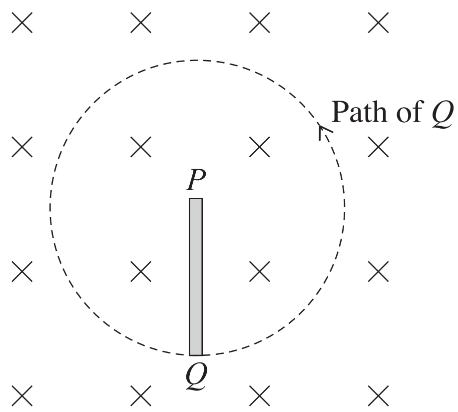
A. $\frac{\lambda}{8}$

B. $\frac{\lambda}{2}$

C. 2λ

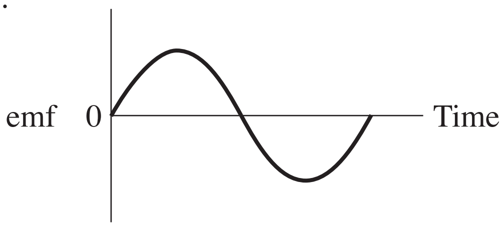
D. 8λ

15 A uniform magnetic field is directed into the page. A conductor *PQ* rotates about the end *P* at a constant rate.

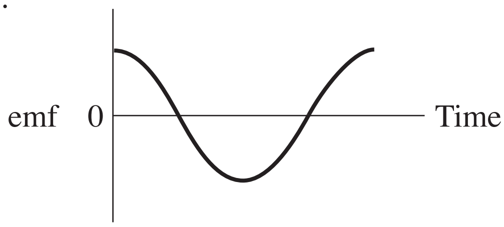


Which graph shows the emf induced between the ends of the conductor, *P* and *Q*, as it rotates one revolution from the position shown?

A.

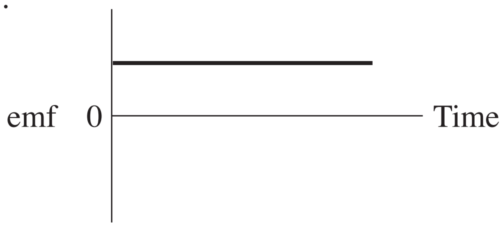


B.

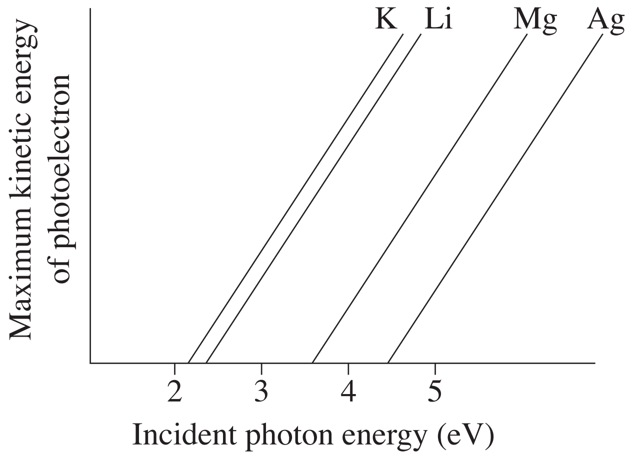


C.

D.



16 The graph shows the relationship between the maximum kinetic energy of emitted photoelectrons and the incident photon energy for four different metal surfaces.



Light of frequency 7×10^{14} Hz is incident on the metals.

From which metals are photoelectrons emitted?

A. K, Li only

B. Mg, Ag only

C. All of the metals

D. None of the metals

17 The diagram shows a type of particle accelerator called a cyclotron.

Cyclotrons accelerate charged particles, following the path as shown.

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An electric field acts on a charged particle as it moves through the gap between the dees. A strong magnetic field is also in place.

Once a charged particle has the required velocity, it exits the accelerator towards a target.

Which of the following is true about a charged particle in a cyclotron?

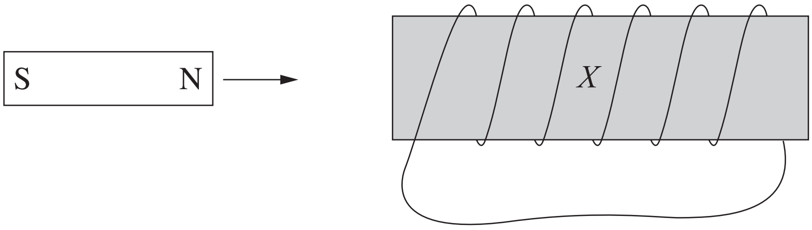
A. It increases speed while inside the dees.

B. It only accelerates while between the dees.

C. It undergoes acceleration inside and between the dees.

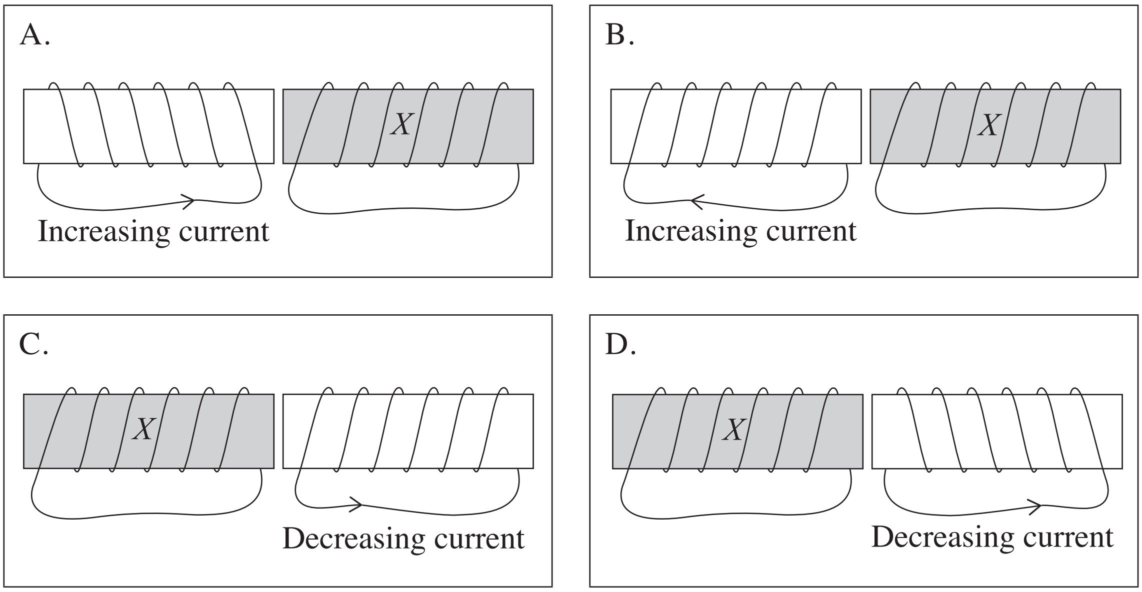
D. It slows down inside the dees and speeds up between the dees.

18 The diagram shows a magnet moving towards a coil X.



This action causes a current to be induced in the coil.

Which situation will induce a current in coil X that is in the same direction as the current induced by the movement of the magnet?



19 In a vacuum chamber there is a uniform electric field and a uniform magnetic field.

A proton having a velocity, v, enters the chamber. Its velocity remains unchanged as it travels through the chamber.

A second proton having a velocity, $2v$, in the same direction as the first proton, then enters the chamber at the same point as the first proton.

