Physics Units 3 & 4

Practice Examinations

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Practice Exam 1 — Easy

Physics — Practice Examination 1

Reading time: 15 minutes

Writing time: 2 hours 30 minutes

- Section A: 20 questions, 20 marks
- Section B: 19 questions, 100 marks
- Total: 120 marks

Approved materials

- One scientific calculator
- Pre-written notes (one folded A3 sheet or two A4 sheets bound together by tape)

A formula sheet is provided at the end of this examination.

Students are **not** permitted to bring mobile phones and/or any unauthorised electronic devices into the examination room.

Section A — Multiple-choice questions (20 marks)

*Answer **all** questions. Choose the response that is **correct** or that **best answers** the question.*

*A correct answer scores 1; an incorrect answer scores 0. Marks will **not** be deducted for incorrect answers.*

No marks will be given if more than one answer is completed for any question.

*Unless otherwise indicated, the diagrams in this book are **not** drawn to scale.*

Where required, take the gravitational field strength to be $g = 9.81\,\mathrm{N\ kg^{-1}}$.

Question 1

A drone of mass $1.5\,\mathrm{kg}$ accelerates straight up at $2.0\,\mathrm{m\ s^{-2}}$. Which one of the following is closest to the total upward thrust force produced by its propellers?

A. $14.7\,\mathrm{N}$

B. $3.0\,\mathrm{N}$

C. $17.7\,\mathrm{N}$

D. $11.7\,\mathrm{N}$

Question 2

A cyclist and bicycle of total mass $80\,\mathrm{kg}$ ride around a flat, circular bend of radius $20\,\mathrm{m}$ at a constant speed of $8.0\,\mathrm{m\ s^{-1}}$. Which one of the following is closest to the magnitude of the net force on the cyclist?

A. $256\,\mathrm{N}$

B. $32\,\mathrm{N}$

C. $3.2\,\mathrm{N}$

D. $5.12 \times 10^{3}\,\mathrm{N}$

Question 3

A drone flying horizontally at a height of $45\,\mathrm{m}$ releases a small package, which leaves the drone with no vertical velocity. Ignoring air resistance, which one of the following is closest to the time the package takes to reach the ground?

A. $2.14\,\mathrm{s}$

B. $9.17\,\mathrm{s}$

C. $4.28\,\mathrm{s}$

D. $3.03\,\mathrm{s}$

Question 4

A single constant force acts on a cart. One graph plots this force against time; a second plots the same force against the cart's displacement. Which one of the following is correct?

A. The area under both graphs gives the impulse on the cart.

B. The area under the force–time graph gives the impulse; the area under the force–distance graph gives the work done.

C. The area under the force–time graph gives the work done; the area under the force–distance graph gives the impulse.

D. The area under both graphs gives the change in kinetic energy.

Question 5

A mountain-bike suspension spring that obeys Hooke's law has a stiffness of $2.4 \times 10^4\,\mathrm{N\ m^{-1}}$ and is compressed by $0.050\,\mathrm{m}$. Which one of the following is closest to the elastic potential energy stored in the spring?

A. $30\,\mathrm{J}$

B. $60\,\mathrm{J}$

C. $6.0 \times 10^2\,\mathrm{J}$

D. $1.2 \times 10^3\,\mathrm{J}$

Question 6

The gravitational field strength at the surface of a planet is $6.0\,\mathrm{N\ kg^{-1}}$. Which one of the following is closest to the gravitational field strength at a point that is two planet-radii from the centre of the planet?

A. $3.0\,\mathrm{N\ kg^{-1}}$

B. $12\,\mathrm{N\ kg^{-1}}$

C. $1.5\,\mathrm{N\ kg^{-1}}$

D. $6.0\,\mathrm{N\ kg^{-1}}$

Question 7

A satellite moves in a circular orbit of radius $7.0 \times 10^{6}\,\mathrm{m}$ at a constant speed of $7.6 \times 10^{3}\,\mathrm{m\ s^{-1}}$. Which one of the following is closest to the magnitude of the satellite's acceleration?

A. $4.13\,\mathrm{m\ s^{-2}}$

B. $8.25\,\mathrm{m\ s^{-2}}$

C. $1.09 \times 10^{-3}\,\mathrm{m\ s^{-2}}$

D. $16.5\,\mathrm{m\ s^{-2}}$

Question 8

Two parallel plates are separated by $0.050\,\mathrm{m}$, with a potential difference of $200\,\mathrm{V}$ across them. Which one of the following is closest to the electric field strength between the plates?

A. $10\,\mathrm{N\ C^{-1}}$

B. $40\,\mathrm{N\ C^{-1}}$

C. $2.5 \times 10^{-4}\,\mathrm{N\ C^{-1}}$

D. $4.0 \times 10^{3}\,\mathrm{N\ C^{-1}}$

Question 9

An electron moves at $2.0 \times 10^{6}\,\mathrm{m\ s^{-1}}$ at right angles to a uniform magnetic field of magnitude $0.30\,\mathrm{T}$. Which one of the following is closest to the magnitude of the magnetic force on the electron?

A. $9.6 \times 10^{-14}\,\mathrm{N}$

B. $4.8 \times 10^{-14}\,\mathrm{N}$

C. $1.92 \times 10^{-13}\,\mathrm{N}$

D. $4.8 \times 10^{-20}\,\mathrm{N}$

Question 10

Which one of the following statements about gravitational, electric and magnetic fields is correct?

A. Gravitational, electric and magnetic fields can all be either attractive or repulsive.

B. Masses only attract one another, whereas electric charges and magnetic poles can either attract or repel.

C. Only gravitational fields can be repulsive; electric and magnetic fields are always attractive.

D. Electric charges only attract, whereas masses can either attract or repel.

Question 11

A flat coil of 50 turns has an area of $0.020\,\mathrm{m}^2$. A uniform magnetic field perpendicular to the coil decreases steadily from $0.40\,\mathrm{T}$ to zero in $0.10\,\mathrm{s}$. Which one of the following is closest to the magnitude of the average emf induced in the coil?

A. $0.08\,\mathrm{V}$

B. $0.40\,\mathrm{V}$

C. $200\,\mathrm{V}$

D. $4.0\,\mathrm{V}$

Question 12

The coil of a DC motor rotates in a uniform magnetic field. The coil is connected to a DC supply through a split-ring commutator. Which one of the following best describes the role of the split-ring commutator in this motor?

A. It reverses the direction of the current in the coil once every full rotation, so that the torque on the coil stays in the same direction.

B. It keeps the current in the coil flowing in one direction only, so that the coil continues to rotate.

C. It reverses the direction of the current in the coil every half rotation, so that the torque on the coil stays in the same direction.

D. It reverses the direction of the magnetic field every half rotation, so that the torque on the coil stays in the same direction.

Question 13

An ideal transformer has 600 turns on its primary coil and 150 turns on its secondary coil. The primary is connected to a $120\,\mathrm{V}$ AC supply. Which one of the following is closest to the secondary (output) voltage?

A. $480\,\mathrm{V}$

B. $30\,\mathrm{V}$

C. $120\,\mathrm{V}$

D. $7.5\,\mathrm{V}$

Question 14

An alternating supply has a peak voltage of $340\,\mathrm{V}$. Which one of the following is closest to the root-mean-square (rms) voltage of the supply?

A. $240\,\mathrm{V}$

B. $481\,\mathrm{V}$

C. $170\,\mathrm{V}$

D. $340\,\mathrm{V}$

Question 15

Green light has a wavelength of 5.0×10^{-7} m. Which one of the following is closest to the energy of a single photon of this light?

A. 1.99×10^{-19} J

B. 7.96×10^{-19} J

C. 3.98×10^{-19} J

D. 1.33×10^{-27} J

Question 16

An electron has a momentum of 3.0×10^{-24} kg m s^{-1}. Which one of the following is closest to the de Broglie wavelength of the electron?

A. 4.42×10^{-10} m

B. 1.11×10^{-10} m

C. 1.99×10^{-57} m

D. 2.21×10^{-10} m

Question 17

A spacecraft travels past Earth at a constant speed of $0.60\,c$. A clock on the spacecraft measures a time interval of 4.0 s between two events that occur at the same point on the spacecraft. Which one of the following is closest to the time interval between these two events as measured by an observer on Earth?

A. 5.0 s

B. 3.2 s

C. 4.0 s

D. 6.25 s

Question 18

A stopwatch is found to read 0.3 s too high for every timing that is made with it. This is best described as

A. a random error, because it varies from one measurement to the next.

B. a systematic error, because it shifts every reading by the same fixed amount.

C. a mistake, which should be removed by repeating the measurement.

D. a consequence of the limited resolution of the stopwatch.

Question 19

A student makes repeated measurements of the same quantity. The readings are all very close to one another, but they are all well above the accepted (true) value. The readings are best described as

A. accurate but not precise.

B. both accurate and precise.

C. precise but not accurate.

D. neither accurate nor precise.

Question 20

A trolley starts from rest and moves with constant acceleration a, so that the distance travelled is given by $s=1/2\,a\,t^2$. To obtain a straight-line graph passing through the origin, a student should plot

A. s against t, which gives a straight line of gradient a.

B. s against $\sqrt{t}$.

C. $\frac{1}{s}$ against t^2.

D. s against t^2, giving a straight line through the origin of gradient $1/2\,a$.

End of Section A

Practice Exam 1 — Section B

*Answer **all** questions in the spaces provided. Write your responses in English.*

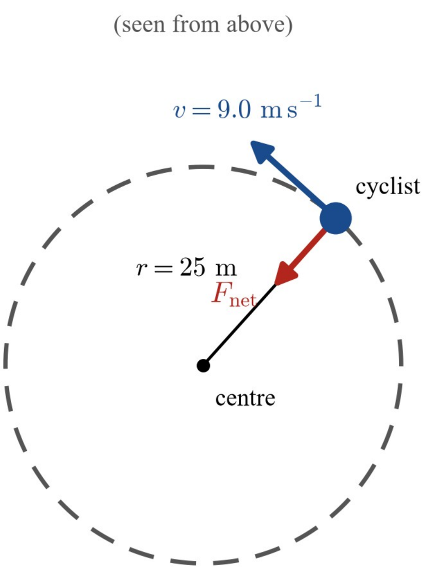
Where an answer box is provided, write your final answer in the box. If an answer box has a unit printed in it, give your answer in that unit.

*In questions where more than one mark is available, appropriate working **must** be shown.*

*Unless otherwise indicated, the diagrams in this book are **not** drawn to scale. Take the gravitational field strength to be* $g = 9.81\,\mathrm{N\,kg^{-1}}$.

Question 1 (6 marks)

A cyclist and bicycle of total mass $85\,\mathrm{kg}$ ride around a flat, circular bend of radius $25\,\mathrm{m}$ at a constant speed of $9.0\,\mathrm{m\,s^{-1}}$, as seen from above.



a. Calculate the magnitude of the net (centripetal) force on the cyclist and bicycle. Give your answer in N. 2 marks

b. Name the force that provides this net force, and state its direction. 1 mark

c. The greatest sideways friction force the road can provide on the tyres is $380\,\mathrm{N}$. Determine the maximum speed at which the cyclist can round this bend without skidding. Give your answer in m s⁻¹. 2 marks

d. Explain, with reference to Newton's first law of motion, what would happen to the cyclist's motion if the road surface on the bend suddenly became frictionless. 1 mark

Question 2 (6 marks)

A delivery drone flying horizontally at a constant height of $40\,\mathrm{m}$ and a constant speed of $12\,\mathrm{m\,s^{-1}}$ releases a package. The package leaves the drone with no vertical velocity. Ignore air resistance except in part **d.**

a. Show that the package takes $2.86\,\mathrm{s}$ to reach the ground. 1 mark

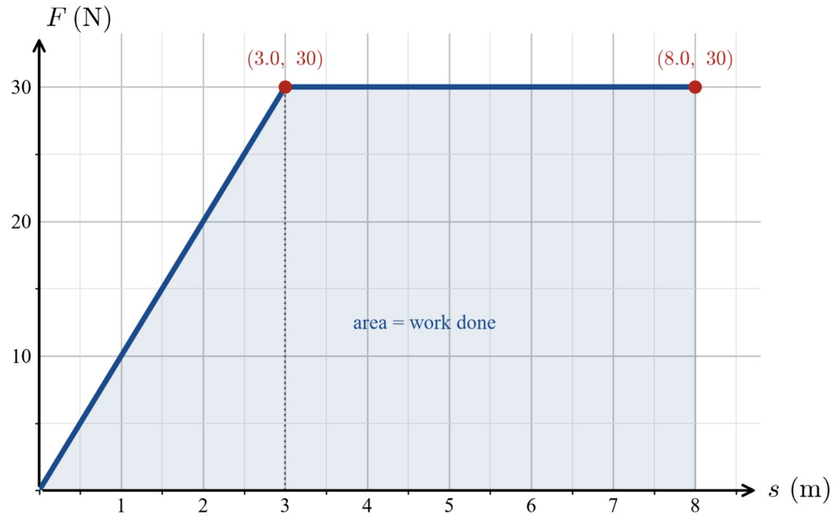
b. Calculate the horizontal distance the package travels between release and landing. Give your answer in m. 2 marks

c. Calculate the speed of the package just before it lands. Give your answer in m s⁻¹. 2 marks

d. (Circle your answer.) If air resistance were significant, the horizontal distance travelled by the package would be: *greater* / *smaller* / *the same*. Justify your answer. No calculations are required. 1 mark

Question 3 (5 marks)

A loaded bike trailer of mass $15\,\mathrm{kg}$ is pushed from rest along a straight, level path. The applied horizontal force varies with distance as shown: it rises uniformly from 0 to $30\,\mathrm{N}$ over the first $3.0\,\mathrm{m}$, then remains constant at $30\,\mathrm{N}$ up to $8.0\,\mathrm{m}$.



a. Show that the work done by the applied force over the $8.0\,\mathrm{m}$ is $195\,\mathrm{J}$. 1 mark

b. A constant friction force of $9.0\,\mathrm{N}$ opposes the motion over the whole $8.0\,\mathrm{m}$. Calculate the kinetic energy of the trailer at the $8.0\,\mathrm{m}$ mark. Give your answer in J. 2 marks

c. Hence calculate the speed of the trailer at the $8.0\,\mathrm{m}$ mark. Give your answer in m s^{-1}. 1 mark

d. State, in terms of energy transformations, what has become of the energy removed from the trailer by friction. 1 mark

Question 4 (4 marks)

A cyclist and bicycle of total mass $80\,\mathrm{kg}$ are moving at $7.0\,\mathrm{m\,s^{-1}}$ when the cyclist rides into a soft safety barrier and is brought to rest.

a. Calculate the magnitude of the change in momentum of the cyclist and bicycle as they are brought to rest. Give your answer in N s. 1 mark

b. The soft barrier brings the cyclist and bicycle to rest in $0.80\,\mathrm{s}$. Calculate the magnitude of the average force exerted on them by the barrier. Give your answer in N. 2 marks

c. Explain, in terms of impulse, why a soft barrier that increases the stopping time reduces the average force on the cyclist compared with a rigid barrier. 1 mark

Question 5 (7 marks)

A communications satellite orbits Earth in a circular orbit at an altitude of $2.0\times10^{6}\,\mathrm{m}$ above Earth's surface. Take the radius of Earth as $R_E = 6.37\times10^{6}\,\mathrm{m}$ and the mass of Earth as $M_E = 5.97\times10^{24}\,\mathrm{kg}$.

a. Show that the radius of the satellite's orbit is $8.37\times10^{6}\,\mathrm{m}$. 1 mark

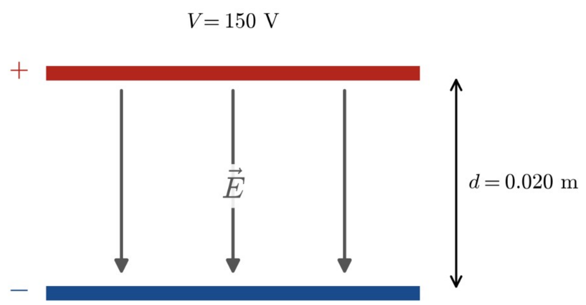
b. Calculate the gravitational field strength due to Earth at the satellite's orbit. Give your answer in N kg^{-1}. 2 marks

c. The satellite moves at constant speed, yet it is accelerating. Explain why the satellite is accelerating, with reference to Newton's second law of motion. 2 marks

d. Calculate the orbital speed of the satellite. Give your answer in m s^{-1}. 2 marks

Question 6 (6 marks)

Two horizontal parallel plates are separated by a distance of $0.020\,\text{m}$, with a potential difference of $150\,\text{V}$ maintained across them.



a. Show that the electric field strength between the plates is $7.5 \times 10^{3}\,\text{V m}^{-1}$. 1 mark

b. A small sphere carrying a charge of $4.0 \times 10^{-8}\,\text{C}$ is placed between the plates. Calculate the magnitude of the electric force on the sphere. Give your answer in N. 2 marks

c. An electron is released from rest at the negative plate and accelerates to the positive plate. Calculate the speed of the electron as it reaches the positive plate. Give your answer in m s^{-1}. 2 marks

d. The plate separation is now doubled, while the potential difference across the plates is kept the same. State the effect of this change on the electric field strength between the plates. 1 mark

Question 7 (5 marks)

An electron travels at a constant speed of $3.0 \times 10^{6}\,\text{m s}^{-1}$ at right angles to a uniform magnetic field of magnitude $0.15\,\text{T}$.

a. Show that the magnitude of the magnetic force on the electron is $7.20 \times 10^{-14}\,\text{N}$. 1 mark

b. Calculate the radius of the circular path followed by the electron in the field. Give your answer to three significant figures, in m. 2 marks

c. The electron now enters the same field with twice the speed. State and explain the effect of this on the radius of its circular path. 2 marks

Question 8 (2 marks)

A simple DC motor consists of a single rectangular coil made up of a number of loops of wire, free to rotate in a uniform magnetic field, and connected to the supply through a split-ring commutator.

a. State **two** changes that could be made to this motor to increase the size of the torque on the coil. For each change, state briefly why it increases the torque. 2 marks

Question 9 (6 marks)

A coil of 200 turns has a cross-sectional area of $2.5 \times 10^{-3}\,\text{m}^{2}$ and is connected to a sensitive ammeter. A magnet is moved so that the uniform magnetic field passing perpendicularly through the coil increases steadily from 0 to $0.60\,\text{T}$ in $0.30\,\text{s}$.

a. Show that the magnetic flux through one turn of the coil at the end of this change is $1.5 \times 10^{-3}\,\text{Wb}$. 1 mark

b. Calculate the magnitude of the average emf induced in the coil during the $0.30\,\text{s}$. Give your answer in V. 2 marks

c. While the field is increasing, the ammeter shows a current in the coil. Explain why a current is induced in the coil, referring to the change in magnetic flux. 2 marks

d. State one change to the way the magnet is moved that would increase the magnitude of the induced emf. 1 mark

Question 10 (3 marks)

A simple generator can be built with a coil that rotates in a magnetic field, connected to the external circuit either through a split-ring commutator or through two slip rings.

a. State which of these two arrangements produces a direct-current (DC) output. 1 mark

b. Explain how the split-ring commutator produces a direct-current output from the rotating coil. 2 marks

Question 11 (5 marks)

An ideal transformer has a primary coil of 240 turns and a secondary coil of 60 turns. The primary coil is connected to a $240\,\mathrm{V}$ AC supply.

a. Calculate the secondary (output) voltage of the transformer. Give your answer in V. 1 mark

b. The secondary coil delivers a current of $5.0\,\mathrm{A}$ to a device. Assuming the transformer is ideal, calculate the current drawn in the primary coil. Give your answer in A. 2 marks

c. Explain why this transformer will operate on an AC supply but will not produce a steady output voltage if connected to a steady DC supply. 2 marks

Question 12 (4 marks)

Electricity is delivered from a substation to a factory through transmission lines that have a total resistance of $0.80\,\Omega$. The current in the lines is $40\,\mathrm{A}$.

a. Calculate the voltage drop across the transmission lines. Give your answer in V. 1 mark

b. Calculate the power dissipated in the transmission lines. Give your answer in W. 2 marks

c. Explain why electrical power is transmitted at high voltage, and correspondingly low current, in order to reduce these line losses. 1 mark

Question 13 (4 marks)

In a Young's double-slit experiment, coherent light of wavelength $6.4 \times 10^{-7}\,\mathrm{m}$ passes through two narrow slits separated by $0.25 \times 10^{-3}\,\mathrm{m}$. The interference pattern is observed on a screen $1.8\,\mathrm{m}$ from the slits, where $L \gg d$.

a. Calculate the spacing between adjacent bright fringes on the screen. Give your answer in m. 2 marks

b. State what happens to the fringe spacing if the slit separation is increased, with everything else unchanged. 1 mark

c. Explain how the appearance of these bright and dark fringes provides evidence for the wave-like nature of light. 1 mark

Question 14 (5 marks)

In a photoelectric experiment, light of frequency $8.0 \times 10^{14}\,\mathrm{Hz}$ shines on a clean metal surface whose work function is $2.1\,\mathrm{eV}$.

a. Show that the energy of each incident photon is $3.3\,\mathrm{eV}$. 1 mark

b. Calculate the maximum kinetic energy of the emitted photoelectrons. Give your answer in eV. 2 marks

c. The intensity of the incident light is increased while its frequency is kept the same. State the effect of this on the maximum kinetic energy of the emitted photoelectrons. 1 mark

d. State one feature of the photoelectric effect that cannot be explained by the wave model of light. 1 mark

Question 15 (4 marks)

An atom in a gas has an electron that drops from an energy level of $-1.5\,\mathrm{eV}$ to a lower energy level of $-3.4\,\mathrm{eV}$, emitting a single photon.

a. Show that the energy of the emitted photon is $1.9\,\mathrm{eV}$. 1 mark

b. Calculate the wavelength of the emitted photon. Give your answer in m. 2 marks

c. Explain, in terms of electron energy levels, why the light emitted by this gas contains only certain specific wavelengths. 1 mark

Question 16 (5 marks)

Muons are created high in Earth's atmosphere and travel down toward the ground at a speed of $0.98\,c$. In the muons' own frame of reference, their average lifetime is $2.2\times10^{-6}\,\mathrm{s}$.

a. Show that the Lorentz factor γ for these muons is approximately 5.0. 1 mark

b. Calculate the average lifetime of these muons as measured by an observer at rest on the ground. Give your answer in s. 2 marks

c. Working entirely in the ground observer's frame of reference, explain why these muons are able to reach the ground, even though their lifetime measured at rest would suggest they should decay high in the atmosphere. 2 marks

Question 17 (2 marks)

An electron has a mass of $9.11\times10^{-31}\,\mathrm{kg}$.

a. Calculate the rest energy of the electron. Give your answer in J. 2 marks

Question 18 (2 marks)

In the Michelson–Morley experiment, the speed of light was compared along two perpendicular paths, and no difference was found between them (a null result).

a. Explain how this null result supports Einstein's postulate that the speed of light has a constant value for all observers. 2 marks

Question 19 (19 marks)

A student investigates free fall. A small, dense steel sphere is released from rest from a measured height h above an electronic sensor, and an electronic timer records the time t for the sphere to fall to the sensor. Air resistance is negligible. Because $h=1/2\,g\,t^2$, a graph of t^2 against h should be a straight line through the origin.