In the chamber, the acceleration of the second proton

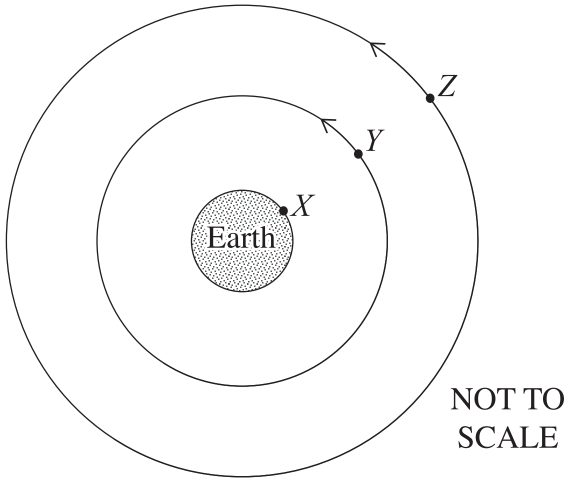
A. is zero.

B. is constant in magnitude and direction.

C. changes in both magnitude and direction.

D. is constant in magnitude, but not direction.

20 Three identical atomic clocks are made so that they tick at precisely the same rate. One is kept in a laboratory, X, on Earth's equator. Another is placed on board a satellite, Y, in a circular orbit with a period of 12 hours. A third is placed in a satellite, Z, that is in a geostationary orbit. The satellites orbit Earth in the equatorial plane.



Assume that the satellites are inertial frames of reference and the clocks are affected ONLY by the predictions of special relativity.

Which statement correctly compares the rates at which the clocks tick, as determined by an observer at X, when the satellites are in the positions shown in the diagram?

A. The clock at Y ticks faster than either the clock at X or the clock at Z.

B. The clock at Y ticks slower than either the clock at X or the clock at Z.

C. The clocks tick at different rates, with X being the fastest and Y being the slowest.

D. The clocks tick at different rates, with Z being the slowest and X being the fastest.

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2024 HIGHER SCHOOL CERTIFICATE EXAMINATION

Centre Number

Student Number

Physics

Section II Answer Booklet

80 marks
Attempt Questions 21–33
Allow about 2 hours and 25 minutes for this section

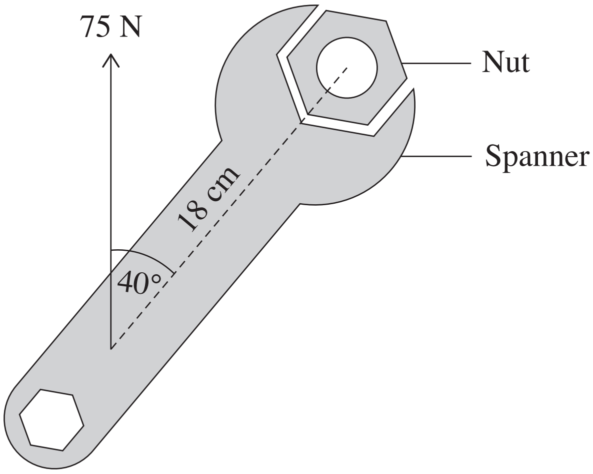
Instructions

- Write your Centre Number and Student Number at the top of this page.
- Answer the questions in the spaces provided. These spaces provide guidance for the expected length of response.
- Show all relevant working in questions involving calculations.
- Extra writing space is provided at the back of this booklet. If you use this space, clearly indicate which question you are answering.

Please turn over

Question 21 (6 marks)

To tighten a nut, a force of 75 N is applied to a spanner at an angle, as shown.



(a) Calculate the magnitude of the torque produced by the applied force. **2**

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(b) Explain TWO ways in which torque can be increased in a simple DC motor. **4**

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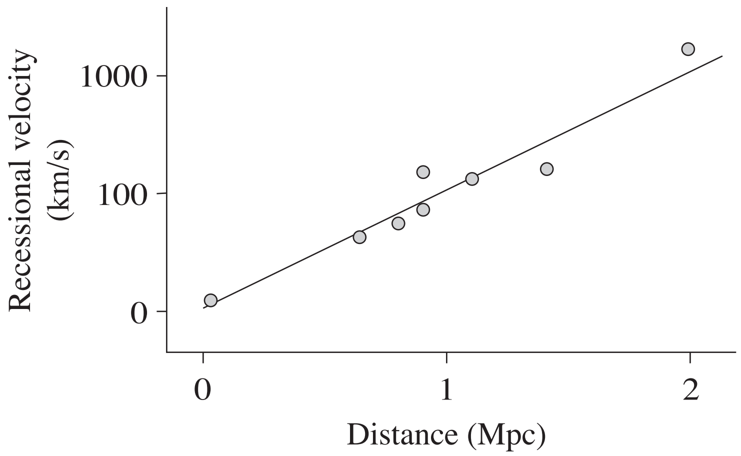
Question 22 (5 marks)

The following graph, based on the data gathered by Hubble, shows the relationship between the recessional velocity of galaxies and their distance from Earth.



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(a) Describe the significance of the graph to our understanding of the universe. **2**

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(b) How were the recessional velocities of galaxies determined? **3**

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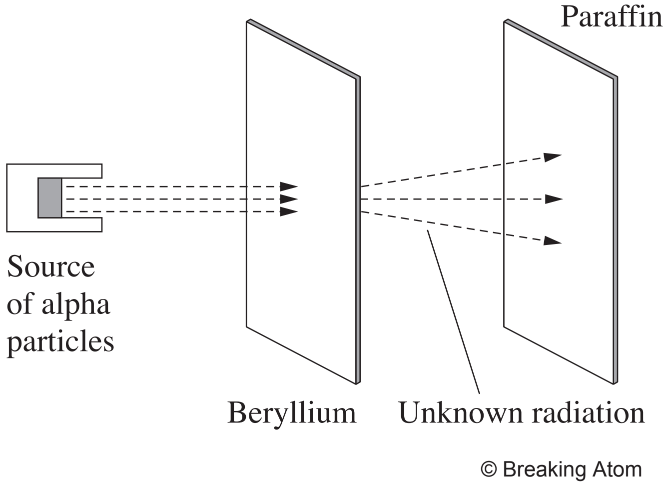
Question 23 (9 marks)

Development of models of the atom has resulted from both experimental investigations and hypotheses based on theoretical considerations.

(a) A key piece of experimental evidence supporting the nuclear model of the atom was a discovery by Chadwick in 1932.

An aspect of the experimental design is shown.



(i) What was the role of paraffin in Chadwick's experiment? **2**

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(ii) How did Chadwick's experiment change the model of the atom? **3**

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Question 23 continues on page 21

Question 23 (continued)

(b) Explain how de Broglie's hypothesis regarding the nature of electrons addressed limitations in the Bohr–Rutherford model of the atom. **4**

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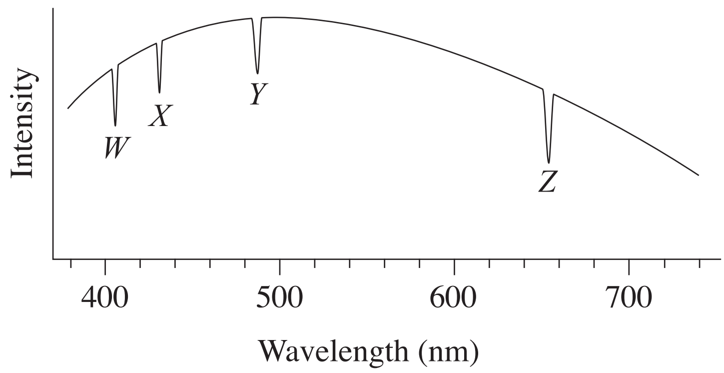
End of Question 23

Please turn over

Question 24 (8 marks)

An absorption spectrum resulting from the passage of visible light from a star's surface through its hydrogen atmosphere is shown. Absorption lines are labelled *W* to *Z* in the diagram.



(a) Determine the surface temperature of the star. **2**

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(b) Absorption line *W* originates from an electron transition between the second and sixth energy levels. Use $\frac{1}{\lambda} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$ to calculate the frequency of light absorbed to produce absorption line *W*. **3**

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Question 24 continues on page 23

Question 24 (continued)

(c) Explain the physical processes that produce an absorption spectrum. **3**

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End of Question 24

Please turn over

Question 25 (6 marks)

The mathematical model below shows the relationship between the orbital radius of a satellite and its period.

$$\frac{r^3}{T^2} = \frac{GM}{4\pi^2}$$

(a) By considering gravitational force, show how this model can be derived. **2**

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Question 25 continues on page 25

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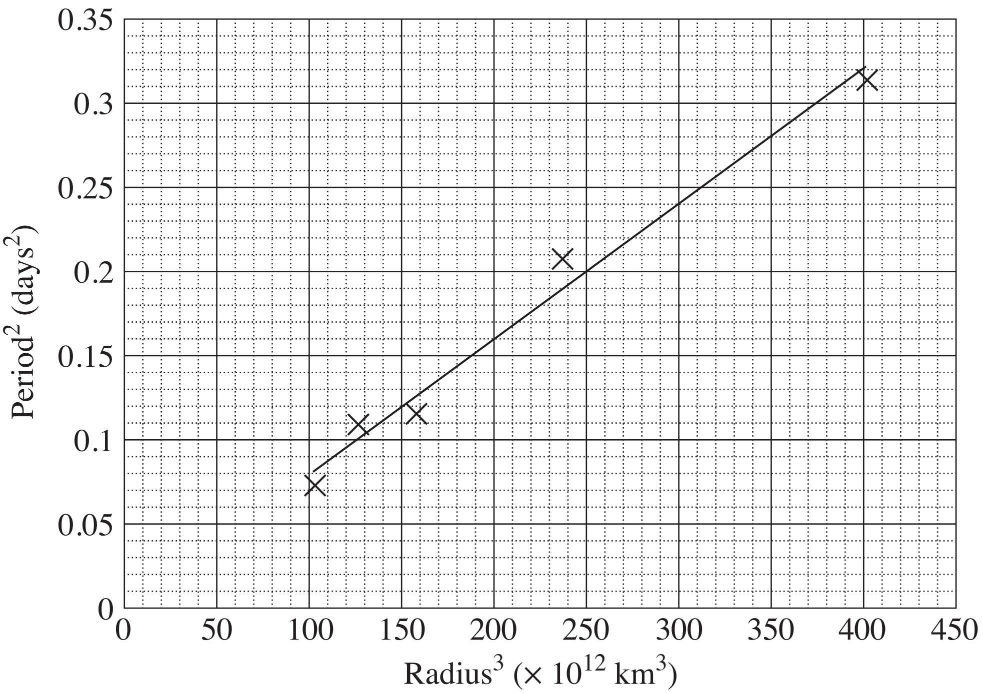
Question 25 (continued)

(b) A planet with five moons is discovered. The following graph is produced from observations of the orbital radius of the moons and their orbital periods, measured in Earth days. **4**



Use the graph to calculate the mass of the planet.

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End of Question 25

Question 26 (3 marks)

Muons are unstable particles produced when cosmic rays strike atoms high in the atmosphere. The muons travel downward, perpendicular to Earth's surface, at almost the speed of light. **3**

Classical physics predicts that these muons will decay before they have time to reach Earth's surface.

Explain qualitatively why these muons can reach Earth's surface, regardless of whether their motion is considered from either the muon's frame of reference or the Earth's frame of reference.

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Question 27 (7 marks)

The simplified model below shows the reactants and products of a proton–antiproton reaction which produces three particles called pions, each having a different charge.

$$\mathrm{p} + \bar{\mathrm{p}} \longrightarrow \pi^+ + \pi^0 + \pi^-$$

There are no other products in this process, which involves only the rearrangement of quarks. No electromagnetic radiation is produced. Assume that the initial kinetic energy of the proton and antiproton is negligible.

Protons consist of two up quarks (u) and a down quark (d). Antiprotons consist of two up antiquarks ($\bar{\mathrm{u}}$) and a down antiquark ($\bar{\mathrm{d}}$). Each of the pions consists of two quarks.

The following tables provide information about hadrons and quarks.

Table 1: Hadron information

Particle	*Rest mass* (MeV/c^2)	*Charge*
proton (p)	940	+1
antiproton ($\bar{\mathrm{p}}$)	940	−1
neutral pion (π^0)	140	zero
positive pion (π^+)	140	+1
negative pion (π^-)	140	−1

Table 2: Quark charges

Particle	*Charge*
down quark (d)	$-\frac{1}{3}$
up quark (u)	$+\frac{2}{3}$
down antiquark ($\bar{\mathrm{d}}$)	$+\frac{1}{3}$
up antiquark ($\bar{\mathrm{u}}$)	$-\frac{2}{3}$

Question 27 continues on page 29

Question 27 (continued)

(a) Identify the quarks present in the π^-, π^+ and the π^0 particles. **2**

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(b) The energy released in the reaction is shared equally between the pions. **2**

Calculate the energy released per pion in this reaction.

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(c) Calculation of the pions' velocities using classical physics predicts that each pion has a velocity, relative to the point at which the proton–antiproton reaction occurred, which exceeds 3×10^8 m s^{-1}. **3**

Explain the problem with this prediction and how it can be resolved.

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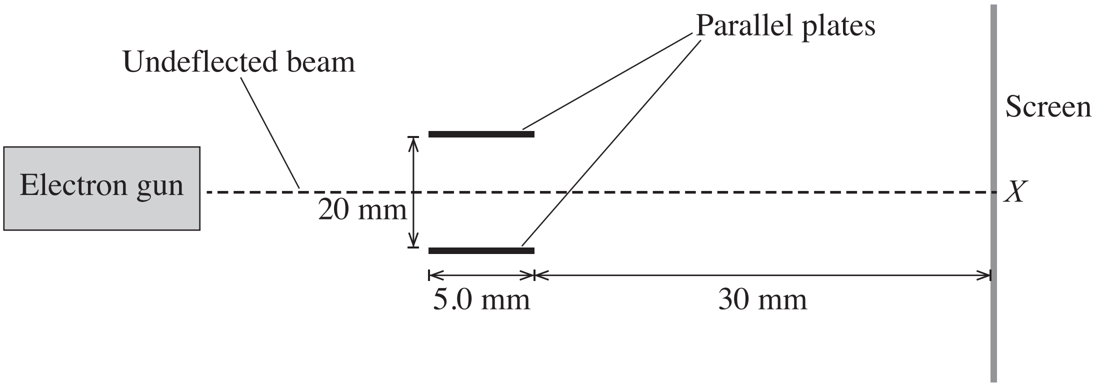
End of Question 27

Question 28 (7 marks)

An electron gun fires a beam of electrons at 2.0×10^6 m s^{-1} through a pair of parallel charged plates towards a screen that is 30 mm from the end of the plates as shown.