The student varies the height h and, at each height, records the fall time three times and calculates the mean value of t^2. The results are shown in the table. The uncertainty in each value of t^2 is $\pm0.02\,\mathrm{s}^2$.

h (m)	0.40	0.80	1.20	1.60	2.00	2.40
t^2 (s²)	0.075	0.170	0.240	0.330	0.400	0.495

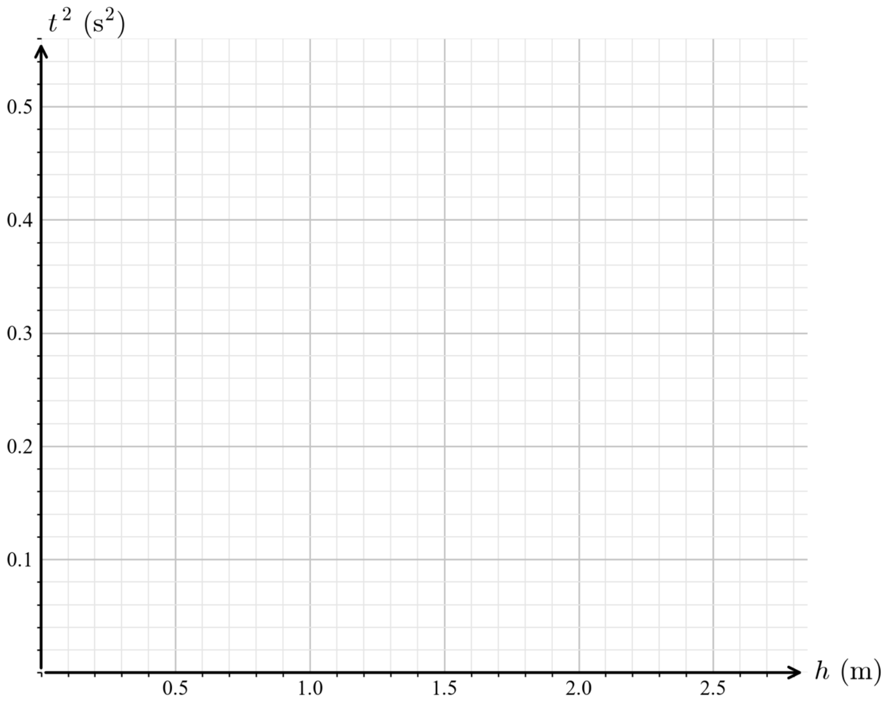
a. For this investigation, identify the independent variable, the dependent variable and one controlled variable. 3 marks

b. Explain why the student used a small, dense steel sphere rather than a light object such as a table-tennis ball. 2 marks

c. Explain why using electronic light gates to measure the fall time gives more reliable results than a hand-operated stopwatch. 2 marks

d. At each height the student measured the fall time three times and averaged the results. State the purpose of taking these repeat measurements. 1 mark

e. On the grid provided, plot t^2 against h, including an uncertainty bar of $\pm 0.02\,\text{s}^2$ on each point, and draw the line of best fit. 5 marks



f. Using two well-separated points on your line of best fit, determine the gradient of the line. Give your answer in s² m⁻¹. 2 marks

g. The motion obeys $h = 1/2\, g t^2$, so that $t^2 = \frac{2}{g} h$. Use your gradient to determine a value for g, the acceleration due to gravity. Give your answer in m s⁻².

2 marks

h. The student repeats the whole investigation on the Moon, where the gravitational field strength is about one sixth of the value on Earth. Predict how the gradient of the graph would change, and justify your answer. 2 marks

End of Section B

Practice Exam 1 — Formula Sheet

This formula sheet is provided for use with all practice examinations in this booklet. It covers the same items as the official VCE Physics Formula Sheet.

Motion and related energy transformations

velocity	$v=\frac{\Delta s}{\Delta t}$
acceleration	$a=\frac{\Delta v}{\Delta t}$
constant acceleration	$v=u+at$
	$s=ut+\frac{1}{2}at^2$
	$s=vt-\frac{1}{2}at^2$
	$v^2=u^2+2as$
	$s=\frac{1}{2}(u+v)t$
Newton's second law	$\Sigma F=ma$
uniform circular motion	$F_{\text{net}}=\frac{mv^2}{r}$
	$v=\frac{2\pi r}{T}$
Hooke's law	$F=-kx$
elastic potential energy	$E_s=\frac{1}{2}kx^2$
gravitational potential energy	$E_g=mg\Delta h$
kinetic energy	$E_k=\frac{1}{2}mv^2$
universal gravitation	$F_g=\frac{Gm_1m_2}{r^2}$
gravitational field	$g=\frac{GM}{r^2}$
impulse	$F\Delta t=m\Delta v$
momentum	$p=mv$

Einstein's special theory of relativity

Lorentz factor	$\gamma=\frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$
time dilation	$t=\gamma t_0$
length contraction	$L=\frac{L_0}{\gamma}$
rest energy	$E_0=mc^2$
total energy	$E_{\text{total}}=E_k+E_0=\gamma mc^2$

relativistic kinetic energy $E_k = (\gamma - 1) m c^2$

Fields and application of field concepts

uniform electric field	$E = \frac{V}{d}$
charge accelerated by a field	$\frac{1}{2} m v^2 = q V$
field of a point charge	$E = \frac{k Q}{r^2}$
electric force on a charge	$F = q E$
Coulomb's law	$F = \frac{k q_1 q_2}{r^2}$
magnetic force on a moving charge	$F = q v B$
force on a current-carrying conductor	$F = n I l B$
radius of a charged particle's path	$r = \frac{m v}{q B}$

Generation and transmission of electricity

current	$I = \frac{V}{R}$
power	$P = V I$
resistors in series	$R_T = R_1 + R_2 + \ldots$
resistors in parallel	$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$
ideal transformer	$\frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{I_2}{I_1}$
rms voltage	$V_{\text{RMS}} = \frac{1}{\sqrt{2}} V_{\text{peak}}$
rms current	$I_{\text{RMS}} = \frac{1}{\sqrt{2}} I_{\text{peak}}$
electromagnetic induction	$\varepsilon = -N \frac{\Delta \Phi_B}{\Delta t}$
magnetic flux	$\Phi_B = B_{\perp} A$
voltage drop along a line	$V_{\text{drop}} = I_{\text{line}} R_{\text{line}}$
power loss in a line	$P_{\text{loss}} = I_{\text{line}}^2 R_{\text{line}}$

Waves

wave equation	$v = f \lambda$
constructive interference	path difference $= n \lambda$
destructive interference	path difference $= \left(n + \frac{1}{2}\right) \lambda$
fringe spacing	$\Delta x = \frac{\lambda L}{d}$ when $L \gg d$

The nature of light and matter

photoelectric effect	$E_{k\,\max} = hf - \phi$
photon energy	$E = hf = \frac{hc}{\lambda}$
photon momentum	$p = \frac{h}{\lambda}$
de Broglie wavelength	$\lambda = \frac{h}{p}$

Data

acceleration due to gravity at Earth's surface	$g = 9.81$ m s^{-2}
mass of the electron	$m_e = 9.11 \times 10^{-31}$ kg
magnitude of the charge of the electron	$q_e = 1.60 \times 10^{-19}$ C
Planck's constant	$h = 6.63 \times 10^{-34}$ J s
	$h = 4.14 \times 10^{-15}$ eV s
speed of light in a vacuum	$c = 3.00 \times 10^{8}$ m s^{-1}
universal gravitational constant	$G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}
mass of Earth	$M_E = 5.97 \times 10^{24}$ kg
radius of Earth	$R_E = 6.37 \times 10^{6}$ m
Coulomb constant	$k = 8.99 \times 10^{9}$ N m^2 C^{-2}

Metric (SI) multipliers

pico (p)	10^{-12}	kilo (k)	10^{3}
nano (n)	10^{-9}	mega (M)	10^{6}
micro (μ)	10^{-6}	giga (G)	10^{9}
milli (m)	10^{-3}	tera (T)	10^{12}

Unit conversions

1 tonne (t)	= 10^{3} kg
1 kilowatt hour (kW h)	= 3.6×10^{6} J

Nomenclature

force due to gravity	F_g
force on A by B	$F_{\text{on A by B}}$
normal force	F_N

End of Formula Sheet

Practice Exam 1 — solutions

Section A — answer key

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

Question 1 — C. The propellers must support the drone against the force due to gravity and also provide the upward acceleration: $F = m(g + a) = 1.5 \times (9.81 + 2.0) = 17.7\,\mathrm{N}$. **A** gives only $mg = 14.7\,\mathrm{N}$ (forgets the acceleration); **B** gives only the net force $ma = 3.0\,\mathrm{N}$; **D** uses $m(g - a) = 11.7\,\mathrm{N}$ (subtracts the acceleration).

Question 2 — A. The net force is the centripetal force: $F = \frac{mv^2}{r} = \frac{80 \times 8.0^2}{20} = 256\,\mathrm{N}$. **B** uses $\frac{mv}{r}$ (does not square v); **C** uses $\frac{v^2}{r}$ (omits the mass); **D** uses mv^2 (omits dividing by r).

Question 3 — D. The vertical motion is a fall from rest: $t = \sqrt{\frac{2h}{g}} = \sqrt{\frac{2 \times 45}{9.81}} = 3.03\,\mathrm{s}$ (the horizontal speed does not affect the fall time). **A** uses $\sqrt{h/g}$ (drops the factor 2); **B** uses $2h/g$ (no square root); **C** uses $\sqrt{4h/g}$.

Question 4 — B. The area under a force–time graph is the impulse ($= \Delta p$); the area under a force–distance graph is the work done ($= \Delta E_k$). **A** and **D** merge the two quantities; **C** swaps them — the classic impulse-versus-work trap.

Question 5 — A. $E_s = 1/2\, k x^2 = 1/2 \times 2.4 \times 10^4 \times 0.050^2 = 30\,\mathrm{J}$. **B** omits the $1/2$; **C** uses $1/2\, k x$ (does not square x); **D** uses kx (the spring force, not the stored energy).

Question 6 — C. The gravitational field obeys an inverse-square law, so at twice the distance the field is $\frac{1}{2^2} = \frac{1}{4}$ of its value: $\frac{6.0}{4} = 1.5\,\mathrm{N\,kg^{-1}}$. **A** halves the field (inverse-linear error); **B** doubles it; **D** leaves it unchanged.

Question 7 — B. For circular motion, $a = \frac{v^2}{r} = \frac{(7.6 \times 10^3)^2}{7.0 \times 10^6} = 8.25\,\mathrm{m\,s^{-2}}$. **A** uses twice the radius (a diameter slip); **D** uses half the radius; **C** uses $\frac{v}{r}$ (does not square v).

Question 8 — D. The field between parallel plates is $E = \frac{V}{d} = \frac{200}{0.050} = 4.0 \times 10^3\,\mathrm{N\,C^{-1}}$. **A** multiplies ($V \times d$); **B** fails to convert $5.0\,\mathrm{cm}$ to $0.050\,\mathrm{m}$; **C** inverts the ratio (d/V).

Question 9 — A. $F = qvB = 1.60 \times 10^{-19} \times 2.0 \times 10^6 \times 0.30 = 9.6 \times 10^{-14}\,\mathrm{N}$. **B** halves the result; **C** doubles it; **D** omits the speed (qB only).

Question 10 — B. Masses only attract one another, whereas electric charges (like/unlike) and magnetic poles (like/unlike) can either attract or repel. **A**, **C** and **D** all misstate which interactions can be repulsive — gravity is always attractive.

Question 11 — D. $\varepsilon = N\frac{\Delta\Phi_B}{\Delta t} = N\frac{A\,\Delta B}{\Delta t} = 50\times\frac{0.020\times0.40}{0.10} = 4.0\,\mathrm{V}$. **A** omits the number of turns N; **B** omits dividing by Δt; **C** omits the area A.

Question 12 — C. For the coil to keep rotating in one direction, the torque on it must always act the same way around the axle. Every half rotation the two sides of the coil swap positions, so the current in the coil must reverse every half rotation to keep the torque direction unchanged; the split-ring commutator reverses the coil's connections to the supply every half rotation, which does exactly this. **A** reverses the current only once every full rotation, which would leave the torque reversed for one half-turn in two; **B** keeps the coil current one-directional, which would also reverse the torque every half rotation; **D** has the magnetic field reversing rather than the current.

Question 13 — B. For an ideal transformer, $V_2 = V_1\frac{N_2}{N_1} = 120\times\frac{150}{600} = 30\,\mathrm{V}$. **A** inverts the turns ratio; **C** leaves the voltage unchanged; **D** applies the ratio twice.

Question 14 — A. $V_{\mathrm{RMS}} = \frac{V_{\mathrm{peak}}}{\sqrt{2}} = \frac{340}{\sqrt{2}} = 240\,\mathrm{V}$. **B** multiplies by $\sqrt{2}$ instead of dividing; **C** divides by 2; **D** leaves the peak value unchanged.

Question 15 — C. $E = \frac{hc}{\lambda} = \frac{6.63\times10^{-34}\times3.00\times10^{8}}{5.0\times10^{-7}} = 3.98\times10^{-19}\,\mathrm{J}$. **A** halves the result; **B** doubles it; **D** uses $\frac{h}{\lambda}$ (the momentum, omitting c).

Question 16 — D. $\lambda = \frac{h}{p} = \frac{6.63\times10^{-34}}{3.0\times10^{-24}} = 2.21\times10^{-10}\,\mathrm{m}$. **A** uses $\frac{2h}{p}$; **B** uses $\frac{h}{2p}$; **C** multiplies ($h\,p$).

Question 17 — A. $\gamma = \frac{1}{\sqrt{1-0.60^2}} = 1.25$, so the dilated time is $t = \gamma t_0 = 1.25\times4.0 = 5.0\,\mathrm{s}$. **B** divides by γ (the length-contraction form); **C** leaves the interval unchanged; **D** multiplies by γ^2.

Question 18 — B. A fixed offset that shifts every reading by the same amount is a systematic error. **A** describes a random error (which varies); **C** describes a mistake (removed by repeating); **D** describes resolution, which is not a fixed offset.

Question 19 — C. Readings clustered tightly together are precise; being consistently far from the true value means they are not accurate. **A** reverses the two terms; **B** and **D** are inconsistent with the description.

Question 20 — D. With $s = 1/2\,a t^2$, plotting s against t^2 gives a straight line through the origin of gradient $1/2\,a$. **A** plots s against t, which is a curve (parabola); **B** and **C** do not linearise the relationship.

Section B — worked solutions

Question 1

Total mass $m = 85\,\mathrm{kg}$, radius $r = 25\,\mathrm{m}$, speed $v = 9.0\,\mathrm{m\ s^{-1}}$.

(a) The net force is the centripetal force:

$$F_{\mathrm{net}} = \frac{mv^2}{r} = \frac{85\times9.0^2}{25} = \frac{6885}{25} = 275\,\mathrm{N}.$$

(1 mark correct use of $F_{\mathrm{net}} = \frac{mv^2}{r}$; **1 mark** value $275\,\mathrm{N}$.)

(b) The net force is provided by the **friction force** of the road on the tyres, directed horizontally **toward the centre** of the circular bend. **(1 mark: friction, directed toward the centre.)**

(c) The maximum friction supplies the maximum centripetal force:

$$v_{max} = \sqrt{\frac{F_{max} r}{m}} = \sqrt{\frac{380 \times 25}{85}} = \sqrt{111.8} = 10.6\,\text{m s}^{-1}.$$

$\therefore$ the cyclist can round the bend at up to $10.6\,\text{m s}^{-1}$. **(1 mark** rearranges $F_{max} = \frac{m v_{max}^2}{r}$; **1 mark** value $10.6\,\text{m s}^{-1}$.)

(d) With no friction there is no sideways force to act as the centripetal force, so the net horizontal force is zero. By Newton's first law the cyclist continues to move in a **straight line at constant velocity** — travelling straight ahead, tangent to the bend, instead of following the curve. **(1 mark: continues in a straight line at constant velocity, justified by Newton's first law / no net force.)**

Question 2

Height $h = 40\,\text{m}$, horizontal speed $v_x = 12\,\text{m s}^{-1}$.

(a) The vertical motion is a fall from rest, $h = 1/2\, g t^2$:

$$t = \sqrt{\frac{2h}{g}} = \sqrt{\frac{2 \times 40}{9.81}} = 2.86\,\text{s},$$

as required. **(1 mark: correct substitution and result.)**

(b) The horizontal velocity is constant, so

$$x = v_x t = 12 \times 2.856 = 34.3\,\text{m}.$$

(1 mark $x = v_x t$; **1 mark** value $34.3\,\text{m}$.)

(c) The vertical velocity at landing is $v_y = g t = 9.81 \times 2.856 = 28.0\,\text{m s}^{-1}$. The horizontal velocity is unchanged at $12\,\text{m s}^{-1}$, so the landing speed is

$$v = \sqrt{v_x^2 + v_y^2} = \sqrt{12^2 + 28.0^2} = \sqrt{929} = 30.5\,\text{m s}^{-1}.$$

(1 mark finds $v_y = g t$; **1 mark** combines components to $30.5\,\text{m s}^{-1}$.)

(d) **Smaller.** Air resistance acts opposite to the package's velocity throughout the flight, continually reducing its horizontal velocity, so the package covers a shorter horizontal distance before landing. **(1 mark: circles *smaller* AND justifies via air resistance opposing the motion / reducing the horizontal velocity. The circled option alone scores 0.)**

Question 3

Mass $m = 15\,\text{kg}$, released from rest.

(a) Work = area under the force–distance graph. Triangle (0 → $3.0\,\text{m}$): $1/2 \times 3.0 \times 30 = 45\,\text{J}$. Rectangle ($3.0 \to 8.0\,\text{m}$): $30 \times 5.0 = 150\,\text{J}$. Total $W = 45 + 150 = 195\,\text{J}$, as required. **(1 mark: correct area giving** $195\,\text{J}$ **.)**

(b) Friction does negative work $W_f = -f s = -9.0 \times 8.0 = -72\,\text{J}$. From rest, the kinetic energy equals the net work done:

$$E_k = W - f s = 195 - 72 = 123\,\text{J}.$$

(1 mark subtracts the friction work $72\,\text{J}$; **1 mark** value $123\,\text{J}$.)

(c) $E_k = 1/2\, m v^2 \Rightarrow v = \sqrt{\dfrac{2E_k}{m}} = \sqrt{\dfrac{2 \times 123}{15}} = \sqrt{16.4} = 4.05\,\mathrm{m\ s^{-1}}$. **(1 mark: value $4.05\,\mathrm{m\ s^{-1}}$.)**

(d) The 72 J removed by friction is transferred to the surroundings, mainly as **heat** in the wheels and the path, with a little **sound**; total energy is conserved. **(1 mark: dissipated as heat (and sound) to the surroundings.)**

Question 4

Total mass $m = 80\,\mathrm{kg}$, $u = 7.0\,\mathrm{m\ s^{-1}}$, brought to rest.

(a) $|\Delta p| = m|\Delta v| = 80 \times 7.0 = 560\,\mathrm{N\ s}$. **(1 mark: value $560\,\mathrm{N\ s}$.)**

(b) The impulse equals the change in momentum, $F\Delta t = \Delta p$, so

$$F = \frac{\Delta p}{\Delta t} = \frac{560}{0.80} = 700\,\mathrm{N}.$$

(1 mark $F = \dfrac{\Delta p}{\Delta t}$; **1 mark** value $700\,\mathrm{N}$.)

(c) The change in momentum Δp (from $7.0\,\mathrm{m\ s^{-1}}$ to rest) is fixed, so the impulse $F\Delta t = \Delta p$ is fixed. Increasing the stopping time Δt therefore decreases the average force F ($F = \Delta p / \Delta t$): the soft barrier spreads the same momentum change over a longer time, so the force on the cyclist is smaller than for a rigid barrier that stops them quickly. **(1 mark: same Δp, so a longer Δt gives a smaller F via $F\Delta t = \Delta p$.)**

Question 5

Altitude $= 2.0 \times 10^6\,\mathrm{m}$, $R_E = 6.37 \times 10^6\,\mathrm{m}$, $M_E = 5.97 \times 10^{24}\,\mathrm{kg}$, $G = 6.67 \times 10^{-11}\,\mathrm{N\ m^2\,kg^{-2}}$.

(a) The orbital radius is measured from Earth's centre:

$$r = R_E + \text{altitude} = 6.37 \times 10^6 + 2.0 \times 10^6 = 8.37 \times 10^6\,\mathrm{m},$$

as required. **(1 mark: adds the altitude to R_E.)**

(b) $g = \dfrac{GM_E}{r^2} = \dfrac{6.67 \times 10^{-11} \times 5.97 \times 10^{24}}{(8.37 \times 10^6)^2} = \dfrac{3.98 \times 10^{14}}{7.01 \times 10^{13}} = 5.68\,\mathrm{N\ kg^{-1}}$. (**1 mark** correct substitution with r from part **a.**; **1 mark** value $5.68\,\mathrm{N\ kg^{-1}}$.)

(c) Although the speed is constant, the satellite's velocity continually changes direction as it moves in a circle, so the satellite is accelerating (the acceleration is centripetal, directed toward Earth's centre). By Newton's second law, an acceleration requires an unbalanced net force; here the **unbalanced gravitational force** on the satellite provides this net (centripetal) force. (**1 mark** velocity changes direction ⇒ accelerating (centripetal); **1 mark** Newton's second law: an unbalanced gravitational force is required to produce this acceleration.)

(d) The gravitational force provides the centripetal force, so the satellite's acceleration equals the local field strength, $g = \dfrac{v^2}{r}$. Hence

$$v = \sqrt{gr} = \sqrt{5.68 \times 8.37 \times 10^6} = \sqrt{4.76 \times 10^7} = 6.90 \times 10^3\,\mathrm{m\ s^{-1}}.$$

(**1 mark** $v = \sqrt{gr}$ (or $\dfrac{GM_E}{r^2} = \dfrac{v^2}{r}$); **1 mark** value $6.90 \times 10^3\,\mathrm{m\ s^{-1}}$.)