There is a uniform electric field between the plates of 1.5×10^4 N C^{-1}. The plates are 5.0 mm wide and 20 mm apart. The electron beam enters mid-way between the plates. X marks the spot on the screen where an undeflected beam would strike.

Ignore gravitational effects on the electron beam.



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(a) Show that the acceleration of an electron between the parallel plates is 2.6×10^{15} m s^{-2}. **2**

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(b) Show that the vertical displacement of the electron beam at the end of the parallel plates is approximately 8.1 mm. **2**

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Question 28 continues on page 31

Question 28 (continued)

(c) How far from point X will the electron beam strike the screen? **3**

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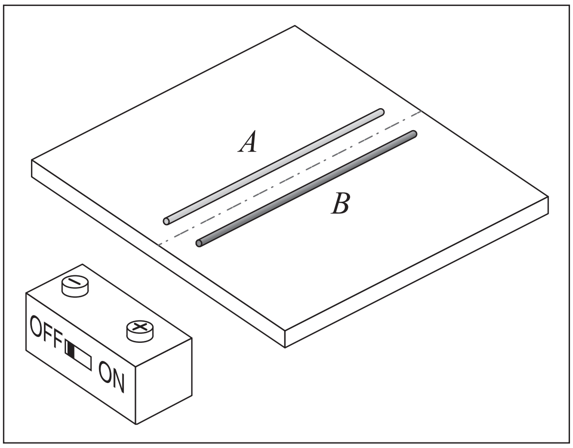
End of Question 28

Please turn over

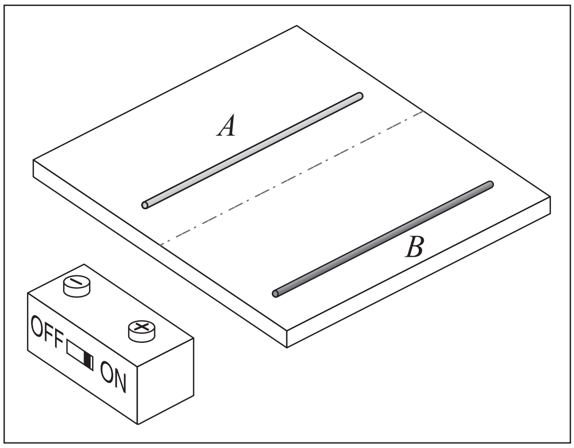
Question 29 (6 marks)

Two horizontal metal rods, *A* and *B*, of different materials are resting on a frictionless table. Initially they are at rest in position 1.

Both rods are then connected to a battery using wires. After the switch is turned on, currents of different magnitude flow in each rod. The rods move to position 2 after time, *t*. In position 2, *B* has a larger displacement than *A* from position 1. The masses of the wires are negligible.

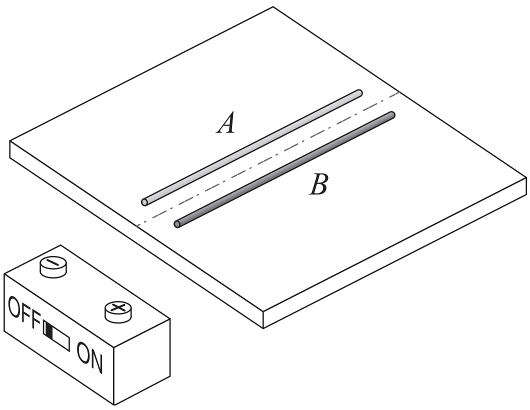


Position 1



Position 2

(a) Position 1 is reproduced below. Draw wires to show how the battery must be connected to the ends of the two rods in order for the magnitude of the current in each rod to be different, and for position 2 to be reached. No components, other than the wires, are required. **2**



Question 29 continues on page 33

Question 29 (continued)

(b) When the switch is turned on, the current in rod *A* is greater than the current in rod *B*. **4**

Consider this statement.

> Position 2 results from the larger current in rod *A,* causing a larger force to act on rod *B*.

Evaluate this statement with reference to relevant physics principles.

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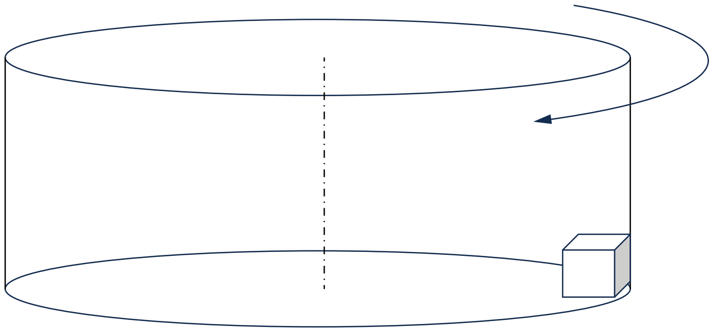
End of Question 29

Please turn over

Question 30 (4 marks)

An object sits on the floor of a hollow cylinder rotating around an axis, as shown. The cylinder's rotation causes the object to undergo uniform circular motion. **4**



Explain the effect on all of the forces acting on the object if the period of the cylinder's rotation is halved. Ignore the effects of friction.

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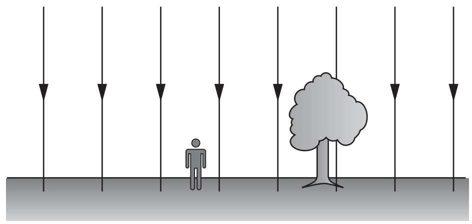
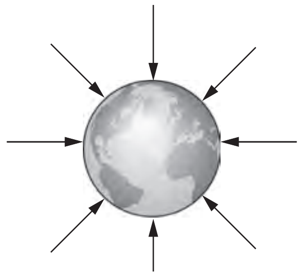
Question 31 (4 marks)

In a thought experiment, a projectile is launched vertically from Earth's surface. Its initial velocity is less than the escape velocity. **4**

The behaviour of the projectile can be analysed by using two different models, Model *A* and Model *B* as shown.

Model A	*Model B*
	
Earth's gravitational field is uniform	Earth's gravitational field is radial

The effects of Earth's atmosphere and Earth's rotational and orbital motions can be ignored.

Compare the maximum height reached by the projectile, using each model. In your answer, describe the energy changes of the projectile.

Question 32 (8 marks)

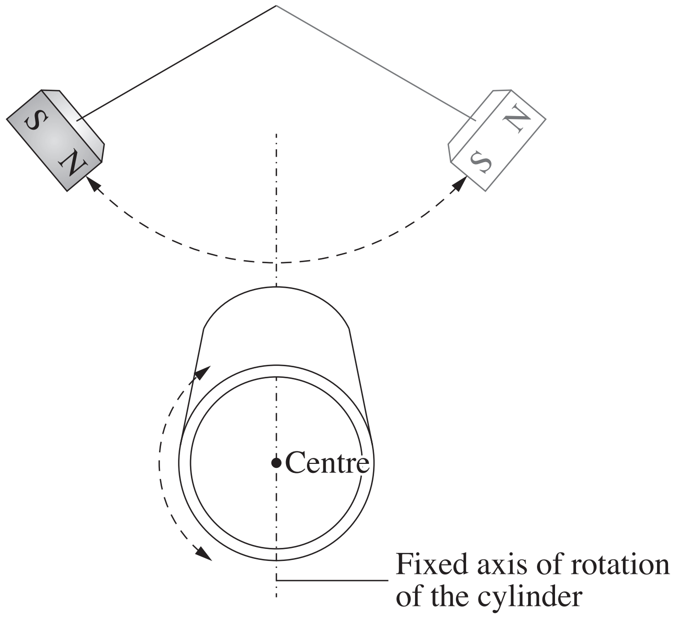
Many scientists have performed experiments to explore the interaction of light and matter. **8**

Analyse how evidence from at least THREE such experiments has contributed to our understanding of physics.

Do NOT write in this area.

Question 33 (7 marks)

A magnet is swinging as a pendulum. Close below it is an aluminium (non-ferromagnetic) can. The can is free to spin around a fixed axis as shown. **7**



Analyse the motion and energy transformations of both the can and the magnet.

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Section II extra writing space

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2024 HIGHER SCHOOL CERTIFICATE EXAMINATION

Physics

DATA SHEET

Charge on electron, q_e	-1.602×10^{-19} C
Mass of electron, m_e	9.109×10^{-31} kg
Mass of neutron, m_n	1.675×10^{-27} kg
Mass of proton, m_p	1.673×10^{-27} kg
Speed of sound in air	340 m s^{-1}
Earth's gravitational acceleration, g	9.8 m s^{-2}
Speed of light, c	$3.00 \times 10^{8} \text{ m s}^{-1}$
Electric permittivity constant, ε_0	$8.854 \times 10^{-12} \text{ A}^2 \text{ s}^4 \text{ kg}^{-1} \text{ m}^{-3}$
Magnetic permeability constant, μ_0	$4\pi \times 10^{-7} \text{ N A}^{-2}$
Universal gravitational constant, G	$6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$
Mass of Earth, M_E	6.0×10^{24} kg
Radius of Earth, r_E	6.371×10^{6} m
Planck constant, h	6.626×10^{-34} J s
Rydberg constant, R (hydrogen)	$1.097 \times 10^{7} \text{ m}^{-1}$
Atomic mass unit, u	1.661×10^{-27} kg $931.5 \text{ MeV}/c^2$
1 eV	1.602×10^{-19} J
Density of water, ρ	$1.00 \times 10^{3} \text{ kg m}^{-3}$
Specific heat capacity of water	$4.18 \times 10^{3} \text{ J kg}^{-1} \text{ K}^{-1}$
Wien's displacement constant, b	2.898×10^{-3} m K

FORMULAE SHEET

Motion, forces and gravity

$s = ut + \frac{1}{2}at^2$

$v = u + at$

$v^2 = u^2 + 2as$

$\vec{F}_{\text{net}} = m\vec{a}$

$W = F_{||}s = Fs\cos\theta$

$\Delta U = mg\Delta h$

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

$P = \frac{\Delta E}{\Delta t}$

$P = F_{||}v = Fv\cos\theta$

$\sum \frac{1}{2}mv^2_{\text{before}} = \sum \frac{1}{2}mv^2_{\text{after}}$

$\sum m\vec{v}_{\text{before}} = \sum m\vec{v}_{\text{after}}$

$\Delta\vec{p} = \vec{F}_{\text{net}}\Delta t$

$a_{\text{c}} = \frac{v^2}{r}$

$\omega = \frac{\Delta\theta}{t}$

$F_{\text{c}} = \frac{mv^2}{r}$

$\tau = r_{\perp}F = rF\sin\theta$

$F = \frac{GMm}{r^2}$

$v = \frac{2\pi r}{T}$

$\frac{r^3}{T^2} = \frac{GM}{4\pi^2}$

$U = -\frac{GMm}{r}$

Waves and thermodynamics

$v = f\lambda$

$f_{\text{beat}} = \left| f_2 - f_1 \right|$

$f = \frac{1}{T}$

$f' = f\frac{(v_{\text{wave}} + v_{\text{observer}})}{(v_{\text{wave}} - v_{\text{source}})}$

$d\sin\theta = m\lambda$

$n_1\sin\theta_1 = n_2\sin\theta_2$

$n_{\text{x}} = \frac{c}{v_{\text{x}}}$

$\sin\theta_{\text{c}} = \frac{n_2}{n_1}$

$I = I_{\max}\cos^2\theta$

$I_1r_1^2 = I_2r_2^2$

$Q = mc\Delta T$

$\frac{Q}{t} = \frac{kA\Delta T}{d}$

Electricity and magnetism

$$E = \frac{V}{d}$$

$$\vec{F} = q\vec{E}$$

$$V = \frac{\Delta U}{q}$$

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

$$W = qV$$

$$I = \frac{q}{t}$$

$$W = qEd$$

$$V = IR$$

$$B = \frac{\mu_0 I}{2\pi r}$$

$$P = VI$$

$$B = \frac{\mu_0 NI}{L}$$

$$F = qv_{\perp}B = qvB\sin\theta$$

$$\Phi = B_{||}A = BA\cos\theta$$

$$F = lI_{\perp}B = lIB\sin\theta$$

$$\varepsilon = -N\frac{\Delta\Phi}{\Delta t}$$

$$\frac{F}{l} = \frac{\mu_0}{2\pi}\frac{I_1 I_2}{r}$$

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

$$\tau = nIA_{\perp}B = nIAB\sin\theta$$

$$V_p I_p = V_s I_s$$

Quantum, special relativity and nuclear

$$\lambda = \frac{h}{mv}$$

$$t = \frac{t_0}{\sqrt{\left(1 - \frac{v^2}{c^2}\right)}}$$

$$K_{max} = hf - \phi$$

$$\lambda_{max} = \frac{b}{T}$$

$$l = l_0\sqrt{\left(1 - \frac{v^2}{c^2}\right)}$$

$$E = mc^2$$

$$E = hf$$

$$p_v = \frac{m_0 v}{\sqrt{\left(1 - \frac{v^2}{c^2}\right)}}$$

$$\frac{1}{\lambda} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

$$N_t = N_0 e^{-\lambda t}$$

$$\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$$

PERIODIC TABLE OF THE ELEMENTS

KEY

Atomic Number	79
Symbol	Au
Standard Atomic Weight	197.0
Name	Gold

1 H 1.008 Hydrogen																	2 He 4.003 Helium
3 Li 6.941 Lithium	4 Be 9.012 Beryllium											5 B 10.81 Boron	6 C 12.01 Carbon	7 N 14.01 Nitrogen	8 O 16.00 Oxygen	9 F 19.00 Fluorine	10 Ne 20.18 Neon
11 Na 22.99 Sodium	12 Mg 24.31 Magnesium											13 Al 26.98 Aluminium	14 Si 28.09 Silicon	15 P 30.97 Phosphorus	16 S 32.07 Sulfur	17 Cl 35.45 Chlorine	18 Ar 39.95 Argon
19 K 39.10 Potassium	20 Ca 40.08 Calcium	21 Sc 44.96 Scandium	22 Ti 47.87 Titanium	23 V 50.94 Vanadium	24 Cr 52.00 Chromium	25 Mn 54.94 Manganese	26 Fe 55.85 Iron	27 Co 58.93 Cobalt	28 Ni 58.69 Nickel	29 Cu 63.55 Copper	30 Zn 65.38 Zinc	31 Ga 69.72 Gallium	32 Ge 72.64 Germanium	33 As 74.92 Arsenic	34 Se 78.96 Selenium	35 Br 79.90 Bromine	36 Kr 83.80 Krypton
37 Rb 85.47 Rubidium	38 Sr 87.61 Strontium	39 Y 88.91 Yttrium	40 Zr 91.22 Zirconium	41 Nb 92.91 Niobium	42 Mo 95.96 Molybdenum	43 Tc Technetium	44 Ru 101.1 Ruthenium	45 Rh 102.9 Rhodium	46 Pd 106.4 Palladium	47 Ag 107.9 Silver	48 Cd 112.4 Cadmium	49 In 114.8 Indium	50 Sn 118.7 Tin	51 Sb 121.8 Antimony	52 Te 127.6 Tellurium	53 I 126.9 Iodine	54 Xe 131.3 Xenon
55 Cs 132.9 Caesium	56 Ba 137.3 Barium	57–71 Lanthanoids	72 Hf 178.5 Hafnium	73 Ta 180.9 Tantalum	74 W 183.9 Tungsten	75 Re 186.2 Rhenium	76 Os 190.2 Osmium	77 Ir 192.2 Iridium	78 Pt 195.1 Platinum	79 Au 197.0 Gold	80 Hg 200.6 Mercury	81 Tl 204.4 Thallium	82 Pb 207.2 Lead	83 Bi 209.0 Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon
87 Fr Francium	88 Ra Radium	89–103 Actinoids	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110 Ds Darmstadtium	111 Rg Roentgenium	112 Cn Copernicium	113 Nh Nihonium	114 Fl Flerovium	115 Mc Moscovium	116 Lv Livermorium	117 Ts Tennessine	118 Og Oganesson