Question 6

Plate separation $d = 0.020\,\mathrm{m}$, potential difference $V = 150\,\mathrm{V}$.

(a) $E=\frac{V}{d}=\frac{150}{0.020}=7.5\times10^{3}\,\mathrm{V\,m^{-1}}$, as required. **(1 mark: correct substitution and result.)**

(b) $F=qE=4.0\times10^{-8}\times7.5\times10^{3}=3.0\times10^{-4}\,\mathrm{N}$. **(1 mark** $F=qE$; **1 mark** value $3.0\times10^{-4}\,\mathrm{N}$.)

(c) The work done on the electron by the field becomes kinetic energy, $1/2\,m_e v^2=qV$, so

$$v=\sqrt{\frac{2qV}{m_e}}=\sqrt{\frac{2\times1.60\times10^{-19}\times150}{9.11\times10^{-31}}}=\sqrt{5.27\times10^{13}}=7.26\times10^{6}\,\mathrm{m\,s^{-1}}.$$

(1 mark $1/2\,m_e v^2=qV$; **1 mark** value $7.26\times10^{6}\,\mathrm{m\,s^{-1}}$.)

(d) The field is $E=\frac{V}{d}$; with V unchanged and d doubled, the field strength is **halved** (to $3.75\times10^{3}\,\mathrm{V\,m^{-1}}$). **(1 mark: the field strength halves.)**

Question 7

Electron: $v=3.0\times10^{6}\,\mathrm{m\,s^{-1}}$, $B=0.15\,\mathrm{T}$, $q=1.60\times10^{-19}\,\mathrm{C}$, $m_e=9.11\times10^{-31}\,\mathrm{kg}$.

(a) $F=qvB=1.60\times10^{-19}\times3.0\times10^{6}\times0.15=7.20\times10^{-14}\,\mathrm{N}$, as required. **(1 mark: correct substitution and result.)**

(b) The magnetic force provides the centripetal force, so $r=\frac{m_e v}{qB}$:

$$r=\frac{9.11\times10^{-31}\times3.0\times10^{6}}{1.60\times10^{-19}\times0.15}=\frac{2.733\times10^{-24}}{2.40\times10^{-20}}=1.14\times10^{-4}\,\mathrm{m}.$$

(1 mark $r=\frac{m_e v}{qB}$; **1 mark** value $1.14\times10^{-4}\,\mathrm{m}$ (3 s.f.).)

(c) Since $r=\frac{m_e v}{qB}$, the radius is directly proportional to the speed (the other quantities are unchanged). Doubling the speed therefore **doubles the radius**, to $2.28\times10^{-4}\,\mathrm{m}$. **(1 mark** $r\propto v$; **1 mark** radius doubles.)

Question 8

(a) Any **two** of:

- increase the **current** I in the coil — a larger current gives a larger force on each side of the coil ($F=nIlB$), hence a larger torque;
- increase the **number of loops** n in the coil — more current-carrying wires in the field means a larger total force and torque;
- increase the **magnetic field strength** B — a stronger field gives a larger force on each current-carrying side, hence a larger torque.

(1 mark each for any two valid changes, each with a correct reason.)

Question 9

$N=200$ turns, $A=2.5\times10^{-3}\,\mathrm{m^2}$, field $\perp$ coil rising $0\to0.60\,\mathrm{T}$ in $0.30\,\mathrm{s}$.

(a) $\Phi_B=B_\perp A=0.60\times2.5\times10^{-3}=1.5\times10^{-3}\,\mathrm{Wb}$, as required. **(1 mark: correct substitution and result.)**

(b) $\varepsilon=N\frac{\Delta\Phi_B}{\Delta t}=200\times\frac{1.5\times10^{-3}}{0.30}=1.0\,\mathrm{V}$. **(1 mark** $\varepsilon=N\frac{\Delta\Phi_B}{\Delta t}$ with $\Delta\Phi_B=1.5\times10^{-3}\,\mathrm{Wb}$; **1 mark** value $1.0\,\mathrm{V}$.)

(c) As the magnetic field through the coil increases, the magnetic flux through the coil changes (increases). By Faraday's law, a changing flux through the coil induces an emf ($\varepsilon = -N\frac{\Delta\Phi_B}{\Delta t}$); because the coil forms a closed circuit, this emf drives an induced current, which the ammeter registers. **(1 mark** increasing field ⇒ changing flux through the coil; **1 mark** changing flux induces an emf (Faraday's law) that drives the current. A bare "the magnet has a changing field" or a Lenz's-law recitation without the flux-change chain scores 0.)

(d) Move the magnet **faster**, so that the flux changes more rapidly (a greater $\frac{\Delta\Phi_B}{\Delta t}$). **(1 mark: move the magnet faster / increase the rate of change of flux.)**

Question 10

(a) The **split-ring commutator** produces a direct-current (DC) output. **(1 mark.)**

(b) As the coil rotates, the emf generated in it reverses direction every half-turn. The split-ring commutator rotates with the coil and swaps the coil's two connections to the external circuit at the same instant the emf would reverse. The reversal of the connections cancels the reversal of the emf, so the current in the external circuit always flows in the **same direction** (although its size varies) — a direct-current output. **(1 mark** the coil emf reverses each half-turn; **1 mark** the commutator swaps the connections each half-turn so the external current stays one-directional.)

Question 11

Ideal transformer: $N_1 = 240$, $N_2 = 60$, $V_1 = 240\ \text{V}$.

(a) $V_2 = V_1\frac{N_2}{N_1} = 240 \times \frac{60}{240} = 60\ \text{V}$. **(1 mark: value** $60\ \text{V}$**.)**

(b) For an ideal transformer, $\frac{N_1}{N_2} = \frac{I_2}{I_1}$, so

$$I_1 = I_2\frac{N_2}{N_1} = 5.0 \times \frac{60}{240} = 1.25\ \text{A}.$$

(Equivalently, $P = V_2 I_2 = V_1 I_1$ gives $I_1 = \frac{60 \times 5.0}{240} = 1.25\ \text{A}$.) **(1 mark** correct transformer current relationship; **1 mark** value $1.25\ \text{A}$.)

(c) A transformer works by electromagnetic induction. An AC supply drives a continually changing current in the primary, producing a continually **changing magnetic flux** in the core; this changing flux threads the secondary coil and induces an emf in it. A steady DC supply produces a **constant** current and hence a constant flux — with no change of flux there is no induced emf in the secondary (except for a brief pulse at switch-on), so no steady output voltage is produced. **(1 mark** transformer action needs a changing flux (electromagnetic induction); **1 mark** steady DC gives constant flux ⇒ no induced secondary emf. A bare "because it needs AC" scores 0.)

Question 12

Line resistance $R_{\text{line}} = 0.80\ \Omega$, line current $I_{\text{line}} = 40\ \text{A}$.

(a) $V_{\text{drop}} = I_{\text{line}} R_{\text{line}} = 40 \times 0.80 = 32\ \text{V}$. **(1 mark: value** $32\ \text{V}$**.)**

(b) $P_{\text{loss}} = I_{\text{line}}^2 R_{\text{line}} = 40^2 \times 0.80 = 1600 \times 0.80 = 1.28 \times 10^3\ \text{W}$. **(1 mark** $P_{\text{loss}} = I_{\text{line}}^2 R_{\text{line}}$; **1 mark** value $1.28 \times 10^3\ \text{W}$.)

(c) For a required power delivery $P = VI$, transmitting at a higher voltage means a correspondingly **lower line current** I. Because the line loss $P_{\text{loss}} = I^2 R_{\text{line}}$ depends on the **square** of the current, reducing the current greatly reduces the power lost in the lines. **(1 mark: higher $V \Rightarrow$ lower I, and $P_{\text{loss}} = I^2 R$ falls sharply as I decreases.)**

Question 13

$\lambda = 6.4 \times 10^{-7}\,\text{m}$, $d = 0.25 \times 10^{-3}\,\text{m}$, $L = 1.8\,\text{m}$.

(a) $\Delta x = \dfrac{\lambda L}{d} = \dfrac{6.4 \times 10^{-7} \times 1.8}{0.25 \times 10^{-3}} = \dfrac{1.152 \times 10^{-6}}{2.5 \times 10^{-4}} = 4.61 \times 10^{-3}\,\text{m}$. **(1 mark** $\Delta x = \dfrac{\lambda L}{d}$; **1 mark** value $4.61 \times 10^{-3}\,\text{m}$.)

(b) Since $\Delta x = \dfrac{\lambda L}{d}$, the fringe spacing is inversely proportional to d, so increasing the slit separation **decreases** the fringe spacing (the fringes move closer together). **(1 mark: fringe spacing decreases.)**

(c) The bright and dark fringes are produced by constructive and destructive **interference** of the light arriving from the two slits (path differences of $n\lambda$ and $(n + 1/2)\lambda$ respectively). Interference — the addition of two waves to give reinforcement and cancellation — is a wave phenomenon, so the pattern is evidence that light behaves as a wave. **(1 mark: fringes arise from interference (constructive/destructive), which is a wave behaviour.)**

Question 14

$f = 8.0 \times 10^{14}\,\text{Hz}$, $\phi = 2.1\,\text{eV}$, $h = 4.14 \times 10^{-15}\,\text{eV s}$.

(a) $E = hf = 4.14 \times 10^{-15} \times 8.0 \times 10^{14} = 3.3\,\text{eV}$, as required. **(1 mark: correct substitution and result, using h in eV s.)**

(b) $E_{k\,\text{max}} = hf - \phi = 3.31 - 2.1 = 1.2\,\text{eV}$. **(1 mark** $E_{k\,\text{max}} = hf - \phi$; **1 mark** value $1.2\,\text{eV}$.)

(c) There is **no change** in the maximum kinetic energy. The maximum kinetic energy depends only on the frequency (and the work function), not on the intensity; increasing the intensity increases the **number** of photoelectrons per second, not their maximum kinetic energy. **(1 mark: no change — maximum kinetic energy depends on frequency, not intensity.)**

(d) Any one of: there is a **threshold frequency** below which no electrons are emitted, no matter how intense the light; emission begins **immediately** even for very dim light; the maximum kinetic energy depends on the **frequency**, not the intensity. The wave model predicts none of these. **(1 mark: any one valid wave-model failure.)**

Question 15

Transition from $-1.5\,\text{eV}$ to $-3.4\,\text{eV}$.

(a) The photon energy equals the drop in the electron's energy:

$$\Delta E = (-1.5) - (-3.4) = 1.9\,\text{eV},$$

as required. **(1 mark: correct energy difference.)**

(b) Converting to joules, $E = 1.9 \times 1.60 \times 10^{-19} = 3.04 \times 10^{-19}\,\text{J}$. Then

$$\lambda = \frac{hc}{E} = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{3.04 \times 10^{-19}} = 6.54 \times 10^{-7}\,\text{m}.$$

(1 mark converts E to joules and uses $\lambda = \dfrac{hc}{E}$; **1 mark** value $6.54 \times 10^{-7}\,\text{m}$.)

(c) The electrons in the atom can occupy only certain discrete (quantised) energy levels. A photon is emitted only when an electron drops between two of these levels, and its energy equals the fixed difference between them. Because only particular energy differences are possible, only photons of particular energies — and hence particular wavelengths — are emitted, giving a line spectrum. **(1 mark: discrete energy levels ⇒ only specific transition energies ⇒ only specific wavelengths.)**

Question 16

$v = 0.98c$, proper lifetime $t_0 = 2.2 \times 10^{-6}$ s.

(a) $\gamma = \dfrac{1}{\sqrt{1 - \dfrac{v^2}{c^2}}} = \dfrac{1}{\sqrt{1 - 0.98^2}} = \dfrac{1}{\sqrt{0.0396}} = 5.0$, as required. **(1 mark: correct evaluation of γ.)**

(b) The ground observer measures the dilated lifetime:

$$t = \gamma t_0 = 5.03 \times 2.2 \times 10^{-6} = 1.1 \times 10^{-5}\text{ s}.$$

(1 mark $t = \gamma t_0$; **1 mark** value 1.1×10^{-5} s.)

(c) Working in the ground frame: the muons' lifetime is dilated to $t = \gamma t_0 \approx 1.1 \times 10^{-5}$ s, about five times longer than the 2.2×10^{-6} s measured at rest. Travelling at $0.98c$ for this longer time, the muons cover a much greater distance before decaying — far enough to reach the ground. **(1 mark** the ground observer sees the muon lifetime dilated (longer); **1 mark** at $0.98c$ the longer lifetime allows them to travel far enough to reach the ground. Mixing in length contraction (a muon-frame idea) in this ground-frame answer is not rewarded.)

Question 17

(a) $E_0 = mc^2 = 9.11 \times 10^{-31} \times (3.00 \times 10^8)^2 = 9.11 \times 10^{-31} \times 9.00 \times 10^{16} = 8.20 \times 10^{-14}$ J. **(1 mark** $E_0 = mc^2$; **1 mark** value 8.20×10^{-14} J.)

Question 18

(a) If light travelled through a fixed medium (an "aether"), then as Earth moves through it the measured speed of light along the two perpendicular paths — one along Earth's motion and one across it — should differ. The experiment found **no difference** (a null result): the speed of light was the same along both perpendicular paths, regardless of Earth's motion. This is exactly what Einstein's postulate requires — that the speed of light has the same constant value for all observers. **(1 mark** two perpendicular paths would give different speeds if there were an aether; **1 mark** the null result shows c is the same in both directions, supporting the constant-c postulate. A bare "the speed of light is constant" without reference to the two paths and the null result is insufficient.)

Question 19

The relationship $h = 1/2\, g t^2$ rearranges to $t^2 = \dfrac{2}{g} h$, so a graph of t^2 (vertical) against h (horizontal) is a straight line through the origin of gradient $\dfrac{2}{g}$.

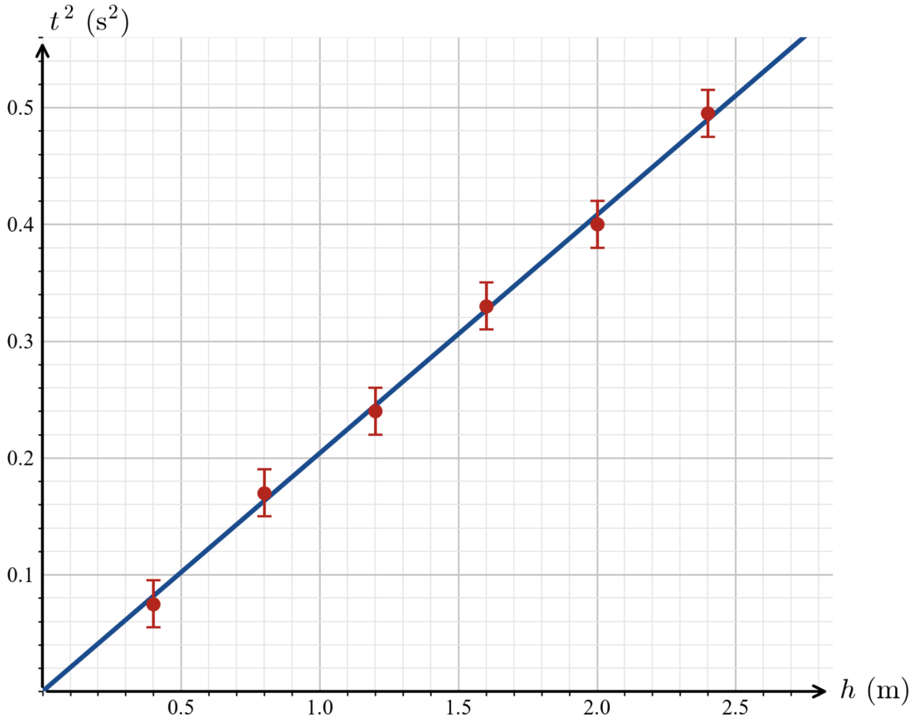
(a) **Independent variable:** the release height h (deliberately set by the student). **Dependent variable:** the fall time t (measured at each height). **Controlled variable (any one):** the sphere used (its mass and diameter) / releasing the sphere from rest each time / the same measuring apparatus and location. **(1 mark each: IV = h; DV = t; one valid controlled variable.)**

(b) A small, dense steel sphere experiences a very small air-resistance force compared with the force due to gravity on it, so its acceleration stays essentially equal to g throughout the fall (genuine free fall) and the data follow $h = 1/2\, g t^2$. A light object such as a table-tennis ball would experience air resistance that is significant compared with the force due to gravity, reducing its acceleration below g and causing the results to deviate from the expected relationship. **(1 mark** dense sphere ⇒ air resistance negligible compared with the force due to gravity, so $a \approx g$; **1 mark** a light object would have significant air resistance, so $a < g$ and the data would deviate.)

(c) Electronic light gates have a much finer time resolution than a hand-operated stopwatch and they start and stop automatically, removing the human reaction-time delay (about $0.2\,\mathrm{s}$) involved in starting and stopping a stopwatch by hand. Each measured fall time is therefore both more accurate and more precise. **(1 mark** finer resolution / automatic timing; **1 mark** removes human reaction-time error, so times are more reliable.)

(d) Repeating the measurement and averaging reduces the effect of random errors on the result, giving a more precise (more reliable) mean value of the fall time at each height. **(1 mark: repeats reduce the effect of random error / improve precision of the mean.)**

(e) A correct plot shows: t^2 (s²) on the vertical axis and h (m) on the horizontal axis, each with a quantity and unit; scales chosen so the points fill most of the grid; the six points plotted correctly; a vertical uncertainty bar of $\pm 0.02\,\mathrm{s}^2$ on each point; and a single straight line of best fit drawn through the scatter and passing close to the origin.



(1 mark axes correct (quantity + unit, correct way round); **1 mark** suitable scales filling the grid; **1 mark** all six points plotted correctly; **1 mark** uncertainty bars drawn; **1 mark** a single straight line of best fit weighing all the points.)

(f) Reading two well-separated points **on the line of best fit** — for example $(0.50\,\mathrm{m}, 0.102\,\mathrm{s}^2)$ and $(2.50\,\mathrm{m}, 0.510\,\mathrm{s}^2)$:

$$\text{gradient} = \frac{\Delta(t^2)}{\Delta h} = \frac{0.510 - 0.102}{2.50 - 0.50} = \frac{0.408}{2.00} = 0.204\,\mathrm{s}^2\,\mathrm{m}^{-1}.$$

(1 mark two well-separated on-line points used (not raw data points); **1 mark** gradient $\approx 0.204\,\mathrm{s}^2\,\mathrm{m}^{-1}$.)

(g) Comparing $t^2 = \frac{2}{g}h$ with a straight line through the origin, the gradient equals $\frac{2}{g}$. Hence

$$g = \frac{2}{\text{gradient}} = \frac{2}{0.204} = 9.8\,\mathrm{m\,s}^{-2}.$$

This agrees well with the accepted value of $9.81\,\mathrm{m\,s}^{-2}$. **(1 mark** gradient $= \frac{2}{g} \Rightarrow g = \frac{2}{\text{gradient}}$; **1 mark** value $\approx 9.8\,\mathrm{m\,s}^{-2}$.)

(h) The gradient is $\frac{2}{g}$. On the Moon g is about one sixth of its value on Earth, so $\frac{2}{g}$ is about **six times larger** — the graph would be about six times steeper (a much larger gradient). This follows because the gradient is inversely proportional to g: a smaller g gives a larger gradient. **(1 mark** gradient increases (about $6\times$); **1 mark** justified because gradient $= \frac{2}{g}$ is inversely proportional to g.)

End of solutions

Practice Exam 2 — Easy

- Reading time: **15 minutes**
- Writing time: **2 hours 30 minutes**
- Section A: 20 questions, 20 marks
- Section B: 19 questions, 100 marks
- Total: 120 marks

Approved materials

- One scientific calculator
- Pre-written notes (one folded A3 sheet or two A4 sheets bound together by tape)

A formula sheet is provided at the end of this examination.

Students are **not** permitted to bring mobile phones and/or any unauthorised electronic devices into the examination room.

Section A — Multiple-choice questions (20 marks)

- Answer **all** questions. Choose the response that is **correct** or that **best answers** the question.
- A correct answer scores 1; an incorrect answer scores 0. Marks will **not** be deducted for incorrect answers.
- No marks will be given if more than one answer is completed for any question.
- Unless otherwise indicated, the diagrams in this book are **not** drawn to scale.
- Where required, take the gravitational field strength at Earth's surface to be $g = 9.81\ \mathrm{N\ kg^{-1}}$.

Question 1

At a fairground, a $30\ \mathrm{kg}$ child rides a carousel horse that moves in a horizontal circle of radius $3.0\ \mathrm{m}$ at a constant speed of $2.4\ \mathrm{m\ s^{-1}}$. Which one of the following is closest to the magnitude of the net force on the child?

A. $24\ \mathrm{N}$

B. $58\ \mathrm{N}$

C. $1.9\ \mathrm{N}$

D. $173\ \mathrm{N}$

Question 2

The same child rides the carousel at constant speed in a horizontal circle. Which one of the following best describes the net force acting on the child?

A. directed outward, away from the centre of the circle

B. directed along the velocity, in the direction of motion

C. directed horizontally toward the centre of the circle

D. zero, because the child moves at constant speed

Question 3

A footballer kicks a ball from ground level at $12\,\mathrm{m\,s^{-1}}$, at 40° above the horizontal. Ignoring air resistance, which one of the following is closest to the maximum height reached by the ball?

A. $3.03\,\mathrm{m}$

B. $6.06\,\mathrm{m}$

C. $4.31\,\mathrm{m}$

D. $7.34\,\mathrm{m}$

Question 4

A roller-coaster car of mass $500\,\mathrm{kg}$ descends a smooth track through a vertical drop of $30\,\mathrm{m}$, starting from rest. Ignoring friction and air resistance, which one of the following is closest to its speed at the bottom of the drop?

A. $17.2\,\mathrm{m\,s^{-1}}$

B. $24.3\,\mathrm{m\,s^{-1}}$

C. $34.3\,\mathrm{m\,s^{-1}}$

D. $12.1\,\mathrm{m\,s^{-1}}$

Question 5

A $200\,\mathrm{kg}$ bumper car moving at $3.0\,\mathrm{m\,s^{-1}}$ strikes a barrier and is brought to rest in $0.40\,\mathrm{s}$. Which one of the following is closest to the magnitude of the average force on the car during the impact?