Lanthanoids

57 La 138.9 Lanthanum	58 Ce 140.1 Cerium	59 Pr 140.9 Praseodymium	60 Nd 144.2 Neodymium	61 Pm Promethium	62 Sm 150.4 Samarium	63 Eu 152.0 Europium	64 Gd 157.3 Gadolinium	65 Tb 158.9 Terbium	66 Dy 162.5 Dysprosium	67 Ho 164.9 Holmium	68 Er 167.3 Erbium	69 Tm 168.9 Thulium	70 Yb 173.1 Ytterbium	71 Lu 175.0 Lutetium

Actinoids

89 Ac Actinium	90 Th 232.0 Thorium	91 Pa 231.0 Protactinium	92 U 238.0 Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendelevium	102 No Nobelium	103 Lr Lawrencium

Standard atomic weights are abridged to four significant figures.
Elements with no reported values in the table have no stable nuclides.
Information on elements with atomic numbers 113 and above is sourced from the International Union of Pure and Applied Chemistry Periodic Table of the Elements (November 2016 version).
The International Union of Pure and Applied Chemistry Periodic Table of the Elements (February 2010 version) is the principal source of all other data. Some data may have been modified.

2024 HSC Physics
Marking Guidelines

Section I

Multiple-choice Answer Key

Question	Answer
1	C
2	B
3	C
4	D
5	A
6	C
7	B
8	B
9	B
10	C
11	D
12	B
13	A
14	B
15	D
16	A
17	C
18	D
19	C
20	B

Section II

Question 21 (a)

Criteria	Marks
• Correctly calculates the magnitude of the torque	2
• Provides a relevant step	1

Sample answer:

$\tau = rF\sin\theta = 0.18 \times 75 \times \sin 40 = 8.7$ Nm

Question 21 (b)

Criteria	Marks
• Explains TWO ways of increasing the torque in a DC motor	4
• Identifies TWO ways of increasing the torque in a DC motor with a partial explanation of either way	3
• Identifies TWO ways of increasing the torque OR • Identifies and partially explains ONE way of increasing the torque	2
• Provides some relevant information	1

Sample answer:

- Increase the area of the motor coil as this increases torque according to $\tau = nIA_{\perp}B$.
- Increase the current through the motor by increasing the voltage as this increases the force on the sides of the motor coil.

Answers could include:

- Radial magnetic field
- More turns.

Question 22 (a)

Criteria	Marks
• Describes the significance of the graph	2
• Provides some relevant information	1

Sample answer:

The graph shows that the further away the galaxy, the faster it is receding. From this it was concluded that the universe is expanding.

Question 22 (b)

Criteria	Marks
• Demonstrates understanding of how the recessional velocities of galaxies were determined	3
• Outlines some aspects of determination of recessional velocities of galaxies	2
• Provides some relevant information	1

Sample answer:

The spectra of the galaxies were compared to the spectra of hydrogen. The degree of red-shift of the galaxies was determined. The larger the red-shift is, the greater recessional velocity of the light source, hence the velocities of the galaxies were able to be determined.

Question 23 (a) (i)

Criteria	Marks
• Outlines the role of paraffin in the experiment	2
• Provides some relevant information	1

Sample answer:

Paraffin has a large number of hydrogen atoms containing single protons. When the unknown radiation hit these protons, they were ejected from the paraffin. These protons were then analysed.

Question 23 (a) (ii)

Criteria	Marks
• Demonstrates understanding of how Chadwick's experiment changed the model of the atom	3
• Outlines the change in the model of the atom	2
• Provides some relevant information	1

Sample answer:

Chadwick deduced that there were neutral particles that were of similar mass to protons coming from the target. From this, the model of the atom changed to include neutrons as well as protons in the nucleus of atoms.

Question 23 (b)

Criteria	Marks
• Explains how the de Broglie hypothesis addressed limitations in the Bohr–Rutherford atomic model	4
• Describes how the de Broglie hypothesis addressed limitations in the Bohr–Rutherford atomic model OR • Explains how the de Broglie hypothesis addressed a limitation in the Bohr–Rutherford atomic model	3
• Demonstrates some understanding of the de Broglie hypothesis and/or a limitation in the Bohr–Rutherford atomic model	2
• Provides some relevant information	1

Sample answer:

De Broglie's hypothesis suggested that electrons in the hydrogen atom are in a stable state when they formed standing waves. As the electron was no longer considered an accelerating charge, the problem of accelerating charges producing electromagnetic radiation was resolved. Additionally, the problem of why electrons had only certain allowed orbits was resolved by the criteria of an electron orbit only being allowed when it consisted of a whole number of electron wavelengths.

Question 24 (a)

Criteria	Marks
• Determines the surface temperature of the star	2
• Provides a relevant step	1

Sample answer:

From the graph, the peak wavelength is 500 nm. Using Wien's Law, $T = \frac{b}{\lambda_{max}}$,

$T = \frac{2.898 \times 10^{-3}}{500 \times 10^{-9}} = 5796$ K

Question 24 (b)

Criteria	Marks
• Calculates the frequency of light associated with absorption line *W* using provided equation	3
• Provides a correct calculation	2
• Provides a relevant step	1

Sample answer:

Using the relationship, and treating it as an emission spectrum

$\frac{1}{\lambda} = 1.097 \times 10^7 \left(\frac{1}{2^2} - \frac{1}{6^2}\right) = 2.44 \times 10^6 \text{ m}^{-1}$

Wavelength is therefore 4.1×10^{-7} m. So $f = \frac{c}{\lambda} = 7.3 \times 10^{14}$ Hz

Question 24 (c)

Criteria	Marks
• Explains the physical processes that result in the absorption spectrum	3
• Outlines some aspects of physical processes involved in the production of an absorption spectrum	2
• Provides some relevant information	1

Sample answer:

The star produces a continuous spectrum of light. When this light passes through the hydrogen atmosphere, certain frequencies of light are absorbed as they have energies (from $E = hf$) that correspond to particular transitions of electrons to higher energy levels. Such frequencies produce wavelengths that do not progress through the atmosphere, and as a result show as a drop in intensity on the graph.