A. $600\,\mathrm{N}$

B. $240\,\mathrm{N}$

C. $2250\,\mathrm{N}$

D. $1500\,\mathrm{N}$

Question 6

A distant planet has a mass of $6.0 \times 10^{24}\,\mathrm{kg}$ and a radius of $4.0 \times 10^{6}\,\mathrm{m}$. Which one of the following is closest to the gravitational field strength at its surface?

A. $25\,\mathrm{N\,kg^{-1}}$

B. $6.25\,\mathrm{N\,kg^{-1}}$

C. $12.5\,\mathrm{N\,kg^{-1}}$

D. $50\,\mathrm{N\,kg^{-1}}$

Question 7

A satellite travels around a planet in a stable circular orbit of radius $5.0 \times 10^{6}\,\mathrm{m}$ at a constant speed of $4.0 \times 10^{3}\,\mathrm{m\ s^{-1}}$. Which one of the following is closest to the magnitude of the satellite's acceleration?

A. $8.0 \times 10^{-4}\,\mathrm{m\ s^{-2}}$

B. $1.6\,\mathrm{m\ s^{-2}}$

C. $3.2\,\mathrm{m\ s^{-2}}$

D. $1.6 \times 10^{7}\,\mathrm{m\ s^{-2}}$

Question 8

Two parallel metal plates are separated by $0.020\,\mathrm{m}$, with a potential difference of $200\,\mathrm{V}$ between them. Which one of the following is closest to the magnitude of the uniform electric field between the plates?

A. $4.0\,\mathrm{N\ C^{-1}}$

B. $5.0 \times 10^{3}\,\mathrm{N\ C^{-1}}$

C. $2.0 \times 10^{4}\,\mathrm{N\ C^{-1}}$

D. $1.0 \times 10^{4}\,\mathrm{N\ C^{-1}}$

Question 9

An electron travels at $2.0 \times 10^{6}\,\mathrm{m\ s^{-1}}$ at right angles to a uniform magnetic field of strength $0.50\,\mathrm{T}$. Which one of the following is closest to the magnitude of the magnetic force on the electron? Take the magnitude of the electron's charge to be $1.60 \times 10^{-19}\,\mathrm{C}$.

A. $3.2 \times 10^{-13}\,\mathrm{N}$

B. $1.6 \times 10^{-13}\,\mathrm{N}$

C. $8.0 \times 10^{-20}\,\mathrm{N}$

D. $8.0 \times 10^{-14}\,\mathrm{N}$

Question 10

A bar magnet is pushed into a stationary coil of wire connected to a sensitive meter, and an emf is registered. Which one of the following best explains why an emf is induced?

A. The moving magnet changes the magnetic flux through the coil, and by Faraday's law this changing flux induces an emf.

B. The magnet's field exerts a force that pushes the electrons around the coil.

C. The magnet's field is constant, so a steady emf is maintained while it is inside the coil.

D. The coil resists the magnet, and this resistance is itself the source of the emf.

Question 11

An ideal transformer steps a $240\,\text{V}$ supply down to $12\,\text{V}$. The primary coil has 500 turns. Which one of the following is closest to the number of turns on the secondary coil?

A. $10\,000$

B. 500

C. 25

D. 50

Question 12

A transmission line dissipates power P when it carries a current I. Which one of the following is closest to the power dissipated when the same line carries one-third of I?

A. $\dfrac{P}{3}$

B. $\dfrac{P}{9}$

C. $3P$

D. $9P$

Question 13

A sinusoidal alternating supply has a peak voltage of $325\,\text{V}$. Which one of the following is closest to its root-mean-square (rms) voltage?

A. $460\,\text{V}$

B. $163\,\text{V}$

C. $325\,\text{V}$

D. $230\,\text{V}$

Question 14

In a double-slit demonstration, light of wavelength $6.0 \times 10^{-7}\,\text{m}$ passes through two slits $0.20\,\text{mm}$ apart, forming fringes on a screen $2.0\,\text{m}$ away. Which one of the following is closest to the spacing between adjacent bright fringes?

A. $6.0 \times 10^{-3}\,\text{m}$

B. $6.0 \times 10^{-6}\,\text{m}$

C. $3.0 \times 10^{-3}\,\text{m}$

D. $1.2 \times 10^{-2}\,\text{m}$

Question 15

Light of frequency 5.0×10^{14} Hz shines on a surface. Which one of the following is closest to the energy of a single photon of this light? Take Planck's constant to be 6.63×10^{-34} J s.

A. 1.66×10^{-19} J

B. 6.63×10^{-19} J

C. 3.32×10^{-19} J

D. 1.33×10^{-48} J

Question 16

An electron moves at 3.0×10^{6} m s^{-1}. Which one of the following is closest to its de Broglie wavelength? Take $h = 6.63 \times 10^{-34}$ J s and $m_e = 9.11 \times 10^{-31}$ kg.

A. 4.1×10^{9} m

B. 2.4×10^{-10} m

C. 7.3×10^{-4} m

D. 2.4×10^{-12} m

Question 17

A spacecraft moves at $0.60\,c$ relative to an observer on Earth. Which one of the following is closest to the Lorentz factor γ for this speed?

A. 0.80

B. 1.56

C. 1.58

D. 1.25

Question 18

A student notices that a stopwatch reads 0.3 s too high on **every** timing it makes. This is an example of

A. a systematic error.

B. a random error.

C. a mistake that should simply be discarded.

D. poor resolution of the stopwatch.

Question 19

A quantity is measured several times. The repeated readings cluster very close together, but their average lies well away from the accepted value. The measurements are best described as

A. accurate but not precise.

B. both accurate and precise.

C. precise but not accurate.

D. neither accurate nor precise.

Question 20

For a mass moving in a circle of fixed radius r, the net force is $F = \frac{m v^2}{r}$. To obtain a straight-line graph through the origin, a student should plot F against

A. v

B. $\frac{1}{v}$

C. $\sqrt{v}$

D. v^2

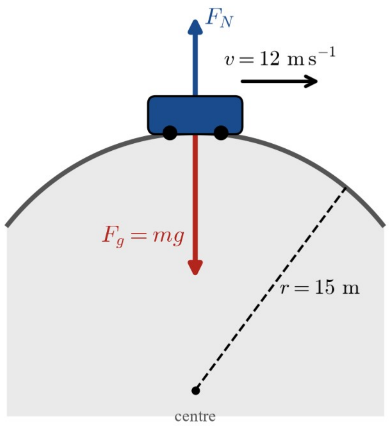
End of Section A

Practice Exam 2 — Section B

- Answer **all** questions in the spaces provided.
- Write your responses in English.
- In questions where more than one mark is available, appropriate working **must** be shown.
- Give each final answer in the unit indicated.
- Unless otherwise indicated, the diagrams in this book are **not** drawn to scale.
- Take the gravitational field strength at Earth's surface to be $g = 9.81\,\mathrm{N\,kg^{-1}}$.

Question 1 (5 marks)

A roller-coaster car of total mass $480\,\mathrm{kg}$ passes over the top of a circular hill of radius $15\,\mathrm{m}$ at a constant speed of $12\,\mathrm{m\,s^{-1}}$.



a. Show that the net force required to keep the car on its circular path at the top of the hill is $4.61 \times 10^3\,\mathrm{N}$. 1 mark

b. At the top of the hill the track pushes up on the car with a normal force. Calculate the magnitude of this normal force. Give your answer in N. 2 marks

c. Explain, with reference to Newton's laws of motion, what would happen to the normal force if the car passed over the top of the hill at a greater speed. 2 marks

Question 2 (5 marks)

At a carnival sideshow, a ball is launched from ground level at $18\,\mathrm{m\,s^{-1}}$, at 35° above the horizontal. Ignore air resistance except in part **d.**

a. Show that the vertical component of the launch velocity is $10.3\,\mathrm{m\,s^{-1}}$. 1 mark

b. Calculate the time the ball is in the air before it returns to its launch height. Give your answer in s. 2 marks

c. Calculate the horizontal range of the ball. Give your answer in m. 1 mark

d. (Circle your answer.) If air resistance were significant, the horizontal range of the ball would be: *greater* / *smaller* / *the same*. Justify your answer. No calculations are required. 1 mark

Question 3 (4 marks)

A drop-tower ride releases a car of mass $320\,\mathrm{kg}$ from rest. The car falls freely through a height of $38\,\mathrm{m}$ before the braking system engages.

a. Show that the gravitational potential energy lost by the car during the fall is $1.19 \times 10^5\,\mathrm{J}$. 1 mark

b. Assuming no energy is dissipated, calculate the speed of the car just before the brakes engage. Give your answer in m s^{-1}. 2 marks

c. In practice the measured speed is slightly less than your answer to part **b.** State, in terms of energy transformation, where this "missing" energy has gone. 1 mark

Question 4 (4 marks)

Two bumper cars move on a level floor. Car A (mass $250\,\text{kg}$, including its driver) moves east at $4.0\,\text{m s}^{-1}$ and collides with a stationary car B (mass $200\,\text{kg}$). After the collision, car A continues east at $1.2\,\text{m s}^{-1}$.

a. Show that car B moves off east at $3.5\,\text{m s}^{-1}$ after the collision. 1 mark

b. The collision lasts $0.25\,\text{s}$. Calculate the magnitude of the average force exerted on car B by car A. Give your answer in N. 2 marks

c. Explain, in terms of impulse, why fitting the cars with softer rubber bumpers (which increase the contact time) would reduce the force on the drivers. 1 mark

Question 5 (3 marks)

A spring-loaded launcher in an arcade game has a spring of stiffness $480\,\text{N m}^{-1}$ that obeys Hooke's law. The spring is compressed by $0.080\,\text{m}$ and used to launch a $0.12\,\text{kg}$ ball horizontally along a frictionless track.

a. Show that the elastic potential energy stored in the compressed spring is $1.54\,\text{J}$. 1 mark

b. Assuming no energy is dissipated, calculate the launch speed of the ball. Give your answer in m s^{-1}. 2 marks

Question 6 (6 marks)

A small satellite orbits Earth in a circular orbit at an altitude of $800\,\text{km}$ above the surface. Take $G = 6.67 \times 10^{-11}\,\text{N m}^2\,\text{kg}^{-2}$, $M_E = 5.97 \times 10^{24}\,\text{kg}$ and $R_E = 6.37 \times 10^{6}\,\text{m}$.

a. Show that the orbital radius is $7.17 \times 10^{6}\,\text{m}$ and that the gravitational field strength at this radius is $7.75\,\text{N kg}^{-1}$. 2 marks

b. Calculate the orbital speed of the satellite. Give your answer in m s^{-1}. 2 marks

c. The satellite moves at constant speed, yet it is accelerating. Explain this, with reference to Newton's laws of motion. 2 marks

Question 7 (5 marks)

Two horizontal parallel plates are separated by $0.050\,\text{m}$, with a potential difference of $200\,\text{V}$ between them. Take the magnitude of the electron's charge to be $1.60 \times 10^{-19}\,\text{C}$ and $m_e = 9.11 \times 10^{-31}\,\text{kg}$.

a. Show that the magnitude of the uniform electric field between the plates is $4.0 \times 10^{3}\,\text{N C}^{-1}$. 1 mark

b. A small sphere carrying a charge of $2.0 \times 10^{-8}\,\text{C}$ is placed between the plates. Calculate the magnitude of the electric force on the sphere. Give your answer in N. 2 marks

c. An electron is released from rest at the negative plate and accelerates toward the positive plate. Calculate the magnitude of the electron's acceleration while it moves between the plates. Give your answer in m s^{-2}. 2 marks

Question 8 (5 marks)

An electron enters a uniform magnetic field of strength $0.25\,\text{T}$ at a speed of $3.0 \times 10^{6}\,\text{m s}^{-1}$, travelling at right angles to the field. Take the magnitude of the electron's charge to be $1.60 \times 10^{-19}\,\text{C}$ and $m_e = 9.11 \times 10^{-31}\,\text{kg}$.

a. Show that the magnitude of the magnetic force on the electron is $1.20 \times 10^{-13}\,\text{N}$. 1 mark

b. Calculate the radius of the circular path followed by the electron. Give your answer in m. 2 marks

c. The electron travels in a circle at constant speed. Explain why the magnetic force does no work on the electron, and state what this means for the electron's speed. 2 marks

Question 9 (5 marks)

A simple direct-current (DC) motor drives a small model ride. It has a single rectangular coil of 40 turns in a uniform magnetic field. Each side of the coil that lies in the field has length $0.060\,\mathrm{m}$, carries a current of $2.5\,\mathrm{A}$, and sits in a field of strength $0.15\,\mathrm{T}$.

a. Calculate the magnitude of the magnetic force on one side of the coil. Give your answer in N. 2 marks

b. Explain how the split-ring commutator allows the coil to keep rotating in the same direction. 2 marks

c. State one change that would increase the turning effect (torque) on the coil. 1 mark

Question 10 (5 marks)

A flat coil of 250 turns has a cross-sectional area of $8.0 \times 10^{-3}\,\mathrm{m}^2$. It sits with its plane perpendicular to a magnetic field produced by a nearby electromagnet. When the electromagnet is switched on, the field through the coil increases steadily from $0.10\,\mathrm{T}$ to $0.40\,\mathrm{T}$ in $0.20\,\mathrm{s}$.

a. Show that the change in magnetic flux through **one** turn of the coil is $2.40 \times 10^{-3}\,\mathrm{Wb}$. 1 mark

b. Calculate the magnitude of the average emf induced in the coil while the field is changing. Give your answer in V. 2 marks

c. Explain, step by step, why an emf is induced in the coil while the electromagnet is switching on. 2 marks

Question 11 (4 marks)

A theme park uses an ideal transformer to step the local supply of $6600\,\mathrm{V}$ down to $240\,\mathrm{V}$ for its lighting. The primary coil has 2750 turns.

a. Show that the secondary coil has 100 turns. 1 mark

b. The lighting draws a current of $15\,\mathrm{A}$ from the secondary coil. Assuming the transformer is ideal, calculate the current in the primary coil. Give your answer in A. 2 marks

c. Explain why this transformer would not operate on a steady direct-current (DC) supply. 1 mark

Question 12 (5 marks)

Power is sent from a substation to a theme park along a transmission line of total resistance $2.0\,\Omega$. The line carries a current of $20\,\mathrm{A}$.

a. Show that the power dissipated as heat in the line is $800\,\mathrm{W}$. 1 mark

b. The voltage at the sending (substation) end of the line is $3300\,\mathrm{V}$. Calculate the voltage delivered to the theme park at the load end of the line. Give your answer in V. 2 marks

c. Explain why transmitting the power at high voltage, rather than low voltage, reduces the energy lost in the line. 2 marks

Question 13 (4 marks)

A simple alternating-current (AC) generator produces a sinusoidal emf with a peak value of $15\,\mathrm{V}$.

a. Explain how the use of slip rings (rather than a split-ring commutator) results in the generator delivering alternating current. 2 marks

b. Calculate the rms voltage of this supply. Give your answer in V. 1 mark

c. State what is meant by the rms voltage of an AC supply. 1 mark

Question 14 (5 marks)

During a laser light show, light of wavelength 6.3×10^{-7} m is shone through a double slit with a slit separation of 0.25 mm. An interference pattern forms on a screen 3.0 m from the slits. Take $c = 3.00 \times 10^{8}$ m s^{-1}.

a. Calculate the frequency of the laser light. Give your answer in Hz. 2 marks

b. Calculate the spacing between adjacent bright fringes on the screen. Give your answer in m. 2 marks

c. The laser is replaced by one that produces light of a shorter wavelength. State and explain what happens to the fringe spacing. 1 mark

Question 15 (5 marks)

Light shines on a clean metal surface whose work function is 2.3 eV. The incident photons each carry an energy of 3.5 eV. Take $h = 4.14 \times 10^{-15}$ eV s.

a. Show that the maximum kinetic energy of the emitted photoelectrons is 1.2 eV. 1 mark

b. Calculate the threshold frequency of this metal. Give your answer in Hz. 2 marks

c. The intensity of the incident light is increased, while its frequency is kept the same. State and explain what happens to (i) the maximum kinetic energy of the photoelectrons, and (ii) the number of photoelectrons emitted per second. 2 marks

Question 16 (4 marks)

An electron is accelerated from rest through a potential difference of 120 V. Take the magnitude of the electron's charge to be 1.60×10^{-19} C, $m_e = 9.11 \times 10^{-31}$ kg and $h = 6.63 \times 10^{-34}$ J s.

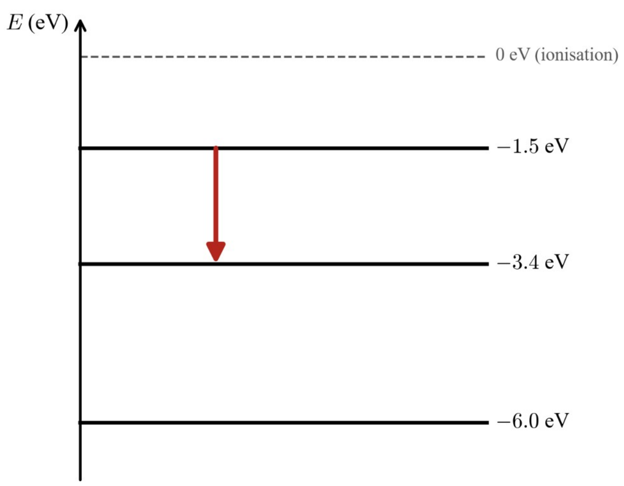
a. Calculate the speed of the electron after it has been accelerated. Give your answer in m s^{-1}. 2 marks

b. Calculate the de Broglie wavelength of the electron. Give your answer in m. 1 mark

c. State the experimental evidence that shows electrons have wave-like properties. 1 mark

Question 17 (4 marks)

An atom has three of its energy levels at -6.0 eV, -3.4 eV and -1.5 eV. The atom makes a transition from the -1.5 eV level to the -3.4 eV level, emitting a single photon. Take $h = 6.63 \times 10^{-34}$ J s, $c = 3.00 \times 10^{8}$ m s^{-1} and 1 eV $= 1.60 \times 10^{-19}$ J.



a. Calculate the energy, in eV, of the emitted photon. 1 mark

b. Calculate the wavelength of the emitted photon. Give your answer in m. 2 marks

c. Explain why this atom can emit photons of only certain specific wavelengths. 1 mark

Question 18 (3 marks)

A spacecraft travels at $0.80\,c$ relative to Earth. The journey between two points takes 6.0 years as measured by clocks on Earth. Ignore any acceleration phases.

a. Show that the Lorentz factor for this speed is 1.67. 1 mark

b. Calculate the time taken for the journey as measured by a clock on the spacecraft. Give your answer in years. 1 mark

c. The departure and the arrival both occur at the location of the spacecraft's own clock. State which clock measures the proper time, and hence which records the shorter time interval. 1 mark

Question 19 (19 marks)

A student investigates the centripetal force required to move an object in a circle, as a model for the forces acting on riders of a spinning "rotor" ride. A rubber stopper of unknown mass slides on a smooth horizontal table, attached by a light string to a pin at the centre so that it moves in a horizontal circle of fixed radius $r=0.90\,\text{m}$. A force sensor in the string measures the tension F (the centripetal force). The student varies the speed v of the stopper and, for each speed, records the tension. The speed is found by timing the revolutions of the stopper.

The relationship being tested is $F=\frac{m}{r}v^2$, so a graph of F against v^2 should be a straight line through the origin.

The student's results are shown below. Each value of F has an uncertainty of $\pm 0.1\,\text{N}$.

v^2 (m² s⁻²)	5	10	15	20	25	30
F (N)	0.31	0.58	0.91	1.19	1.53	1.78

a. Complete a table like the one below by identifying, for this investigation, the independent variable, the dependent variable, and one variable that is controlled (held constant). 3 marks

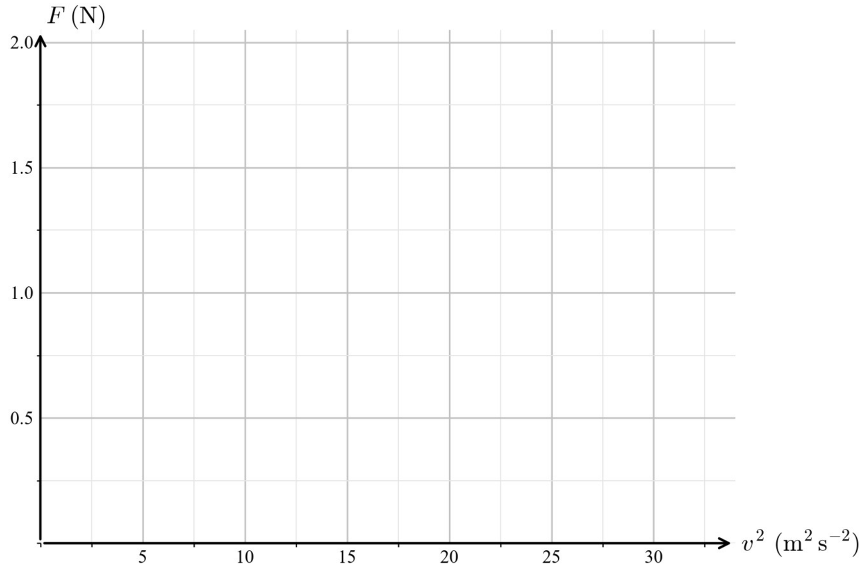
Independent variable	Dependent variable	One controlled variable

b. The stopper slides on a smooth (frictionless) horizontal table. Explain why, in this arrangement, the tension in the string equals the net force on the stopper. 2 marks

c. To find each speed, the student times 10 complete revolutions of the stopper and then calculates $v=\frac{2\pi r}{T}$, where T is the period. Explain why timing 10 revolutions, rather than a single revolution, gives a better value for the speed. 2 marks

d. The student repeats the measurement of F several times at each speed and uses the average. State the purpose of repeating and averaging these measurements. 1 mark

e. On the grid provided, plot F against v^2, including an uncertainty bar for each point, and draw the straight line of best fit. 5 marks



f. Using two well-separated points **on your line of best fit**, determine the gradient of the line. Give your answer in N per $m^2\,s^{-2}$.
2 marks

g. The relationship is $F = \frac{m}{r}v^2$, with $r = 0.90\,\mathrm{m}$. Use your gradient to determine the mass of the stopper. Give your answer in kg.
2 marks

h. Predict how the graph would change if the whole experiment were repeated with the radius doubled to $1.80\,\mathrm{m}$, using the same stopper. Justify your answer.
2 marks

End of Section B

Practice Exam 2 — Formula Sheet

This formula sheet is provided for use with all practice examinations in this booklet. It covers the same items as the official VCE Physics Formula Sheet.