Answers could include:

Absorption spectron of non-stellar origin

Question 25 (a)

Criteria	Marks
• Shows how the mathematical model is derived	2
• Shows some relevant steps	1

Sample answer:

$$F_C = F_G$$

$$\frac{mv^2}{r} = \frac{GMm}{r^2}$$

$$\left(\frac{2\pi r}{T}\right)^2 = \frac{GM}{r}$$

$$\frac{4\pi^2 r^2}{T^2} = \frac{GM}{r}$$

$$\frac{r^3}{T^2} = \frac{GM}{4\pi^2}$$

Question 25 (b)

Criteria	Marks
• Calculates the mass of the planet using the graph's line of best fit and correct working	4
• Show some steps in calculating the gradient • Relates the gradient to the mathematical model and/or mass of the planet	3
• Show some steps in calculating the gradient OR • Relates the graph to the mathematical model and/or mass of the planet	2
• Provides some relevant information	1

Sample answer:

Using the line of best fit

$$\text{Gradient} = 0.0008 \times \frac{\text{days}^2}{10^{12}\ \text{km}^3} = \frac{0.0008 \times (24 \times 60 \times 60)^2}{10^{12} \times 1000^3}\ \text{s}^2\text{m}^{-3} = 6.0 \times 10^{-15}\ \text{s}^2\text{m}^{-3}$$

$$\text{Gradient} = \frac{T^2}{r^3} = \frac{4\pi^2}{GM}$$

$$6.0 \times 10^{-15} = \frac{4\pi^2}{6.67 \times 10^{-11} \times M}$$

$$\text{M} = 9.9 \times 10^{25}\ \text{kg}$$

Question 26

Criteria	Marks
• Explains why muons reach the Earth's surface with reference to relativistic effects in both frames of reference	3
• Outlines some relativistic effects that apply to the muon OR • Explains one relativistic effect that applies to the muon	2
• Provides some relevant information	1

Sample answer:

In the muon's reference frame, the distance travelled is less than that observed by a stationery observer on Earth's surface, due the effects of length contraction. This shortened distance means that they will get further than would be expected by an observer observing the rest length.

From the Earth's frame of reference, the time dilation means that the half-life of the muon is dilated compared to the half-life measured in the rest frame of the muon. This greater time allows more muons to reach the ground than would otherwise be expected.

Question 27 (a)

Criteria	Marks
• Identifies the quarks in all three pions	2
• Identifies the quarks in at least one pion	1

Sample answer:

π^-: $\bar{\mathrm{u}}\mathrm{d}$

π^+: $\mathrm{u}\bar{\mathrm{d}}$

π^0: $\mathrm{u}\bar{\mathrm{u}}$

Question 27 (b)

Criteria	Marks
• Calculates the energy released per pion	2
• Shows a relevant calculation	1

Sample answer:

Initial mass: $940 + 940 = 1880$ MeV/c^2

Final mass: $3 \times 140 = 420$ MeV/c^2

Mass change $= \frac{1460}{3}$ per pion $= 487$ MeV/c^2

So, $E = mc^2 = 487$ MeV

Answers could include:

Answers in joules or electron volts

Question 27 (c)

Criteria	Marks
• Explains the problem and how it can be resolved	3
• Demonstrates understanding of the problem and/or its solution	2
• Provides relevant information	1

Sample answer:

The problem raised by this calculation is that the pions' velocities exceed the velocity of light (3×10^8), which is impossible.

The pions' velocities are relativistic, so their relativistic masses are greater than their rest masses which limits their velocity to less than the speed of light. Some of the energy imparted to each pion is converted into increased mass.

Answers could include:

Reference to relativistic momentum increase.

Question 28 (a)

Criteria	Marks
• Shows the acceleration of the electron is 2.6×10^{15} m s^{-2}	2
• Shows a correct substitution	1

Sample answer:

From $F = ma$ and $F = Eq$, $a = \dfrac{qE}{m} = \dfrac{1.5 \times 10^4 \times 1.602 \times 10^{-19}}{9.109 \times 10^{-31}} = 2.6 \times 10^{15}$ m s^{-2}

Question 28 (b)

Criteria	Marks
• Shows the vertical displacement is approximately 8.1 mm	2
• Shows a correct substitution	1

Sample answer:

The beam travels through the plates in $t = \dfrac{s}{v} = \dfrac{5 \times 10^{-3}}{2 \times 10^6} = 2.5 \times 10^{-9}$ seconds.

Vertical displacement is $s = \dfrac{1}{2}at^2 = 0.5 \times 2.6 \times 10^{15} \times (2.5 \times 10^{-9})^2 = 0.008125$ m = 8.1 mm

Question 28 (c)

Criteria	Marks
• Correctly calculates the distance between point *X* and the final position	3
• Completes relevant steps	2
• Provides some relevant information	1

Sample answer:

The electron beam velocity in the vertical direction when leaving the plates is
$v = at = 2.6 \times 10^{15} \times 2.5 \times 10^{-9} = 6.5 \times 10^6$ m s^{-1}

After leaving the plates, the beam takes $t = \dfrac{s}{v} = s = \dfrac{0.03}{2 \times 10^6} = 1.5 \times 10^{-8}$ s

The vertical displacement is from the end of the plates

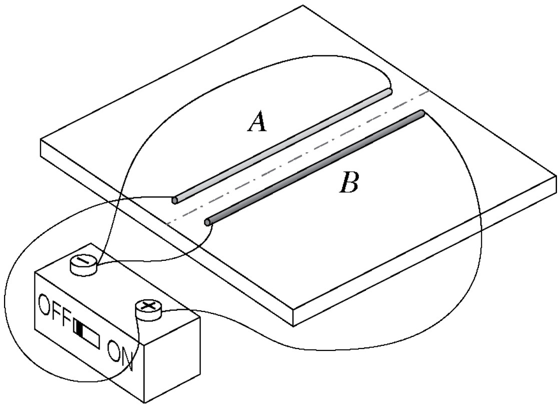
$$s = vt = 6.5 \times 10^6 \times 1.5 \times 10^{-8} = 0.0975 \text{ m}$$

So the final position on the screen is 0.0081 + 0.0975 = 0.11 m

Question 29 (a)

Criteria	Marks
• Draws connections to both rods that show different currents flowing in opposite directions	2
• Draws a complete circuit incorporating both rods	1

Sample answer:



Question 29 (b)

Criteria	Marks
• Evaluates the statement with thorough reference to relevant physics principles	4
• Evaluates the statement using some relevant physics principles	3
• Demonstrates some understanding of relevant physics principle(s)	2
• Provides some relevant information	1

Sample answer:

Rod *B* does have a larger displacement from the original position than rod *A*. However this is not due to the current in rod *A* being larger. The force on rod *B* due to electromagnetic force from rod *A* is the same magnitude as the force on rod *A* due to electromagnetic force from rod *B*, according to Newton's third law. The magnitude of electromagnetic force between both rods is given by $\frac{F}{l} = \frac{\mu_0}{2\pi}\frac{I_1 I_2}{r}$.

Since the larger displacement of Rod *B* cannot be explained by a larger electromagnetic force acting on it, it must be due to Rod *B* having a smaller mass. A smaller mass would mean that it has a larger acceleration ($a = \frac{F}{m}$), causing it to have a larger displacement during time t ($s = \frac{1}{2}at^2$).

Question 30

Criteria	Marks
• Explains the effect of halving the period on all the forces acting on the object	4
• Demonstrates understanding of the change in the period on the forces acting on the object	3
• Outlines an effect of the rotation of the object on a force on the object	2
• Provides some relevant information	1

Sample answer:

The forces acting on the object are gravitational force downwards, force from the floor upwards and centripetal force from the side of the cylinder towards the centre of the cylinder.