Motion and related energy transformations

velocity	$v=\frac{\Delta s}{\Delta t}$
acceleration	$a=\frac{\Delta v}{\Delta t}$
constant acceleration	$v=u+at$
	$s=ut+\frac{1}{2}at^2$
	$s=vt-\frac{1}{2}at^2$
	$v^2=u^2+2as$
	$s=\frac{1}{2}(u+v)t$
Newton's second law	$\Sigma F=ma$
uniform circular motion	$F_{\text{net}}=\frac{mv^2}{r}$
	$v=\frac{2\pi r}{T}$
Hooke's law	$F=-kx$
elastic potential energy	$E_s=\frac{1}{2}kx^2$
gravitational potential energy	$E_g=mg\Delta h$
kinetic energy	$E_k=\frac{1}{2}mv^2$
universal gravitation	$F_g=\frac{Gm_1m_2}{r^2}$
gravitational field	$g=\frac{GM}{r^2}$
impulse	$F\Delta t=m\Delta v$
momentum	$p=mv$

Einstein's special theory of relativity

Lorentz factor	$\gamma=\frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$
time dilation	$t=\gamma t_0$
length contraction	$L=\frac{L_0}{\gamma}$
rest energy	$E_0=mc^2$
total energy	$E_{\text{total}}=E_k+E_0=\gamma mc^2$

relativistic kinetic energy $E_k = (\gamma - 1) m c^2$

Fields and application of field concepts

uniform electric field $E = \frac{V}{d}$

charge accelerated by a field $\frac{1}{2} m v^2 = q V$

field of a point charge $E = \frac{k Q}{r^2}$

electric force on a charge $F = q E$

Coulomb's law $F = \frac{k q_1 q_2}{r^2}$

magnetic force on a moving charge $F = q v B$

force on a current-carrying conductor $F = n I l B$

radius of a charged particle's path $r = \frac{m v}{q B}$

Generation and transmission of electricity

current $I = \frac{V}{R}$

power $P = V I$

resistors in series $R_T = R_1 + R_2 + \ldots$

resistors in parallel $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$

ideal transformer $\frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{I_2}{I_1}$

rms voltage $V_{\text{RMS}} = \frac{1}{\sqrt{2}} V_{\text{peak}}$

rms current $I_{\text{RMS}} = \frac{1}{\sqrt{2}} I_{\text{peak}}$

electromagnetic induction $\varepsilon = -N \frac{\Delta \Phi_B}{\Delta t}$

magnetic flux $\Phi_B = B_\perp A$

voltage drop along a line $V_{\text{drop}} = I_{\text{line}} R_{\text{line}}$

power loss in a line $P_{\text{loss}} = I_{\text{line}}^2 R_{\text{line}}$

Waves

wave equation $v = f \lambda$

constructive interference path difference $= n \lambda$

destructive interference path difference $= \left(n + \frac{1}{2}\right) \lambda$

fringe spacing $\Delta x = \frac{\lambda L}{d}$ when $L \gg d$

The nature of light and matter

photoelectric effect	$E_{k\,max} = hf - \phi$
photon energy	$E = hf = \frac{hc}{\lambda}$
photon momentum	$p = \frac{h}{\lambda}$
de Broglie wavelength	$\lambda = \frac{h}{p}$

Data

acceleration due to gravity at Earth's surface	$g = 9.81\ \mathrm{m\ s^{-2}}$
mass of the electron	$m_e = 9.11 \times 10^{-31}$ kg
magnitude of the charge of the electron	$q_e = 1.60 \times 10^{-19}$ C
Planck's constant	$h = 6.63 \times 10^{-34}$ J s
	$h = 4.14 \times 10^{-15}$ eV s
speed of light in a vacuum	$c = 3.00 \times 10^{8}\ \mathrm{m\ s^{-1}}$
universal gravitational constant	$G = 6.67 \times 10^{-11}\ \mathrm{N\ m^2\ kg^{-2}}$
mass of Earth	$M_E = 5.97 \times 10^{24}$ kg
radius of Earth	$R_E = 6.37 \times 10^{6}$ m
Coulomb constant	$k = 8.99 \times 10^{9}\ \mathrm{N\ m^2\ C^{-2}}$

Metric (SI) multipliers

pico (p)	10^{-12}	kilo (k)	10^{3}
nano (n)	10^{-9}	mega (M)	10^{6}
micro (μ)	10^{-6}	giga (G)	10^{9}
milli (m)	10^{-3}	tera (T)	10^{12}

Unit conversions

1 tonne (t)	$= 10^{3}$ kg
1 kilowatt hour (kW h)	$= 3.6 \times 10^{6}$ J

Nomenclature

force due to gravity	F_g
force on A by B	$F_{\mathrm{on\ A\ by\ B}}$
normal force	F_N

End of Formula Sheet

Practice Exam 2 — solutions

Section A — answer key

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

Question 1 — B. $F=\frac{mv^2}{r}=\frac{30\times2.4^2}{3.0}=57.6\approx58\,\mathrm{N}$. **A** uses $\frac{mv}{r}$ (speed not squared); **C** omits the mass ($\frac{v^2}{r}$); **D** forgets to divide by r (mv^2).

Question 2 — C. In uniform circular motion the net force is centripetal — directed toward the centre of the circle. **A** invents an outward force; **B** points it along the velocity; **D** confuses constant speed with zero net force.

Question 3 — A. $H=\frac{(u\sin\theta)^2}{2g}=\frac{(12\sin40^\circ)^2}{2\times9.81}=3.03\,\mathrm{m}$. **B** omits the factor 2; **C** uses $\cos$ instead of $\sin$; **D** uses the full launch speed rather than its vertical component.

Question 4 — B. Energy conservation: $1/2\,mv^2=mg\Delta h$, so $v=\sqrt{2g\Delta h}=\sqrt{2\times9.81\times30}=24.3\,\mathrm{m\ s^{-1}}$ (the mass cancels). **A** drops the factor 2; **C** uses $4g\Delta h$; **D** halves $g\Delta h$.

Question 5 — D. $F=\frac{\Delta p}{\Delta t}=\frac{200\times3.0}{0.40}=1500\,\mathrm{N}$. **A** stops at the impulse $\Delta p=600\,\mathrm{N\ s}$; **B** multiplies by Δt instead of dividing; **C** uses $1/2\,mv^2$ (energy) in place of momentum.

Question 6 — A. $g=\frac{GM}{r^2}=\frac{6.67\times10^{-11}\times6.0\times10^{24}}{(4.0\times10^6)^2}=25\,\mathrm{N\ kg^{-1}}$. **B** uses the diameter $2r$ in place of r; **C** inserts a spurious factor $1/2$; **D** doubles the field.

Question 7 — C. $a=\frac{v^2}{r}=\frac{(4.0\times10^3)^2}{5.0\times10^6}=3.2\,\mathrm{m\ s^{-2}}$. **A** uses $\frac{v}{r}$ (speed not squared); **B** inserts a spurious factor $1/2$; **D** forgets to divide by r (v^2).

Question 8 — D. $E=\frac{V}{d}=\frac{200}{0.020}=1.0\times10^4\,\mathrm{N\ C^{-1}}$. **A** multiplies $V\times d$; **B** uses $2d$ (halves the field); **C** uses $d/2$ (doubles the field).

Question 9 — B. $F=qvB=1.60\times10^{-19}\times2.0\times10^6\times0.50=1.6\times10^{-13}\,\mathrm{N}$. **A** omits the field factor $B=0.50$; **C** omits the speed; **D** halves the correct value.

Question 10 — A. The moving magnet makes the flux through the coil change; by Faraday's law, $\varepsilon=-N\frac{\Delta\Phi_B}{\Delta t}$, a changing flux induces an emf. **B** invents a direct force on the electrons; **C** wrongly claims a constant flux; **D** is a Lenz-style tautology that names no changing flux.

Question 11 — C. $N_2 = N_1 \frac{V_2}{V_1} = 500 \times \frac{12}{240} = 25$ turns. **A** inverts the ratio; **B** leaves the turns unchanged; **D** uses the wrong factor.

Question 12 — B. The line loss is $P_{\text{loss}} = I^2 R$, so with R unchanged the loss scales as the square of the current: at $I/3$ the loss is $(1/3)^2 = 1/9$ of P. **A** forgets to square the current; **C** and **D** have the proportion backwards (a smaller current cannot increase the loss).

Question 13 — D. $V_{\text{RMS}} = \frac{V_{\text{peak}}}{\sqrt{2}} = \frac{325}{\sqrt{2}} = 230\,\text{V}$. **A** multiplies by $\sqrt{2}$ ($460\,\text{V}$); **B** divides by 2 ($163\,\text{V}$); **C** leaves the peak value unchanged ($325\,\text{V}$).

Question 14 — A. $\Delta x = \frac{\lambda L}{d} = \frac{6.0 \times 10^{-7} \times 2.0}{0.20 \times 10^{-3}} = 6.0 \times 10^{-3}\,\text{m}$. **B** fails to convert $0.20\,\text{mm}$ to metres; **C** uses $2d$; **D** uses $d/2$.

Question 15 — C. $E = hf = 6.63 \times 10^{-34} \times 5.0 \times 10^{14} = 3.32 \times 10^{-19}\,\text{J}$. **A** halves the value; **B** doubles it; **D** uses $\frac{h}{f}$ (inverted).

Question 16 — B. $\lambda = \frac{h}{m_e v} = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 3.0 \times 10^{6}} = 2.4 \times 10^{-10}\,\text{m}$. **A** inverts to $\frac{m_e v}{h}$; **C** omits the speed; **D** uses c in place of v.

Question 17 — D. $\gamma = \frac{1}{\sqrt{1-(v/c)^2}} = \frac{1}{\sqrt{1-0.60^2}} = \frac{1}{0.80} = 1.25$. **A** is the reciprocal $\sqrt{1-(v/c)^2}$; **B** omits the square root; **C** uses $\sqrt{1-v/c}$ (forgets to square v/c).

Question 18 — A. A fixed offset that shifts **every** reading in the same direction is a systematic error. **B** would scatter readings both ways; **C** a mistake is a one-off blunder, not a repeatable offset; **D** resolution is the smallest readable division, not an offset.

Question 19 — C. Tightly clustered readings are precise; an average far from the accepted value is not accurate — precise but not accurate. **A** reverses the two terms; **B** and **D** are ruled out by the clustering (precise) and the offset (not accurate).

Question 20 — D. Writing $F = \frac{m}{r} v^2$ with m and r constant, F is proportional to v^2, so a plot of F against v^2 is a straight line through the origin (gradient m/r). **A**, **B** and **C** give curves, not a straight line through the origin.

Section B — worked solutions

Question 1 $m = 480\,\text{kg}$, $r = 15\,\text{m}$, $v = 12\,\text{m s}^{-1}$.

(a) The net (centripetal) force needed at the top is

$$F_{\text{net}} = \frac{mv^2}{r} = \frac{480 \times 12^2}{15} = 4608 = 4.61 \times 10^3\,\text{N},$$

as required. **(1 mark: correct substitution giving $4.61 \times 10^3\,\text{N}$.)**

(b) At the top of the hill the centre of the circle is below the car, so the net force points **downward**. The forces on the car are its force due to gravity $F_g = mg$ (down) and the normal force F_N (up):

$$F_g - F_N = \frac{mv^2}{r} \Rightarrow F_N = mg - \frac{mv^2}{r} = 480 \times 9.81 - 4608 = 4708.8 - 4608 = 100.8\,\text{N}.$$

$\therefore$ the track pushes up on the car with a normal force of about $101\,\text{N}$ (i.e. $1.0\times10^2\,\text{N}$). **(1 mark** sets $mg-F_N=\frac{mv^2}{r}$ (net force downward); **1 mark** correct value $\approx 101\,\text{N}$.)

(c) The required centripetal force $\frac{mv^2}{r}$ increases as the speed increases, while the force due to gravity mg is unchanged. From $F_N=mg-\frac{mv^2}{r}$, the normal force therefore **decreases**. By Newton's second law the net downward force must equal $\frac{mv^2}{r}$; once $\frac{mv^2}{r}=mg$ (at $v=\sqrt{gr}$) the normal force falls to zero and the car is on the verge of leaving the track. **(1 mark** required centripetal force rises while mg is fixed, so F_N falls; **1 mark** links this to Newton's second law / the $F_N=0$ condition.)

Question 2 $u=18\,\text{m s}^{-1}$, $\theta=35^\circ$.

(a) $u_y=u\sin\theta=18\sin35^\circ=10.3\,\text{m s}^{-1}$, as required. **(1 mark: correct vertical component.)**

(b) The ball returns to its launch height, so by the symmetry of the flight

$$t=\frac{2u_y}{g}=\frac{2\times10.3}{9.81}=2.10\,\text{s}.$$

(1 mark $t=\frac{2u_y}{g}$; **1 mark** correct value $2.10\,\text{s}$.)

(c) The horizontal component $u_x=18\cos35^\circ=14.7\,\text{m s}^{-1}$ is constant. Carrying the unrounded values of u_x and t through,

$$R=u_x t=14.74\times2.105=31.0\,\text{m}.$$

(1 mark: correct range $31.0\,\text{m}$.)

(d) **Smaller.** Air resistance acts opposite to the ball's velocity throughout the flight, reducing both the horizontal and vertical components of its velocity, so the ball covers less horizontal distance before landing. **(1 mark: circles *smaller* AND justifies via air resistance opposing the motion / reducing the horizontal velocity. The circled option alone scores 0.)**

Question 3 $m=320\,\text{kg}$, $\Delta h=38\,\text{m}$, released from rest.

(a) $E_g=mg\Delta h=320\times9.81\times38=1.19\times10^5\,\text{J}$, as required. **(1 mark: correct value $1.19\times10^5\,\text{J}$.)**

(b) With no dissipation, all the gravitational potential energy becomes kinetic energy: $1/2\,mv^2=mg\Delta h$, so

$$v=\sqrt{2g\Delta h}=\sqrt{2\times9.81\times38}=\sqrt{745.6}=27.3\,\text{m s}^{-1}.$$

(1 mark $1/2\,mv^2=mg\Delta h$ (or $v=\sqrt{2g\Delta h}$); **1 mark** correct value $27.3\,\text{m s}^{-1}$.)

(c) The measured speed is lower because some of the gravitational potential energy is transferred by air resistance (and friction) to **heat and sound** in the surroundings, rather than to kinetic energy of the car. **(1 mark: energy dissipated as heat/sound by air resistance and friction.)**

Question 4 $m_A=250\,\text{kg}$, $u_A=4.0\,\text{m s}^{-1}$ east, $m_B=200\,\text{kg}$, $u_B=0$; after the collision $v_A=1.2\,\text{m s}^{-1}$ east.

(a) Conservation of momentum (taking east as positive):

$$m_A u_A=m_A v_A+m_B v_B\Rightarrow v_B=\frac{m_A(u_A-v_A)}{m_B}=\frac{250\times(4.0-1.2)}{200}=\frac{700}{200}=3.5\,\text{m s}^{-1}\,\text{east},$$

as required. **(1 mark: momentum conservation giving $3.5\,\text{m s}^{-1}$.)**

(b) The impulse on car B equals its change in momentum: $\Delta p_B = m_B v_B = 200 \times 3.5 = 700\,\mathrm{N\ s}$. The average force is

$$F = \frac{\Delta p_B}{\Delta t} = \frac{700}{0.25} = 2800\,\mathrm{N} = 2.8 \times 10^3\,\mathrm{N}.$$

(1 mark $F = \frac{\Delta p_B}{\Delta t}$ with $\Delta p_B = m_B v_B$; **1 mark** correct value $2.8 \times 10^3\,\mathrm{N}$.)

(c) Each driver undergoes a fixed change in momentum during the collision, so the impulse $F\,\Delta t = \Delta p$ is fixed. Increasing the contact time Δt therefore **decreases** the average force F ($F = \Delta p / \Delta t$), so softer bumpers reduce the force on the drivers. **(1 mark: same Δp, so a longer Δt gives a smaller F.)**

Question 5 $k = 480\,\mathrm{N\ m^{-1}}$, $x = 0.080\,\mathrm{m}$, $m = 0.12\,\mathrm{kg}$.

(a) $E_s = 1/2\,k\,x^2 = 1/2 \times 480 \times 0.080^2 = 1/2 \times 480 \times 0.0064 = 1.54\,\mathrm{J}$, as required. **(1 mark: correct value $1.54\,\mathrm{J}$.)**

(b) With no energy dissipated, the stored elastic potential energy becomes kinetic energy: $1/2\,m\,v^2 = E_s$, so

$$v = \sqrt{\frac{2E_s}{m}} = \sqrt{\frac{2 \times 1.536}{0.12}} = \sqrt{25.6} = 5.06\,\mathrm{m\ s^{-1}}.$$

∴ the ball is launched at $5.06\,\mathrm{m\ s^{-1}}$. **(1 mark** $1/2\,m\,v^2 = E_s$; **1 mark** correct value $5.06\,\mathrm{m\ s^{-1}}$.)

Question 6 Altitude = $800\,\mathrm{km} = 0.800 \times 10^6\,\mathrm{m}$.

(a) Orbital radius: $r = R_E + h = 6.37 \times 10^6 + 0.800 \times 10^6 = 7.17 \times 10^6\,\mathrm{m}$. The gravitational field strength there is

$$g' = \frac{G\,M_E}{r^2} = \frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24}}{(7.17 \times 10^6)^2} = 7.75\,\mathrm{N\ kg^{-1}},$$

as required. **(1 mark** $r = R_E + h = 7.17 \times 10^6\,\mathrm{m}$ (altitude added to Earth's radius); **1 mark** $g' = 7.75\,\mathrm{N\ kg^{-1}}$.)

(b) The gravitational force provides the centripetal force, $\frac{m\,v^2}{r} = m\,g'$. Carrying the unrounded value $g' = 7.746\,\mathrm{N\ kg^{-1}}$ through,

$$v = \sqrt{g'\,r} = \sqrt{7.746 \times 7.17 \times 10^6} = \sqrt{5.55 \times 10^7} = 7.45 \times 10^3\,\mathrm{m\ s^{-1}}.$$

(1 mark $\frac{m\,v^2}{r} = m\,g'$ (or $v = \sqrt{G\,M_E / r}$); **1 mark** correct value $7.45 \times 10^3\,\mathrm{m\ s^{-1}}$.)

(c) Although its speed is constant, the satellite's velocity continually changes **direction**, so it is accelerating (a centripetal acceleration, directed toward Earth). By Newton's second law this acceleration requires an unbalanced force; that force is the gravitational attraction of Earth, which is directed toward Earth's centre. **(1 mark** constant speed but changing velocity direction ⇒ centripetal acceleration; **1 mark** the unbalanced gravitational force provides it, by Newton's second law.)

Question 7 $d = 0.050\,\mathrm{m}$, $V = 200\,\mathrm{V}$.

(a) $E = \frac{V}{d} = \frac{200}{0.050} = 4.0 \times 10^3\,\mathrm{N\ C^{-1}}$, as required. **(1 mark: correct value $4.0 \times 10^3\,\mathrm{N\ C^{-1}}$.)**

(b) $F = q\,E = 2.0 \times 10^{-8} \times 4.0 \times 10^3 = 8.0 \times 10^{-5}\,\mathrm{N}$. **(1 mark** $F = q\,E$; **1 mark** correct value $8.0 \times 10^{-5}\,\mathrm{N}$.)

(c) The force on the electron is $F = q\,E = 1.60 \times 10^{-19} \times 4.0 \times 10^3 = 6.40 \times 10^{-16}\,\mathrm{N}$, and by Newton's second law its acceleration is

$$a=\frac{F}{m_e}=\frac{6.40\times10^{-16}}{9.11\times10^{-31}}=7.0\times10^{14}\,\mathrm{m\ s^{-2}}.$$

(1 mark $F=qE$; **1 mark** $a=\dfrac{F}{m_e}$ giving $7.0\times10^{14}\,\mathrm{m\ s^{-2}}$.)

Question 8 $B=0.25\,\mathrm{T}$, $v=3.0\times10^6\,\mathrm{m\ s^{-1}}$, perpendicular entry.

(a) $F=qvB=1.60\times10^{-19}\times3.0\times10^6\times0.25=1.20\times10^{-13}\,\mathrm{N}$, as required. **(1 mark: correct value** $1.20\times10^{-13}\,\mathrm{N}$**.)**

(b) The magnetic force provides the centripetal force, so $qvB=\dfrac{m_e v^2}{r}$ and

$$r=\frac{m_e v}{qB}=\frac{9.11\times10^{-31}\times3.0\times10^6}{1.60\times10^{-19}\times0.25}=\frac{2.73\times10^{-24}}{4.0\times10^{-20}}=6.83\times10^{-5}\,\mathrm{m}.$$

(1 mark $r=\dfrac{m_e v}{qB}$; **1 mark** correct value $6.83\times10^{-5}\,\mathrm{m}$.)

(c) The magnetic force $F=qvB$ is always **perpendicular** to the electron's velocity. Work is force times displacement in the direction of the force, so a force at right angles to the motion does **no work** on the electron. With no work done, the electron's kinetic energy — and hence its **speed** — is unchanged; only the direction of its velocity changes. **(1 mark** force always perpendicular to velocity ⇒ zero work; **1 mark** so the speed (kinetic energy) stays constant.)

Question 9 Single coil, $n=40$ turns, $l=0.060\,\mathrm{m}$, $I=2.5\,\mathrm{A}$, $B=0.15\,\mathrm{T}$.

(a) $F=nIlB=40\times2.5\times0.060\times0.15=0.90\,\mathrm{N}$. **(1 mark** $F=nIlB$; **1 mark** correct value $0.90\,\mathrm{N}$.)

(b) As the coil rotates, the split-ring commutator reverses the direction of the current in the coil every half turn (each time the coil passes through the vertical). This reverses the magnetic force on each side at just the right moment, so the turning effect always acts in the **same rotational direction** and the coil keeps spinning one way (without the commutator the torque would reverse each half turn and the coil would merely oscillate). **(1 mark** commutator reverses the current in the coil every half turn; **1 mark** so the force/torque keeps driving rotation the same way.)

(c) Any one of: increase the current I; use a stronger magnetic field B; use more turns on the coil; or use a coil of larger area. **(1 mark: one valid factor that increases the torque.)**

Question 10 $N=250$, $A=8.0\times10^{-3}\,\mathrm{m}^2$, field $\perp$ to coil plane, B: $0.10\rightarrow0.40\,\mathrm{T}$ in $\Delta t=0.20\,\mathrm{s}$.

(a) With the field perpendicular to the plane of the coil, $\Phi_B=B_\perp A$, so

$$\Delta\Phi_B=\Delta B\times A=(0.40-0.10)\times8.0\times10^{-3}=0.30\times8.0\times10^{-3}=2.40\times10^{-3}\,\mathrm{Wb},$$

as required. **(1 mark: correct value** $2.40\times10^{-3}\,\mathrm{Wb}$**.)**

$$|\varepsilon|=N\frac{\Delta\Phi_B}{\Delta t}=250\times\frac{2.40\times10^{-3}}{0.20}=250\times0.012=3.0\,\mathrm{V}.$$

(1 mark $\varepsilon=N\dfrac{\Delta\Phi_B}{\Delta t}$; **1 mark** correct value $3.0\,\mathrm{V}$.)

(b) As the electromagnet switches on, the current in it rises, so the magnetic field it produces rises. This increases the magnetic flux through the coil ($\Phi_B=B_\perp A$). Because the flux through the coil is **changing**, by Faraday's law $\varepsilon = -N\dfrac{\Delta\Phi_B}{\Delta t}$ an emf is induced in the coil for as long as the flux keeps changing. **(1 mark** rising field $\Rightarrow$ increasing flux through the coil; **1 mark** changing flux $\Rightarrow$ induced emf by Faraday's law.)

Question 11 Ideal transformer, $V_1 = 6600\,\text{V}$, $V_2 = 240\,\text{V}$, $N_1 = 2750$.

(a) $\dfrac{N_1}{N_2} = \dfrac{V_1}{V_2}$, so $N_2 = N_1\dfrac{V_2}{V_1} = 2750 \times \dfrac{240}{6600} = 100$ turns, as required. **(1 mark: correct value 100 turns.)**

(b) For an ideal transformer $\dfrac{I_2}{I_1} = \dfrac{N_1}{N_2}$, so

$$I_1 = I_2\frac{N_2}{N_1} = 15 \times \frac{100}{2750} = 0.545\,\text{A}.$$

(Equivalently, $P = V_2 I_2 = 240 \times 15 = 3600\,\text{W}$, and $I_1 = P / V_1 = 3600 / 6600 = 0.545\,\text{A}$.) **(1 mark** correct turns/current relationship; **1 mark** correct value $0.545\,\text{A}$.)

(c) A transformer works only when the flux linking the two coils is **changing**, so that an emf is induced in the secondary (electromagnetic induction). A steady DC supply produces a constant current and hence a constant flux, so there is no changing flux and no induced emf in the secondary — the transformer does not operate. **(1 mark: DC gives constant flux $\Rightarrow$ no changing flux $\Rightarrow$ no induced emf in the secondary.)**

Question 12 $R_{\text{line}} = 2.0\,\Omega$, $I_{\text{line}} = 20\,\text{A}$.

(a) $P_{\text{loss}} = I_{\text{line}}^2 R_{\text{line}} = 20^2 \times 2.0 = 400 \times 2.0 = 800\,\text{W}$, as required. **(1 mark: correct value $800\,\text{W}$.)**

(b) The voltage dropped across the line is $V_{\text{drop}} = I_{\text{line}} R_{\text{line}} = 20 \times 2.0 = 40\,\text{V}$. The voltage delivered at the load end is

$$V_{\text{load}} = V_{\text{send}} - V_{\text{drop}} = 3300 - 40 = 3260\,\text{V}.$$

(1 mark $V_{\text{drop}} = I_{\text{line}} R_{\text{line}} = 40\,\text{V}$; **1 mark** $V_{\text{load}} = 3260\,\text{V}$.)

(c) For a given power to be delivered, $P = VI$, so transmitting at a higher voltage means a **smaller current** in the line. The power lost is $P_{\text{loss}} = I_{\text{line}}^2 R_{\text{line}}$, which depends on the **square** of the current; a smaller current therefore reduces the line loss substantially. **(1 mark** higher $V \Rightarrow$ smaller I for the same power; **1 mark** $P_{\text{loss}} = I^2 R$ so lower current sharply cuts the loss.)

Question 13 Peak emf $= 15\,\text{V}$.

(a) Slip rings keep each end of the rotating coil permanently connected to the **same** output terminal. As the coil rotates, the emf it generates reverses direction every half turn, and because the connections do not swap, this reversing emf appears directly at the output — an alternating current. (A split-ring commutator would swap the connections every half turn, flipping the output back to one direction to give DC.) **(1 mark** slip rings keep each coil end tied to the same terminal; **1 mark** so the reversing emf passes straight to the output as AC.)

(b) $V_{\text{RMS}} = \dfrac{V_{\text{peak}}}{\sqrt{2}} = \dfrac{15}{\sqrt{2}} = 10.6\,\text{V}$. **(1 mark: correct value $10.6\,\text{V}$.)**

(c) The rms voltage is the steady (DC) voltage that would deliver the same average power to a resistive load as the alternating supply does. **(1 mark: the DC-equivalent voltage that delivers the same average power.)**

Question 14 $\lambda = 6.3 \times 10^{-7}\,\text{m}$, $d = 0.25\,\text{mm} = 0.25 \times 10^{-3}\,\text{m}$, $L = 3.0\,\text{m}$.

(a) $f = \dfrac{c}{\lambda} = \dfrac{3.00 \times 10^8}{6.3 \times 10^{-7}} = 4.76 \times 10^{14}\,\text{Hz}$. **(1 mark** $f = \dfrac{c}{\lambda}$; **1 mark** correct value $4.76 \times 10^{14}\,\text{Hz}$.)

$$\Delta x = \frac{\lambda L}{d} = \frac{6.3 \times 10^{-7} \times 3.0}{0.25 \times 10^{-3}} = \frac{1.89 \times 10^{-6}}{2.5 \times 10^{-4}} = 7.56 \times 10^{-3}\,\mathrm{m}.$$

(1 mark $\Delta x = \frac{\lambda L}{d}$ with d in metres; **1 mark** correct value $7.56 \times 10^{-3}\,\mathrm{m}$.)

(b) Since $\Delta x = \frac{\lambda L}{d}$, the fringe spacing is proportional to the wavelength. A shorter wavelength therefore gives a **smaller** fringe spacing — the bright fringes move closer together. **(1 mark: shorter $\lambda \Rightarrow$ smaller fringe spacing, because $\Delta x \propto \lambda$.)**

Question 15 $\phi = 2.3\,\mathrm{eV}$, photon energy $hf = 3.5\,\mathrm{eV}$.

(a) $E_{k\,\max} = hf - \phi = 3.5 - 2.3 = 1.2\,\mathrm{eV}$, as required. **(1 mark: correct value $1.2\,\mathrm{eV}$.)**

(b) At the threshold frequency the photon energy just equals the work function, $hf_0 = \phi$, so

$$f_0 = \frac{\phi}{h} = \frac{2.3}{4.14 \times 10^{-15}} = 5.56 \times 10^{14}\,\mathrm{Hz}.$$

(1 mark $f_0 = \frac{\phi}{h}$ (with ϕ and h in eV); **1 mark** correct value $5.56 \times 10^{14}\,\mathrm{Hz}$.)

(c)

(i) The maximum kinetic energy is **unchanged**: $E_{k\,\max} = hf - \phi$ depends only on the frequency of the light, not its intensity. (ii) The number of photoelectrons emitted per second **increases**: greater intensity at the same frequency means more photons arriving per second, so more electrons are ejected per second. **(1 mark** $E_{k\,\max}$ unchanged (depends on frequency only); **1 mark** more photoelectrons per second (more photons per second).)

Question 16 Electron accelerated from rest through $V = 120\,\mathrm{V}$.

(a) $1/2\, m_e v^2 = qV$, so

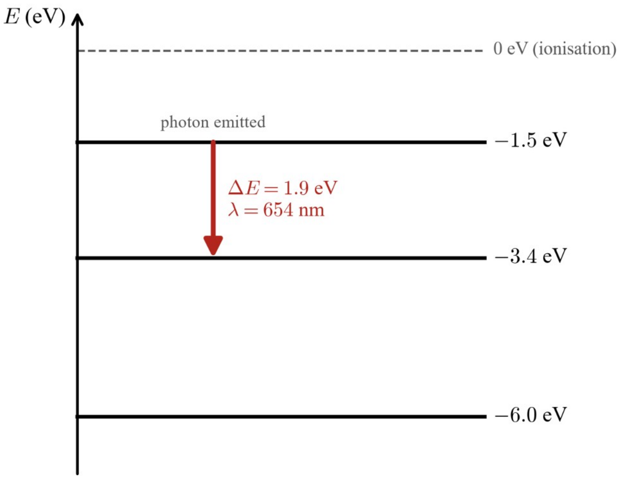
$$v = \sqrt{\frac{2qV}{m_e}} = \sqrt{\frac{2 \times 1.60 \times 10^{-19} \times 120}{9.11 \times 10^{-31}}} = \sqrt{4.22 \times 10^{13}} = 6.49 \times 10^{6}\,\mathrm{m\,s^{-1}}.$$

(1 mark $1/2\, m_e v^2 = qV$; **1 mark** correct value $6.49 \times 10^{6}\,\mathrm{m\,s^{-1}}$.)

(b) $\lambda = \frac{h}{m_e v} = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 6.49 \times 10^{6}} = 1.12 \times 10^{-10}\,\mathrm{m}$. **(1 mark: correct value $1.12 \times 10^{-10}\,\mathrm{m}$.)**

(c) When a beam of electrons is passed through a thin crystal (or a narrow gap of comparable size to the wavelength), it produces a **diffraction / interference pattern** — behaviour characteristic of waves — showing that electrons have wave-like properties. **(1 mark: electron diffraction produces an interference/diffraction pattern.)**

Question 17 Transition from $-1.5\,\mathrm{eV}$ to $-3.4\,\mathrm{eV}$.



(a) The photon energy equals the drop in the atom's energy:

$$\Delta E=(-1.5)-(-3.4)=1.9\,\text{eV}.$$

(1 mark: correct value $1.9\,\text{eV}$**.)**

(b) Converting to joules, $\Delta E=1.9\times1.60\times10^{-19}=3.04\times10^{-19}\,\text{J}$. Then $E=\dfrac{hc}{\lambda}$ gives

$$\lambda=\frac{hc}{\Delta E}=\frac{6.63\times10^{-34}\times3.00\times10^{8}}{3.04\times10^{-19}}=6.54\times10^{-7}\,\text{m}.$$

(1 mark $\lambda=\dfrac{hc}{\Delta E}$ with ΔE in joules; **1 mark** correct value $6.54\times10^{-7}\,\text{m}$.)

(c) The atom's energy levels are **quantised** — only certain discrete energies are allowed. A photon is emitted only when the atom drops between two of these levels, so the photon energy can only equal one of the fixed differences between levels; each such energy corresponds to one specific wavelength ($\lambda=hc/\Delta E$). **(1 mark: discrete/quantised energy levels ⇒ only specific transition energies, hence specific wavelengths.)**

Question 18 $v=0.80\,c$; Earth-measured journey time $=6.0$ years.

(a) $\gamma=\dfrac{1}{\sqrt{1-(v/c)^2}}=\dfrac{1}{\sqrt{1-0.80^2}}=\dfrac{1}{\sqrt{0.36}}=\dfrac{1}{0.60}=1.67$, as required. **(1 mark: correct value** 1.67**.)**

(b) The two events (departure and arrival) occur at the same place in the spacecraft's frame, so the spacecraft clock measures the proper time t_0, and the Earth clock measures the dilated time $t=\gamma t_0$. Hence

$$t_0=\frac{t}{\gamma}=\frac{6.0}{1.667}=3.6\,\text{years}.$$

(1 mark: $t_0=t/\gamma=3.6$ **years.)**

(c) The spacecraft clock measures the **proper time** (the two events happen at the same location in its frame), and it therefore records the **shorter** interval — 3.6 years, compared with 6.0 years on Earth. **(1 mark: spacecraft clock measures proper time and reads the shorter interval.)**

Question 19 $r=0.90\,\text{m}$; the relationship is $F=\dfrac{m}{r}v^2$, so a graph of F against v^2 is a straight line through the origin with gradient $\dfrac{m}{r}$.

(a) A correct table (one variable per cell):

Independent variable	Dependent variable	One controlled variable
the speed v (plotted as v^2)	the centripetal force F (string tension)	the radius r (also: the stopper's mass)

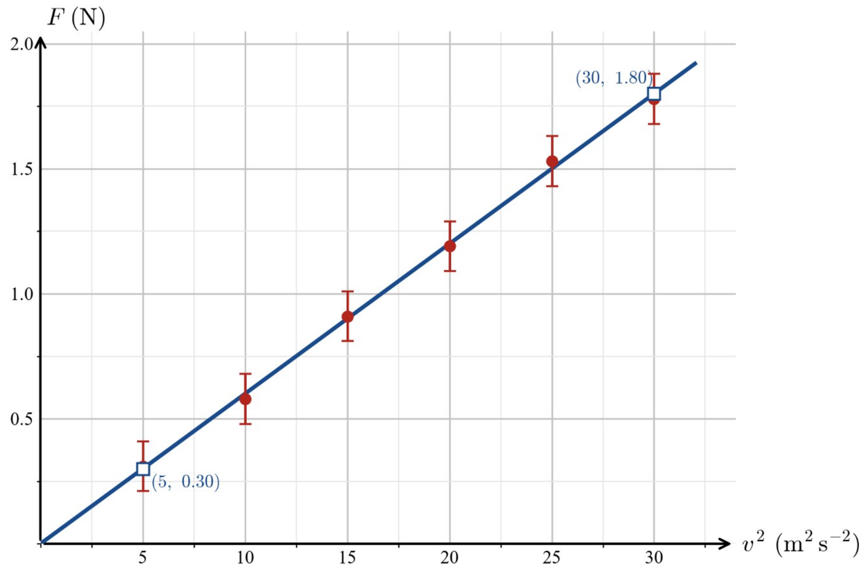
(**1 mark** independent = speed v; **1 mark** dependent = force F; **1 mark** a genuine controlled variable from the stem, e.g. the radius r or the stopper mass. Equipment is not a variable.)

(b) Vertically, the stopper does not accelerate: its force due to gravity F_g is balanced by the normal force from the smooth table. Horizontally, the only force acting on the stopper is the string tension. Since there is no other horizontal force (the table is frictionless), the tension is the single unbalanced force and therefore equals the net (centripetal) force. (**1 mark** vertical forces (F_g and normal force) balance, so no vertical net force; **1 mark** the horizontal tension is then the only unbalanced force = net force.)

(c) The main uncertainty in timing is the experimenter's reaction time, which is roughly the same whether one or ten revolutions are timed. Timing 10 revolutions and dividing by 10 spreads that fixed timing error over ten periods, so its effect on each period T (and hence on v) is about ten times smaller — a more precise value of the speed. (**1 mark** the fixed reaction-time (random) error is spread over 10 periods; **1 mark** so T, and hence v, is measured more precisely.)

(d) Repeating and averaging reduces the effect of **random errors** on the measured force, giving a more reliable (more precise) mean value for each point. **(1 mark: repeats reduce the effect of random error / improve the reliability of the mean.)**

(e) A correct graph:



- axes correctly labelled with the plotted quantities and units, and scales that fill the grid **(1 mark)**;
- all six points plotted correctly **(1 mark)**;
- a vertical uncertainty bar of $\pm 0.1\,\mathrm{N}$ drawn on each point **(1 mark)**;
- a single straight line of best fit drawn, passing through (or very near) the origin, weighing all the points — **not** forced through the first and last points **(1 mark)**;
- the line balances the scatter of the points about it **(1 mark)**.

(f) Reading two well-separated points **on the line of best fit** — for example $(5.0, 0.30)$ and $(30.0, 1.80)$:

$$\text{gradient} = \frac{\Delta F}{\Delta(v^2)} = \frac{1.80 - 0.30}{30.0 - 5.0} = \frac{1.50}{25.0} = 0.060\,\mathrm{N}\ \text{per}\ \mathrm{m^2\,s^{-2}}.$$

(**1 mark** two well-separated on-line points used (not raw data points); **1 mark** gradient ≈ 0.060.)

(g) The gradient equals $\frac{m}{r}$, so

$$m = \text{gradient} \times r = 0.060 \times 0.90 = 0.054 \text{ kg}.$$

∴ the stopper has a mass of about 0.054 kg (54 g). **(1 mark** $m = \text{gradient} \times r$; **1 mark** correct value ≈ 0.054 kg.)

(h) The gradient of the graph is $\frac{m}{r}$. Doubling the radius to 1.80 m (same stopper) **halves** the gradient, to $\frac{0.054}{1.80} = 0.030$ N per m^2s^{-2}. The line would therefore be **less steep** — for a given v^2, a smaller centripetal force is needed at the larger radius. **(1 mark** the gradient $\frac{m}{r}$ halves (line less steep); **1 mark** justified by $F = \frac{m}{r}v^2$ with r doubled.)

Practice Exam 3 — Medium

Physics — Units 3 & 4 — Practice Examination 3

- Reading time: **15 minutes**
- Writing time: **2 hours 30 minutes**
- Section A: 20 questions, 20 marks
- Section B: 19 questions, 100 marks
- Total: 120 marks

Approved materials

- One scientific calculator
- Pre-written notes (one folded A3 sheet or two A4 sheets bound together by tape)

A formula sheet is provided at the end of this examination.

Students are **not** permitted to bring mobile phones and/or any unauthorised electronic devices into the examination room.

Section A — Multiple-choice questions (20 marks)

- Answer **all** questions.
- Choose the response that is **correct** or that **best answers** the question.
- A correct answer scores 1; an incorrect answer scores 0.
- Marks will **not** be deducted for incorrect answers.
- No marks will be given if more than one answer is completed for any question.
- Unless otherwise indicated, the diagrams in this book are **not** drawn to scale.

Where required, take the magnitude of the gravitational field strength at Earth's surface to be $g = 9.81\,\mathrm{N\ kg^{-1}}$.

Question 1

An electric vehicle (EV) of mass $1600\,\mathrm{kg}$ tows a trailer of mass $400\,\mathrm{kg}$ along a straight, level road. A driving (traction) force of $3.0 \times 10^3\,\mathrm{N}$ acts on the EV, and resistance forces are negligible. Which one of the following is closest to the force in the coupling between the EV and the trailer?

A. $6.0 \times 10^2\,\mathrm{N}$

B. $3.0 \times 10^3\,\mathrm{N}$

C. $2.4 \times 10^3\,\mathrm{N}$

D. $1.5\,\mathrm{N}$

Question 2

An EV of mass $1500\,\mathrm{kg}$ rounds a flat, level bend of radius $25\,\mathrm{m}$ at a constant speed of $12\,\mathrm{m\ s^{-1}}$. Which one of the following is closest to the magnitude of the net force on the EV?

A. $7.2 \times 10^2\,\mathrm{N}$

B. $5.76\,\mathrm{N}$

C. $8.64 \times 10^3\,\mathrm{N}$

D. $2.16 \times 10^5\,\mathrm{N}$

Question 3

An EV of mass $1600\,\mathrm{kg}$ travelling at $20\,\mathrm{m\ s^{-1}}$ uses regenerative braking to slow to $8.0\,\mathrm{m\ s^{-1}}$. Which one of the following is closest to the maximum amount of energy that could be recovered during this braking?

A. $3.20 \times 10^{5}\,\mathrm{J}$

B. $2.69 \times 10^{5}\,\mathrm{J}$

C. $1.15 \times 10^{5}\,\mathrm{J}$

D. $5.38 \times 10^{5}\,\mathrm{J}$

Question 4

In a crash test, an EV of mass $1200\,\mathrm{kg}$ strikes a barrier at $15\,\mathrm{m\ s^{-1}}$ and rebounds in the opposite direction at $3.0\,\mathrm{m\ s^{-1}}$. Which one of the following is closest to the magnitude of the impulse delivered to the car by the barrier?

A. $3.6 \times 10^{3}\,\mathrm{N\ s}$

B. $1.44 \times 10^{4}\,\mathrm{N\ s}$

C. $1.8 \times 10^{4}\,\mathrm{N\ s}$

D. $2.16 \times 10^{4}\,\mathrm{N\ s}$

Question 5

A single horizontal force acts on an EV as it moves along a straight road. One graph plots this force against time; a second plots the same force against the car's displacement. Which one of the following is correct?

A. The area under both graphs gives the impulse on the car.

B. The area under the force–time graph gives the impulse; the area under the force–displacement graph gives the work done on the car.

C. The area under the force–time graph gives the work done; the area under the force–displacement graph gives the impulse.

D. The area under both graphs gives the change in kinetic energy of the car.

Question 6

A weather satellite is in a circular orbit at an altitude of $6.00 \times 10^{5}\,\mathrm{m}$ above Earth's surface. Which one of the following is closest to its orbital speed?

A. $7.56 \times 10^{3}\,\mathrm{m\ s^{-1}}$

B. $1.07 \times 10^{4}\,\mathrm{m\ s^{-1}}$

C. $2.58 \times 10^{4}\,\mathrm{m\ s^{-1}}$

D. $5.71 \times 10^{7}\,\mathrm{m\ s^{-1}}$

Question 7

Two parallel plates in an EV battery-testing rig are $5.0\,\text{cm}$ apart, with a potential difference of $200\,\text{V}$ between them. Which one of the following is closest to the magnitude of the uniform electric field between the plates?

A. $40\,\text{N C}^{-1}$

B. $10\,\text{N C}^{-1}$

C. $2.5 \times 10^{-4}\,\text{N C}^{-1}$

D. $4.0 \times 10^{3}\,\text{N C}^{-1}$

Question 8

An electron travelling at $3.0 \times 10^{6}\,\text{m s}^{-1}$ enters a uniform magnetic field of magnitude $0.020\,\text{T}$ at right angles to the field. Which one of the following is closest to the radius of the electron's circular path?

A. $1.71 \times 10^{-5}\,\text{m}$

B. $1.17 \times 10^{3}\,\text{m}$

C. $8.54 \times 10^{-4}\,\text{m}$

D. $9.60 \times 10^{-15}\,\text{m}$

Question 9

An EV traction motor is a simple DC motor with a single coil rotating in a uniform magnetic field. Which one of the following best explains the role of the split-ring commutator?

A. It reverses the direction of the current in the coil every half-turn, so that the torque continues to turn the coil in the same direction.

B. It converts the alternating current in the coil into direct current in the external circuit.

C. It increases the strength of the magnetic field acting on the coil.

D. It maintains a constant, unbroken current in the coil, in the same way as the slip rings of an alternator.

Question 10

A flat coil of 200 turns and area $0.015\,\text{m}^2$ sits in a magnetic field directed perpendicular to the plane of the coil. The field falls uniformly from $0.40\,\text{T}$ to zero in $0.10\,\text{s}$. Which one of the following is closest to the magnitude of the average emf induced in the coil?