The period of rotation is related to centripetal force by:

$$F_C = \frac{mv^2}{r} = \frac{m}{r}\left(\frac{2\pi r}{T}\right)^2 = \frac{4m\pi^2 r^2}{rT^2} = \frac{4m\pi^2 r}{T^2}$$

Therefore, halving the period will increase the centripetal force by a factor of 4. The gravitational force downward and the force of the floor upward remains unchanged because the changing period does not affect gravitational or the vertical reaction force.

Question 31

Criteria	Marks
• Correctly compares the maximum height of the projectile in each model • Describes the energy change of the projectile in each model	4
• Compares maximum height with reference to the models • Refers to energy change in each model	3
• Provides aspects of a comparison of maximum heights and/or energy change	2
• Provides some relevant information	1

Sample answer:

In both models, the initial kinetic energy is the same and at the maximum height, the initial kinetic energy is fully converted to gravitational potential energy.

In Model A, for each metre moved vertically, the same amount of kinetic energy is converted to gravitational potential energy. In Model B, because of the decreasing gravitational field strength, the amount of kinetic energy converted to gravitational potential energy per metre decreases as the object travels upward.

Therefore, in Model B, the object reaches a greater maximum height before all the kinetic energy is converted to potential energy.

Question 32

Criteria	Marks
• Provides a detailed analysis using evidence from at least THREE experiments investigating the interaction of light and matter • Provides a clear link between experimental evidence and greater understanding of physics	8
• Provides analysis using evidence from experiments investigating the interaction of light and matter • Provides a link between experimental evidence and greater understanding of physics	6–7
• Provides evidence from experiments investigating the interaction of light and matter • Relates evidence to a greater understanding of physics	4–5
• Provides some information about evidence from an experiment AND/OR a link to physics	2–3
• Provides some relevant information	1

Answers could include:

Reference to:

- Black body radiation experiments and the development of quantum physics
- Photoelectric experiments and the development of quantum physics
- Spectroscopy experiments and the development of astrophysics and the atomic model
- Polarisation experiments and the development of the wave nature of light
- Interference and diffraction and the development of the wave model of light
- Cosmic gamma rays and the development of theory of special relativity and/or the standard model.

Question 33

Criteria	Marks
• Provides a detailed analysis of the motion of the can AND the magnet • Provides a detailed analysis of the energy transformations in the system	7
• Analyses the motion of the can AND the magnet • Provides an analysis of the energy transformations in the system	6
• Describes the motion of the can and/or the magnet • Describes the energy transformations of the magnet and/or can	4–5
• Demonstrates some understanding of the motion of the can and/or the magnet and/or the energy transformations of both magnet and/or can	2–3
• Provides some relevant information	1

Sample answer:

As the magnet swings from a high position towards the can, it loses gravitational potential energy and gains kinetic energy.

The motion of the magnet provides changing magnetic flux through the aluminium can. This change in flux is greatest when the relative motion of the magnet and can is greatest, and induces an emf according to $\varepsilon = -N\dfrac{\Delta\Phi}{\Delta t}$.

This emf gives rise to eddy currents in the can, which produces resistive heating as well as a magnetic field that opposes the movement of the magnet, according to Lenz's law.

The interaction of the magnetic fields of the magnet and the can, due to Eddy currents, also results in the can rotating clockwise initially.

Over time, this results in a dampening of the magnet's movement, and the interaction of the eddy currents' magnetic field with the magnet results in the rotation of the can backwards and forwards, with diminishing amplitude as the total energy is ultimately converted to heat.

Answers could include:

Reference to non-uniform, clockwise rotation of the can

2024 HSC Physics
Mapping Grid

Section I

Question	Marks	Content	Syllabus outcomes
1	1	Mod 5 Circular Motion	PH12-12
2	1	Mod 7 Light Wave Model	PH12-14
3	1	Mod 8 Deep Inside the Atom	PH12-15
4	1	Mod 6 Applications of the Motor Effect	PH12-6, PH12-13
5	1	Mod 8 Origins of the Elements	PH12-5, PH12-15
6	1	Mod 7 Light Quantum Model	PH12-14
7	1	Mod 8 Properties of the Nucleus	PH12-15
8	1	Mod 6 Electromagnetic Induction	PH12-13
9	1	Mod 5 Projectile Motion	PH12-12
10	1	Mod 6 The Motor Effect	PH12-13
11	1	Mod 5 Motion in Gravitational Fields	PH12-12
12	1	Mod 7 Light and Special Relativity	PH12-5, PH12-14
13	1	Mod 5 Motion in Gravitational Fields	PH12-12
14	1	Mod 8 Quantum Mechanical Nature of the Atom	PH12-15
15	1	Mod 6 Electromagnetic Induction	PH12-6, PH12-13
16	1	Mod 7 Light Quantum Model	PH12-5, PH12-14
17	1	Mod 5 Circular Motion	PH12-12
18	1	Mod 6 Electromagnetic Induction	PH12-6, PH12-13
19	1	Mod 8 Structure of the Atom	PH12-6, PH12-15
20	1	Mod 7 Light and Special Relativity	PH12-14

Section II

Question	Marks	Content	Syllabus outcomes
21 (a)	2	Mod 5 Circular Motion	PH12-6, PH12-12
21 (b)	4	Mod 6 Applications of the Motor Effect	PH12-13
22 (a)	2	Mod 8 Origins of the Elements	PH12-5, PH12-15
22 (b)	3	Mod 7 Electromagnetic Spectrum	PH12-14
23 (a) (i)	2	Mod 8 Structure of the Atom	PH12-15
23 (a) (ii)	3	Mod 8 Structure of the Atom	PH12-15
23 (b)	4	Mod 8 Quantum Mechanical Nature of the Atom	PH12-15
24 (a)	2	Mod 7 Light Quantum Model	PH12-6, PH12-14
24 (b)	3	Mod 8 Quantum Mechanical Nature of the Atom	PH12-6, PH12-15
24 (c)	3	Mod 8 Structure of the Atom Mod 8 Quantum Mechanical Nature of the Atom	PH12-15
25 (a)	2	Mod 5 Motion in Gravitational Fields	PH12-6, PH12-12
25 (b)	4	Mod 5 Motion in Gravitational Fields	PH12-5, PH12-6, PH12-12

Question	Marks	Content	Syllabus outcomes
26	3	Mod 7 Light and Special Relativity	PH12-14
27 (a)	2	Mod 8 Deep Inside the Atom	PH12-5, PH12-15
27 (b)	2	Mod 7 Light and Special Relativity	PH12-14
27 (c)	3	Mod 7 Light and Special Relativity	PH12-14
28 (a)	2	Mod 6 Charged Particles, Conductors and Electric and Magnetic Fields	PH12-6, PH12-13
28 (b)	2	Mod 5 Projectile Motion Mod 6 Charged Particles, Conductors and Electric and Magnetic Fields	PH12-6, PH12-12, PH12-13
28 (c)	3	Mod 5 Projectile Motion	PH12-6, PH12-12
29 (a)	2	Mod 6 Charged Particles, Conductors and Electric and Magnetic Fields	PH12-13
29 (b)	4	Mod 6 The Motor Effect	PH12-13
30	4	Mod 5 Circular Motion	PH12-12
31	4	Mod 5 Motion in Gravitational Fields	PH12-6, PH12-12
32	8	Mod 7 Electromagnetic Spectrum Mod 8 Quantum Mechanical Nature of the Atom	PH12-7, PH12-14, PH12-15
33	7	Mod 6 Electromagnetic Induction	PH12-6, PH12-7, PH12-13