A. $0.06\,\text{V}$

B. $1.2\,\text{V}$

C. $12\,\text{V}$

D. $800\,\text{V}$

Question 11

An ideal transformer in an EV charger steps 240 V down to 48 V. The secondary delivers a current of 20 A to the charging circuit. Which one of the following is closest to the current drawn in the primary?

A. $1.0\times10^{2}\text{ A}$

B. 4.0 A

C. 20 A

D. 0.80 A

Question 12

Power is delivered to a charging station along a transmission line of resistance $8.0\,\Omega$ carrying a current of 15 A. Which one of the following is closest to the power dissipated in the transmission line?

A. 225 W

B. 120 W

C. 960 W

D. $1.8\times10^{3}\text{ W}$

Question 13

The AC supply to a household EV charger has a peak voltage of 170 V. Which one of the following is closest to the rms voltage of this supply?

A. 120 V

B. 240 V

C. 85 V

D. 170 V

Question 14

A photodiode sensor in an EV is illuminated by light of wavelength 450 nm. Which one of the following is closest to the energy of one photon of this light?

A. $8.95\times10^{-32}\text{ J}$

B. $1.47\times10^{-27}\text{ J}$

C. $4.42\times10^{-19}\text{ J}$

D. $4.42\times10^{-28}\text{ J}$

Question 15

In a materials-testing beam, electrons travel at $2.0 \times 10^{6}\,\mathrm{m\ s^{-1}}$. Which one of the following is closest to the de Broglie wavelength of these electrons?

A. $2.75 \times 10^{9}\,\mathrm{m}$

B. $3.32 \times 10^{-40}\,\mathrm{m}$

C. $1.21 \times 10^{-57}\,\mathrm{m}$

D. $3.64 \times 10^{-10}\,\mathrm{m}$

Question 16

An atom in a metal-vapour street lamp emits a photon of energy $2.10\,\mathrm{eV}$. Which one of the following is closest to the wavelength of the emitted light?

A. $296\,\mathrm{nm}$

B. $591\,\mathrm{nm}$

C. $1.18 \times 10^{3}\,\mathrm{nm}$

D. $2.61 \times 10^{3}\,\mathrm{nm}$

Question 17

A subatomic particle in an accelerator moves at $0.90\,c$. In the frame of the particle, its lifetime (proper time) is $1.5 \times 10^{-8}\,\mathrm{s}$. Which one of the following is closest to the lifetime of the particle measured in the laboratory frame?

A. $6.54 \times 10^{-9}\,\mathrm{s}$

B. $1.5 \times 10^{-8}\,\mathrm{s}$

C. $7.89 \times 10^{-8}\,\mathrm{s}$

D. $3.44 \times 10^{-8}\,\mathrm{s}$

Question 18

While measuring voltages during an EV charging experiment, a student notices that the voltmeter reads $0.3\,\mathrm{V}$ even when it is disconnected from the circuit. This is an example of

A. a systematic error; repeating the readings will not reduce its effect.

B. a random error; averaging many readings will remove it.

C. a mistake; the affected reading should simply be discarded.

D. a loss of precision; the readings will become more widely scattered.

Question 19

A charging cable has a resistance whose true value is $2.50\,\Omega$. A student's five measurements of this resistance are 2.71, 2.72, 2.70, 2.71 and $2.72\,\Omega$. These measurements are best described as

A. accurate but not precise.

B. precise but not accurate.

C. both accurate and precise.

D. neither accurate nor precise.

Question 20

An EV is braked from various initial speeds v and its braking distance d is measured. For constant deceleration a, the model is $d=\frac{v^2}{2a}$. To obtain a straight-line graph from which a can be found, a student should plot

A. d against v; the gradient equals $\frac{1}{a}$.

B. v against d; the gradient equals $2a$.

C. d against v^2; the gradient equals $\frac{1}{2a}$.

D. d against v^2; the gradient equals $2a$.

End of Section A

Practice Exam 3 — Section B

*Answer **all** questions in the spaces provided. Write your responses in English. In questions where more than one mark is available, appropriate working **must** be shown. Where a final answer requires a particular unit, that unit is stated in the question; give your answer in that unit. Unless otherwise indicated, the diagrams in this book are **not** drawn to scale. Take the magnitude of the gravitational field strength at Earth's surface to be* $g = 9.81\,\mathrm{N\ kg^{-1}}$.

Question 1 (6 marks)

An EV of mass $1800\,\mathrm{kg}$ tows a trailer of mass $600\,\mathrm{kg}$ along a straight, level road. Together they accelerate forward at $0.50\,\mathrm{m\ s^{-2}}$. The total resistance force (friction and air resistance) is $700\,\mathrm{N}$ on the EV and $200\,\mathrm{N}$ on the trailer.

a. Show that the total driving (traction) force on the EV is $2.10 \times 10^3\,\mathrm{N}$. 1 mark

b. Calculate the force in the coupling that connects the EV to the trailer. Give your answer in N. 2 marks

c. The driver then brakes, so that the EV and trailer decelerate on the level road. With reference to Newton's laws of motion, describe how the force in the coupling differs from your answer to part **b.**, and explain why. 3 marks

Question 2 (5 marks)

An EV of mass $1600\,\mathrm{kg}$ is driven around a flat (unbanked) circular test loop of radius $30\,\mathrm{m}$ at constant speed. The maximum sideways friction force the road can provide on the tyres is $9.6 \times 10^3\,\mathrm{N}$.

a. Show that the maximum speed at which the car can stay on the circular path is $13.4\,\mathrm{m\ s^{-1}}$. 1 mark

b. Calculate the time taken to complete one lap of the loop at this maximum speed. Give your answer in s. 2 marks

c. Explain, in terms of the forces acting on the car, why the car cannot maintain this circular path if it travels any faster. 2 marks

Question 3 (5 marks)

As an EV drives over loose gravel, a small stone is flicked up from a tyre. The stone leaves ground level with a speed of $8.0\,\mathrm{m\ s^{-1}}$ at 60° above the horizontal. Ignore air resistance.

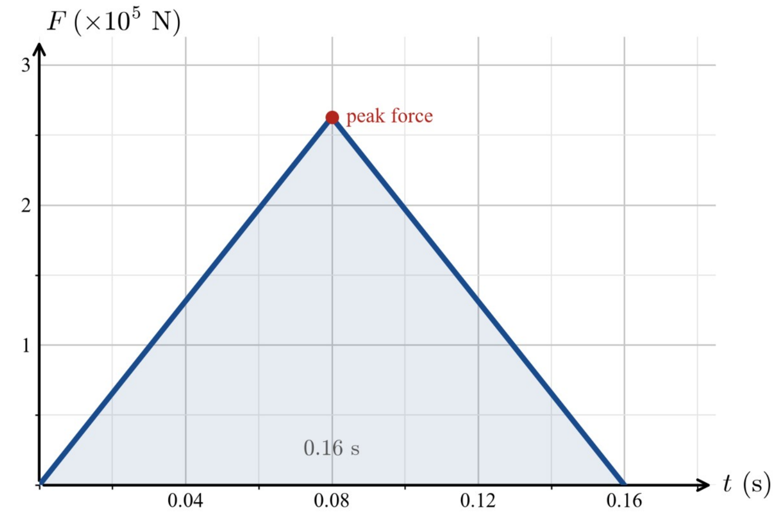
a. Show that the vertical component of the stone's launch velocity is $6.93\,\mathrm{m\ s^{-1}}$. 1 mark

b. Calculate the maximum height the stone reaches above the ground. Give your answer in m. 2 marks

c. Calculate the time the stone takes to return to ground level. Give your answer in s. 2 marks

Question 4 (5 marks)

In a crash test, an EV of mass $1500\,\mathrm{kg}$ travelling at $14\,\mathrm{m\ s^{-1}}$ is brought to rest by a barrier. A sensor records the force exerted on the car by the barrier against time; the force–time graph is triangular and the collision lasts $0.16\,\mathrm{s}$, as shown below.



a. Show that the magnitude of the impulse delivered to the car is 2.10×10^4 N s. 1 mark

b. The area under the force–time graph equals the impulse. Using this, determine the peak force recorded during the collision. Give your answer in N. 2 marks

c. Explain, in terms of impulse, how fitting the EV with a crumple zone that increases the collision time reduces the peak force on the occupants. 2 marks

Question 5 (6 marks)

A navigation satellite that supports vehicle positioning moves in a circular orbit of radius 2.66×10^7 m about the centre of Earth. The mass of the satellite is 900 kg.

a. Show that the orbital speed of the satellite is 3.87×10^3 m s^{-1}. 1 mark

b. Show that the period of the orbit is 4.32×10^4 s. 1 mark

c. Calculate the centripetal acceleration of the satellite. Give your answer in m s^{-2}. 2 marks

d. The satellite moves at constant speed, yet it is accelerating. Explain why, with reference to Newton's second law of motion. 2 marks

Question 6 (5 marks)

A simplified model of an EV traction motor consists of a single rectangular coil of 80 turns, free to rotate in a uniform magnetic field of magnitude 0.45 T. Each side of the coil that lies in the field has length 0.12 m, and the coil carries a current of 15 A.

a. Show that the magnitude of the force on one side of the coil (in the field) is 65 N. 1 mark

b. State **two** changes to the motor that would increase the torque on the coil. 2 marks

c. Explain the role of the split-ring commutator in keeping the coil rotating continuously in one direction. 2 marks

Question 7 (5 marks)

In a device used to analyse the composition of a battery electrode, singly-charged ions of mass 1.15×10^{-26} kg and charge 1.60×10^{-19} C travel at 2.5×10^4 m s^{-1} into a uniform magnetic field of magnitude 0.30 T, directed at right angles to the ion velocity.

a. Show that the magnitude of the magnetic force on one ion is 1.2×10^{-15} N. 1 mark

b. Calculate the radius of the circular path followed by the ion in the field. Give your answer in m. 2 marks

c. A second ion has the same charge and speed but a greater mass. Explain how the radius of its path compares with that of the first ion. 2 marks

Question 8 (5 marks)

A satellite of mass $1200\,\text{kg}$ moves in a circular orbit of radius $1.5 \times 10^{7}\,\text{m}$ from the centre of Earth.

a. Show that the gravitational field strength at this radius is $1.77\,\text{N kg}^{-1}$. 1 mark

b. Calculate the magnitude of the force due to gravity (F_g) acting on the satellite at this radius. Give your answer in N. 2 marks

c. Explain, using the field model, why the gravitational field strength would be smaller if the satellite moved to a higher orbit. 2 marks

Question 9 (5 marks)

An EV is charged wirelessly by placing it over an inductive charging pad. A receiving coil in the car has 150 turns and an area of $0.020\,\text{m}^2$. During operation, the magnetic field passing perpendicularly through the coil changes uniformly from $+0.012\,\text{T}$ to $-0.012\,\text{T}$ in $8.0 \times 10^{-3}\,\text{s}$.

a. Show that the change in magnetic flux through one turn of the coil is $4.8 \times 10^{-4}\,\text{Wb}$. 1 mark

b. Calculate the magnitude of the average emf induced in the receiving coil during this change. Give your answer in V. 2 marks

c. Explain why the charging pad must be supplied with alternating current rather than direct current. Refer to magnetic flux and Faraday's law of induction. 2 marks

Question 10 (4 marks)

A charging station uses an ideal transformer to step $6.6 \times 10^{3}\,\text{V}$ (from the local supply) down to $240\,\text{V}$ for a household-style charger. The primary winding has 2750 turns.

a. Calculate the number of turns on the secondary winding. Give your answer as a whole number. 2 marks

b. The charger draws a current of $32\,\text{A}$ from the secondary. Calculate the current in the primary winding. Give your answer in A. 1 mark

c. Explain why this transformer would not operate if it were connected to a steady DC supply. 1 mark

Question 11 (5 marks)

A remote fast-charging station is supplied through a transmission line of total resistance $4.0\,\Omega$. The substation feeds the line at $5000\,\text{V}$, and the charging station operates at $4600\,\text{V}$.

a. Show that the voltage drop along the transmission line is $400\,\text{V}$. 1 mark

b. Calculate the current in the transmission line. Give your answer in A. 2 marks

c. Calculate the power dissipated in the transmission line. Give your answer in W. 2 marks

Question 12 (4 marks)

A rooftop photovoltaic (PV) array is used to charge an EV. The array delivers $5.0\,\text{kW}$ of DC electrical power at $320\,\text{V}$ to an inverter.

a. Calculate the DC current supplied by the array to the inverter. Give your answer in A. 1 mark

b. Explain why an inverter is needed between the PV array and the household AC charging circuit. 2 marks

c. The output of the inverter is AC with a peak voltage of $340\,\text{V}$. Calculate the rms voltage of the inverter output. Give your answer in V. 1 mark

Question 13 (3 marks)

A laser rangefinder built into an EV uses coherent light of wavelength $650\,\mathrm{nm}$. In a laboratory test, this light passes through two narrow slits separated by $0.25\,\mathrm{mm}$, and an interference pattern is observed on a screen $3.0\,\mathrm{m}$ away.

a. Show that the spacing between adjacent bright fringes on the screen is $7.8 \times 10^{-3}\,\mathrm{m}$. 1 mark

b. State how the fringe spacing would change if a shorter wavelength of light were used instead, and explain why. 2 marks

Question 14 (4 marks)

A photodiode in an EV uses a metal surface with a work function of $2.30\,\mathrm{eV}$. Light of wavelength $414\,\mathrm{nm}$ is shone onto the surface.

a. Show that the energy of each photon of this light is $3.00\,\mathrm{eV}$ (4.80×10^{-19} J). 1 mark

b. Calculate the maximum kinetic energy of the photoelectrons emitted from the surface. Give your answer in eV. 1 mark

c. The intensity of the $414\,\mathrm{nm}$ light is now doubled. State and explain the effect of this change on (i) the maximum kinetic energy of the emitted photoelectrons and (ii) the number of photoelectrons emitted per second. 2 marks

Question 15 (3 marks)

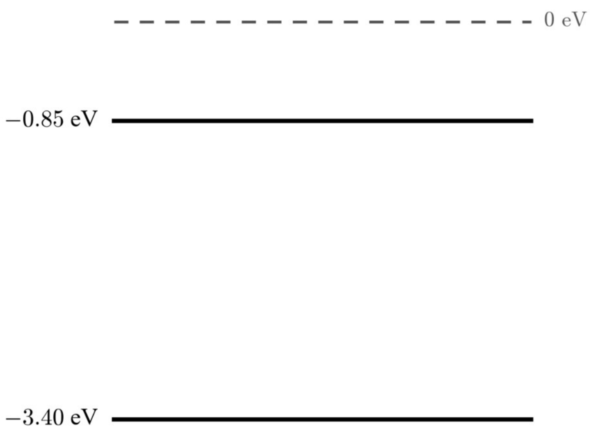
To examine the crystal structure of a battery electrode, a beam of electrons is accelerated to a speed of $4.0 \times 10^{6}\,\mathrm{m\,s^{-1}}$ and directed at a thin sample.

a. Show that the de Broglie wavelength of these electrons is $1.82 \times 10^{-10}\,\mathrm{m}$. 1 mark

b. When the beam passes through the sample, a pattern of rings is observed on a detector. Explain what this diffraction pattern demonstrates about the nature of electrons. 2 marks

Question 16 (4 marks)

An atom in a metal-vapour lamp has electron energy levels including one at $-0.85\,\mathrm{eV}$ and one at $-3.40\,\mathrm{eV}$, as shown in the diagram. The atom emits a photon when an electron moves from the $-0.85\,\mathrm{eV}$ level to the $-3.40\,\mathrm{eV}$ level.



a. Show that the energy of the emitted photon is $2.55\,\mathrm{eV}$. 1 mark

b. Calculate the wavelength of the emitted light. Give your answer in nm. 2 marks

c. On the energy-level diagram, draw an arrow that represents this transition. 1 mark

Question 17 (4 marks)

Muons are created high in Earth's atmosphere and travel toward the ground at $0.97c$. In the muon's own frame of reference, the average lifetime of a muon is $2.2\,\mu s$.

a. Show that the Lorentz factor γ for these muons is 4.11. 1 mark

b. Calculate the average lifetime of these muons as measured by an observer at rest on the ground. Give your answer in μs. 2 marks

c. (Circle your answer.) An observer travelling alongside the muon would measure the muon's average lifetime to be: *less than* / *equal to* / *greater than* $2.2\,\mu s$. Justify your answer. No calculations are required. 1 mark

Question 18 (3 marks)

An electron and a positron, each of rest mass 9.11×10^{-31} kg, are effectively at rest when they meet and annihilate one another.

a. Show that the total rest energy converted into radiation in this annihilation is 1.64×10^{-13} J. 1 mark

b. The energy is released as two identical photons. Calculate the energy of each photon and hence its frequency. Give the frequency in Hz. 2 marks

Question 19 (19 marks)

A team investigates the emergency braking of an EV on a dry proving-ground track. The car is driven at a chosen initial speed v, and at a marked line the driver brakes as hard as possible. The distance d from the marked line to where the car stops (the *braking distance*) is measured. The independent variable is the initial speed v; the dependent variable is the braking distance d.

For a constant braking deceleration a, the braking distance is modelled by $d = \frac{v^2}{2a}$.

The recorded data are shown in the table. Each braking distance has an uncertainty of ± 2 m.

Initial speed v (m s^{-1})	6.0	10.0	14.0	18.0	22.0	26.0
v^2 (m^2 s^{-2})	36	100	196	324	484	676
Braking distance d (m)	4.5	9.2	20.8	31.5	49.7	66.4

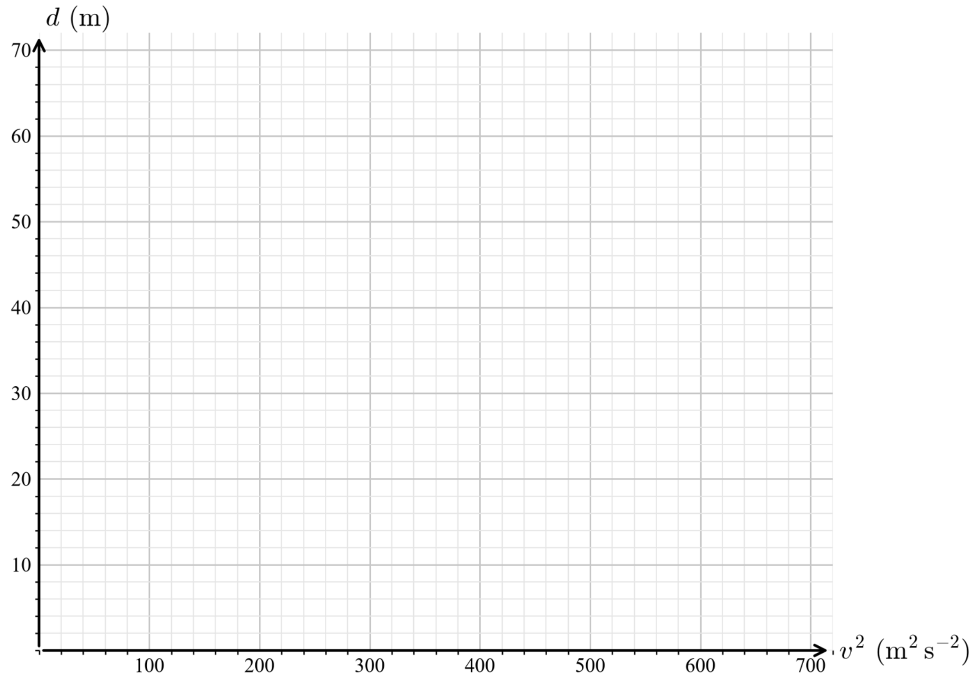
a. State the independent variable, the dependent variable, and **one** variable that should be controlled in this investigation. 3 marks

b. Explain why the braking distance is measured from a marked line at which the brakes are first applied, rather than from the point where the car is first seen to slow. 2 marks

c. The team measures each braking distance with a surveyor's measuring wheel rather than by counting paces. Explain how this improves the quality of the data. 2 marks

d. The measurement at each speed is repeated three times and the results are averaged. State the purpose of repeating the measurements. 1 mark

e. On the grid provided, plot a graph of braking distance d (vertical axis) against v^2 (horizontal axis). Include uncertainty bars of ± 2 m on each point and draw a line of best fit. 5 marks



f. Using two well-separated points on your line of best fit, determine the gradient of the graph. Give your answer in $s^2\,m^{-1}$. 2 marks

g. The car has a mass of $1700\,kg$. Using your gradient and the model $d = \frac{v^2}{2a}$, determine (i) the braking deceleration a and (ii) the braking force. Give the force in N. 2 marks

h. Predict and justify how the braking distance from a given speed would change if the car carried four passengers (increasing its mass) but the braking force stayed the same.

2 marks

End of Section B

Practice Exam 3 — Formula Sheet

This formula sheet is provided for use with all practice examinations in this booklet. It covers the same items as the official VCE Physics Formula Sheet.

Motion and related energy transformations

velocity	$v=\frac{\Delta s}{\Delta t}$
acceleration	$a=\frac{\Delta v}{\Delta t}$
constant acceleration	$v=u+at$
	$s=ut+\frac{1}{2}at^2$
	$s=vt-\frac{1}{2}at^2$
	$v^2=u^2+2as$
	$s=\frac{1}{2}(u+v)t$
Newton's second law	$\Sigma F=ma$
uniform circular motion	$F_{\text{net}}=\frac{mv^2}{r}$
	$v=\frac{2\pi r}{T}$
Hooke's law	$F=-kx$
elastic potential energy	$E_s=\frac{1}{2}kx^2$
gravitational potential energy	$E_g=mg\Delta h$
kinetic energy	$E_k=\frac{1}{2}mv^2$
universal gravitation	$F_g=\frac{Gm_1m_2}{r^2}$
gravitational field	$g=\frac{GM}{r^2}$
impulse	$F\Delta t=m\Delta v$
momentum	$p=mv$

Einstein's special theory of relativity

Lorentz factor	$\gamma=\frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$
time dilation	$t=\gamma t_0$
length contraction	$L=\frac{L_0}{\gamma}$
rest energy	$E_0=mc^2$
total energy	$E_{\text{total}}=E_k+E_0=\gamma mc^2$

relativistic kinetic energy	$E_k = (\gamma - 1) m c^2$

Fields and application of field concepts

uniform electric field	$E = \frac{V}{d}$
charge accelerated by a field	$\frac{1}{2} m v^2 = q V$
field of a point charge	$E = \frac{k Q}{r^2}$
electric force on a charge	$F = q E$
Coulomb's law	$F = \frac{k q_1 q_2}{r^2}$
magnetic force on a moving charge	$F = q v B$
force on a current-carrying conductor	$F = n I l B$
radius of a charged particle's path	$r = \frac{m v}{q B}$

Generation and transmission of electricity

current	$I = \frac{V}{R}$
power	$P = V I$
resistors in series	$R_T = R_1 + R_2 + \ldots$
resistors in parallel	$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$
ideal transformer	$\frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{I_2}{I_1}$
rms voltage	$V_{\text{RMS}} = \frac{1}{\sqrt{2}} V_{\text{peak}}$
rms current	$I_{\text{RMS}} = \frac{1}{\sqrt{2}} I_{\text{peak}}$
electromagnetic induction	$\varepsilon = -N \frac{\Delta \Phi_B}{\Delta t}$
magnetic flux	$\Phi_B = B_{\perp} A$
voltage drop along a line	$V_{\text{drop}} = I_{\text{line}} R_{\text{line}}$
power loss in a line	$P_{\text{loss}} = I_{\text{line}}^2 R_{\text{line}}$

Waves

wave equation	$v = f \lambda$
constructive interference	path difference $= n \lambda$
destructive interference	path difference $= \left(n + \frac{1}{2}\right) \lambda$
fringe spacing	$\Delta x = \frac{\lambda L}{d}$ when $L \gg d$

The nature of light and matter

photoelectric effect	$E_{k\,\max} = hf - \phi$
photon energy	$E = hf = \dfrac{hc}{\lambda}$
photon momentum	$p = \dfrac{h}{\lambda}$
de Broglie wavelength	$\lambda = \dfrac{h}{p}$

Data

acceleration due to gravity at Earth's surface	$g = 9.81$ m s^{-2}
mass of the electron	$m_e = 9.11 \times 10^{-31}$ kg
magnitude of the charge of the electron	$q_e = 1.60 \times 10^{-19}$ C
Planck's constant	$h = 6.63 \times 10^{-34}$ J s
	$h = 4.14 \times 10^{-15}$ eV s
speed of light in a vacuum	$c = 3.00 \times 10^{8}$ m s^{-1}
universal gravitational constant	$G = 6.67 \times 10^{-11}$ N m^{2} kg^{-2}
mass of Earth	$M_E = 5.97 \times 10^{24}$ kg
radius of Earth	$R_E = 6.37 \times 10^{6}$ m
Coulomb constant	$k = 8.99 \times 10^{9}$ N m^{2} C^{-2}

Metric (SI) multipliers

pico (p)	10^{-12}	kilo (k)	10^{3}
nano (n)	10^{-9}	mega (M)	10^{6}
micro (μ)	10^{-6}	giga (G)	10^{9}
milli (m)	10^{-3}	tera (T)	10^{12}

Unit conversions

1 tonne (t)	= 10^{3} kg
1 kilowatt hour (kW h)	= 3.6×10^{6} J

Nomenclature

force due to gravity	F_g
force on A by B	$F_{\text{on A by B}}$
normal force	F_N

End of Formula Sheet

Practice Exam 3 — solutions

Section A — answer key

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

Question 1 — A. Whole system: $a=\frac{3.0\times10^{3}}{1600+400}=1.5\,\mathrm{m\ s^{-2}}$. The coupling accelerates only the trailer, so $F=m_{\text{trailer}}a=400\times1.5=6.0\times10^{2}\,\mathrm{N}$. **B** quotes the whole driving force; **C** uses the EV's mass (1600×1.5); **D** quotes the acceleration as if it were a force.

Question 2 — C. $F_{\text{net}}=\frac{mv^{2}}{r}=\frac{1500\times12^{2}}{25}=8.64\times10^{3}\,\mathrm{N}$, directed toward the centre. **A** fails to square v; **B** omits the mass; **D** omits dividing by r.

Question 3 — B. Energy recoverable $=\Delta E_k=1/2\,m\left(v_i^2-v_f^2\right)=1/2\times1600\times\left(20^2-8.0^2\right)=2.69\times10^{5}\,\mathrm{J}$. **A** uses only the initial kinetic energy $1/2\,mv_i^2$; **C** computes $1/2\,m\left(v_i-v_f\right)^2$; **D** omits the factor $1/2$.

Question 4 — D. The car reverses direction, so $\Delta v=15-(-3.0)=18\,\mathrm{m\ s^{-1}}$ and impulse $=m|\Delta v|=1200\times18=2.16\times10^{4}\,\mathrm{N\ s}$. **C** ignores the rebound (1200×15); **B** subtracts the rebound speed (1200×12); **A** uses the rebound speed alone (1200×3.0).

Question 5 — B. The area under a force–time graph is the impulse ($=\Delta p$); the area under a force–displacement graph is the work done ($=\Delta E_k$). **C** swaps the two — the classic impulse-versus-work trap; **A** and **D** collapse the two areas into a single quantity.

Question 6 — A. Orbital radius $r=R_E+h=6.37\times10^{6}+6.00\times10^{5}=6.97\times10^{6}\,\mathrm{m}$; $v=\sqrt{\frac{GM}{r}}=\sqrt{\frac{6.67\times10^{-11}\times5.97\times10^{24}}{6.97\times10^{6}}}=7.56\times10^{3}\,\mathrm{m\ s^{-1}}$. **C** omits R_E and uses $r=h$ (the #1 orbit error); **B** uses $\sqrt{2GM/r}$; **D** omits the square root.

Question 7 — D. $E=\frac{V}{d}=\frac{200}{0.050}=4.0\times10^{3}\,\mathrm{N\ C^{-1}}$. **A** leaves d in centimetres ($200/5.0$); **B** multiplies $V\times d$; **C** computes d/V.

Question 8 — C. $r=\frac{mv}{qB}=\frac{9.11\times10^{-31}\times3.0\times10^{6}}{1.60\times10^{-19}\times0.020}=8.54\times10^{-4}\,\mathrm{m}$. **A** omits B; **B** inverts the expression (qB/mv); **D** computes the force qvB instead of the radius.

Question 9 — A. The split-ring commutator reverses the current in the coil every half-turn, so the torque always acts to rotate the coil the same way. **B** describes a rectifier/generator idea, not the motor torque; **C** is false — it does not change the field; **D** describes slip rings (which keep the connection unbroken and would let the torque reverse).

Question 10 — C. $\varepsilon = N\dfrac{\Delta\Phi_B}{\Delta t} = \dfrac{N\,A\,\Delta B}{\Delta t} = \dfrac{200\times0.015\times0.40}{0.10} = 12\,\text{V}$. **A** omits N; **B** omits dividing by Δt; **D** omits the area A.

Question 11 — B. For an ideal transformer $\dfrac{I_1}{I_2} = \dfrac{V_2}{V_1}$, so $I_1 = 20\times\dfrac{48}{240} = 4.0\,\text{A}$. **A** inverts the ratio ($20\times240/48$); **C** assumes the current is unchanged; **D** squares the voltage ratio.

Question 12 — D. $P_{\text{loss}} = I_{\text{line}}^2 R_{\text{line}} = 15^2\times8.0 = 1.8\times10^3\,\text{W}$. **B** computes $I\,R$ (the voltage drop, not a power); **C** computes $I\,R^2$; **A** uses I^2 alone, omitting R.

Question 13 — A. $V_{\text{RMS}} = \dfrac{V_{\text{peak}}}{\sqrt{2}} = \dfrac{170}{\sqrt{2}} = 120\,\text{V}$. **B** multiplies by $\sqrt{2}$ instead of dividing (240 V); **C** divides by 2 (85 V); **D** quotes the peak value unchanged (170 V).

Question 14 — C. $E = \dfrac{h\,c}{\lambda} = \dfrac{6.63\times10^{-34}\times3.00\times10^8}{450\times10^{-9}} = 4.42\times10^{-19}\,\text{J}$. **D** fails to convert $450\,\text{nm}$ to metres; **B** computes h/λ (a momentum); **A** computes $h\,c\,\lambda$.

Question 15 — D. $\lambda = \dfrac{h}{m\,v} = \dfrac{6.63\times10^{-34}}{9.11\times10^{-31}\times2.0\times10^6} = 3.64\times10^{-10}\,\text{m}$. **A** inverts the expression ($m\,v/h$); **B** omits the mass (h/v); **C** multiplies the three quantities.

Question 16 — B. $\lambda = \dfrac{h\,c}{E} = \dfrac{4.14\times10^{-15}\times3.00\times10^8}{2.10} = 5.91\times10^{-7}\,\text{m} = 591\,\text{nm}$. **A** uses twice the photon energy; **C** uses half the energy; **D** multiplies $h\,c$ by E instead of dividing.

Question 17 — D. $\gamma = \dfrac{1}{\sqrt{1-0.90^2}} = 2.29$; the laboratory (dilated) lifetime is $t = \gamma\,t_0 = 2.29\times1.5\times10^{-8} = 3.44\times10^{-8}\,\text{s}$. **B** leaves the lifetime unchanged; **A** divides by γ (length-contraction confusion); **C** multiplies by γ^2.

Question 18 — A. A non-zero reading when the meter is disconnected is a constant offset (a zeroing fault) — a systematic error that shifts every reading by the same amount, so averaging repeats will not remove it. **B** describes a random error; **C** wrongly treats a repeatable offset as a one-off mistake; **D** describes scatter (precision), not a fixed offset.

Question 19 — B. The five readings are closely grouped (a spread of only $0.02\,\Omega$, so **precise**) but all sit about $0.21\,\Omega$ above the true $2.50\,\Omega$ (so **not accurate**). **A** reverses the two ideas; **C** ignores the offset from the true value; **D** ignores the tight grouping.

Question 20 — C. Writing $d = \dfrac{1}{2a}v^2$ shows that a graph of d against v^2 is a straight line through the origin with gradient $\dfrac{1}{2a}$. **A** (d vs v) and **B** (v vs d) are curved, not straight; **D** has the correct axes but misreads the gradient as $2a$.

Section B — worked solutions

Question 1 $M = 1800\,\text{kg}$, $m = 600\,\text{kg}$, $a = 0.50\,\text{m s}^{-2}$; resistances $700\,\text{N}$ (EV) and $200\,\text{N}$ (trailer).

(a) For the whole system, $\Sigma F = (M+m)a = 2400\times0.50 = 1200\,\text{N}$. This is the driving force minus the total resistance, so

$$F_{\text{drive}} = (M+m)a + (700+200) = 1200 + 900 = 2.10\times10^3\,\text{N},$$

as required. **(1 mark: system $\Sigma F = m a$ combined with the total resistance.)**

(b) Isolate the trailer: the forward force on it is the coupling force F_c, opposed by its $200\,\text{N}$ resistance, and its net force is $600 \times 0.50 = 300\,\text{N}$:

$$F_c - 200 = 600 \times 0.50 = 300 \Rightarrow F_c = 500\,\text{N}.$$

∴ the coupling pulls the trailer forward with $500\,\text{N}$. **(1 mark** isolates the trailer with $\Sigma F = m a$; **1 mark** correct value $500\,\text{N}$.)

(c) During braking the EV decelerates. By Newton's first law the trailer tends to keep moving forward, so the coupling can no longer pull it forward; instead the coupling force **reverses** and pushes **backward** on the trailer (the coupling is now in compression). By Newton's second law, this backward push together with the trailer's resistance forces supplies the net backward force that decelerates the trailer ($\Sigma F = m a$ with a now backward). By Newton's third law the trailer pushes forward on the EV with an equal and opposite force. **(1 mark** coupling force reverses to a backward push on the trailer; **1 mark** N1 inertia — the trailer tends to continue forward; **1 mark** N2 — a net backward force is now required to decelerate the trailer.)

Question 2 $m = 1600\,\text{kg}$, $r = 30\,\text{m}$, maximum friction $F = 9.6 \times 10^3\,\text{N}$.

(a) The friction supplies the centripetal force, so at the maximum speed $F = \dfrac{m v^2}{r}$:

$$v = \sqrt{\frac{F r}{m}} = \sqrt{\frac{9.6 \times 10^3 \times 30}{1600}} = \sqrt{180} = 13.4\,\text{m s}^{-1},$$

as required. **(1 mark: correct substitution and result.)**

(b) One lap covers the circumference $2\pi r = 2\pi \times 30 = 188.5\,\text{m}$, so

$$T = \frac{2\pi r}{v} = \frac{188.5}{13.42} = 14.0\,\text{s}.$$

(1 mark $T = \dfrac{2\pi r}{v}$; **1 mark** correct value $14.0\,\text{s}$.)

(c) The centripetal force needed, $\dfrac{m v^2}{r}$, increases with v^2. The friction available from the road has a maximum value ($9.6 \times 10^3\,\text{N}$). If the car goes faster than $13.4\,\text{m s}^{-1}$, the required centripetal force exceeds this maximum friction, so the net inward force is too small to hold the car on the circle and it slides outward onto a larger-radius path. **(1 mark** required centripetal force rises with speed; **1 mark** friction is limited to a maximum, so above v_{max} it cannot supply the needed inward force.)

Question 3 $u = 8.0\,\text{m s}^{-1}$, $\theta = 60^\circ$.

(a) $u_y = u \sin\theta = 8.0 \times \sin 60^\circ = 8.0 \times 0.8660 = 6.93\,\text{m s}^{-1}$, as required. **(1 mark: correct vertical component.)**

(b) At the top the vertical velocity is zero, so $v_y^2 = u_y^2 - 2 g H$ gives

$$H = \frac{u_y^2}{2g} = \frac{6.93^2}{2 \times 9.81} = \frac{48.0}{19.62} = 2.45\,\text{m}.$$

(1 mark $H = \dfrac{u_y^2}{2g}$; **1 mark** correct value $2.45\,\text{m}$.)

(c) Returning to the same level, by symmetry (up as positive):

$$t = \frac{2u_y}{g} = \frac{2 \times 6.93}{9.81} = 1.41\,\text{s}.$$

(1 mark $t = \frac{2u_y}{g}$ (or equivalent); **1 mark** correct value $1.41\,\text{s}$.)

Question 4 $m = 1500\,\text{kg}$, initial speed $14\,\text{m s}^{-1}$, brought to rest; collision time $0.16\,\text{s}$.

(a) Impulse = change in momentum $= m\,\Delta v = 1500 \times 14 = 2.10 \times 10^4\,\text{N s}$, as required. **(1 mark: correct impulse.)**

(b) The area under the triangular force–time graph is $1/2 \times (\text{base}) \times (\text{peak force})$, and this equals the impulse:

$$1/2 \times 0.16 \times F_{\text{peak}} = 2.10 \times 10^4 \Rightarrow F_{\text{peak}} = \frac{2.10 \times 10^4}{0.080} = 2.63 \times 10^5\,\text{N}.$$

(1 mark area of triangle = impulse; **1 mark** correct value $2.63 \times 10^5\,\text{N}$.)

(c) In the collision the occupants undergo a fixed change in momentum Δp (from the collision speed to rest), so the impulse $F\,\Delta t = \Delta p$ is fixed. Increasing the collision time Δt (with the crumple zone) therefore decreases the average — and hence the peak — force, since $F = \frac{\Delta p}{\Delta t}$. **(1 mark** same Δp, so $F\,\Delta t = \Delta p$ is fixed; **1 mark** a longer Δt gives a smaller force.)

Question 5 $r = 2.66 \times 10^7\,\text{m}$, $m = 900\,\text{kg}$; $GM = 6.67 \times 10^{-11} \times 5.97 \times 10^{24} = 3.98 \times 10^{14}$.

(a) The gravitational force provides the centripetal force, so $\frac{GMm}{r^2} = \frac{mv^2}{r}$ and

$$v = \sqrt{\frac{GM}{r}} = \sqrt{\frac{3.98 \times 10^{14}}{2.66 \times 10^7}} = 3.87 \times 10^3\,\text{m s}^{-1},$$

as required. **(1 mark: correct substitution and result.)**

(b) $T = \frac{2\pi r}{v} = \frac{2\pi \times 2.66 \times 10^7}{3.87 \times 10^3} = 4.32 \times 10^4\,\text{s}$ (about 12 hours), as required. **(1 mark: correct period.)**

(c) $a = \frac{v^2}{r} = \frac{(3.87 \times 10^3)^2}{2.66 \times 10^7} = 0.563\,\text{m s}^{-2}$, directed toward the centre of Earth. **(1 mark** $a = \frac{v^2}{r}$ (or GM/r^2); **1 mark** correct value $0.563\,\text{m s}^{-2}$.)

(d) Although the speed is constant, the **direction** of the velocity is continually changing, so the velocity is changing and the satellite is accelerating (centripetally, toward Earth). By Newton's second law, a changing velocity requires a net (unbalanced) force; here that net force is the gravitational force on the satellite, directed toward Earth, which provides the centripetal force. **(1 mark** velocity direction changes, so there is a centripetal acceleration; **1 mark** by Newton's second law an unbalanced (gravitational) force is required — cites the **second** law.)

Question 6 $n = 80$ turns, $B = 0.45\,\text{T}$, $l = 0.12\,\text{m}$, $I = 15\,\text{A}$.

(a) $F = nIlB = 80 \times 15 \times 0.12 \times 0.45 = 65\,\text{N}$ (to 2 significant figures), as required. **(1 mark: correct substitution and result.)**

(b) Any **two** of: increase the current I; increase the number of loops n; use a stronger magnetic field B; increase the area of the coil (a longer side l in the field). **(1 mark each for any two valid factors that increase the torque.)**

(c) As the coil rotates, the split-ring commutator reverses the direction of the current through the coil every half-turn, at the moment the plane of the coil is perpendicular to the magnetic field (the position where the torque on the coil is zero). This keeps the force on each side of the coil acting in the sense that continues to turn the coil the same way, so the coil rotates continuously in one direction rather than oscillating back and forth. **(1 mark** the commutator reverses the current in the coil every half-turn; **1 mark** this keeps the torque acting in the same rotational sense, maintaining continuous rotation.)

Question 7 $m=1.15\times10^{-26}$ kg, $q=1.60\times10^{-19}$ C, $v=2.5\times10^{4}$ m s^{-1}, $B=0.30$ T.

(a) $F=qvB=1.60\times10^{-19}\times2.5\times10^{4}\times0.30=1.2\times10^{-15}$ N, as required. **(1 mark: correct substitution and result.)**

(b) The magnetic force provides the centripetal force, so $qvB=\frac{mv^2}{r}$ and

$$r=\frac{mv}{qB}=\frac{1.15\times10^{-26}\times2.5\times10^{4}}{1.60\times10^{-19}\times0.30}=5.99\times10^{-3}\,\text{m}.$$

(**1 mark** $r=\frac{mv}{qB}$; **1 mark** correct value 5.99×10^{-3} m.)

(c) From $r=\frac{mv}{qB}$, with v, q and B unchanged, the radius is proportional to the mass ($r\propto m$). The second ion has a greater mass, so it follows a **larger-radius** path than the first ion. **(1 mark** $r\propto m$ for fixed v, q, B; **1 mark** greater mass gives a larger radius.)

Question 8 $m=1200$ kg, $r=1.5\times10^{7}$ m; $GM=3.98\times10^{14}$.

(a) $g=\frac{GM}{r^2}=\frac{3.98\times10^{14}}{(1.5\times10^{7})^2}=\frac{3.98\times10^{14}}{2.25\times10^{14}}=1.77$ N kg^{-1}, as required. **(1 mark: correct substitution and result.)**

(b) $F_g=mg=1200\times1.77=2.12\times10^{3}$ N (equivalently $F_g=\frac{GMm}{r^2}$), directed toward Earth. **(1 mark** $F_g=mg$ (or GMm/r^2); **1 mark** correct value 2.12×10^{3} N.)

(c) The gravitational field of Earth obeys an inverse-square law, $g=\frac{GM}{r^2}$. At a higher orbit the distance r from Earth's centre is greater, so $g\propto\frac{1}{r^2}$ is smaller; in field-line terms the field lines are further apart (less dense) at a greater distance, representing a weaker field. **(1 mark** cites the inverse-square dependence $g=GM/r^2$; **1 mark** larger r gives a smaller field / field lines less dense.)

Question 9 $N=150$, $A=0.020\,\text{m}^2$, field changes from $+0.012$ T to -0.012 T in $\Delta t=8.0\times10^{-3}$ s.

(a) $\Delta\Phi_B=A\,\Delta B=0.020\times(0.012-(-0.012))=0.020\times0.024=4.8\times10^{-4}$ Wb, as required. **(1 mark: correct change in flux, using the full** 0.024 T **change.)**

(b) $\varepsilon=N\frac{\Delta\Phi_B}{\Delta t}=\frac{150\times4.8\times10^{-4}}{8.0\times10^{-3}}=\frac{0.072}{0.0080}=9.0$ V. **(1 mark** $\varepsilon=N\frac{\Delta\Phi_B}{\Delta t}$; **1 mark** correct value 9.0 V.)

(c) An alternating current produces a magnetic field that is continually changing, so the magnetic flux $\Phi_B=B_\perp A$ through the receiving coil is continually changing. By Faraday's law, $\varepsilon=-N\frac{\Delta\Phi_B}{\Delta t}$, a changing flux induces an emf in the coil. A direct current would give a constant field and therefore a constant flux, so $\frac{\Delta\Phi_B}{\Delta t}=0$ and no emf (and no charging) would be induced. **(1 mark** AC → changing field → changing flux through the coil; **1 mark** by Faraday's law a changing flux induces an emf, whereas constant (DC) flux induces none.)

Question 10 Ideal transformer, $V_1=6.6\times10^{3}$ V, $V_2=240$ V, $N_1=2750$.

(a) $\dfrac{N_1}{N_2}=\dfrac{V_1}{V_2}$, so $N_2=N_1\dfrac{V_2}{V_1}=2750\times\dfrac{240}{6600}=100$ turns. (**1 mark** correct ratio; **1 mark** correct value 100 turns.)

(b) For an ideal transformer $\dfrac{I_1}{I_2}=\dfrac{V_2}{V_1}$, so $I_1=32\times\dfrac{240}{6600}=1.16\,\text{A}$. **(1 mark: correct value** $1.16\,\text{A}$.**)**

(c) A transformer works by electromagnetic induction, which requires a **changing** magnetic flux in the core. A steady DC supply produces a constant flux, so no emf is induced in the secondary and the transformer does not operate. **(1 mark: DC gives constant flux, so no induced emf in the secondary — not merely "because it needs AC".)**

Question 11 $R_{\text{line}}=4.0\,\Omega$; line fed at $5000\,\text{V}$, station at $4600\,\text{V}$.

(a) $V_{\text{drop}}=5000-4600=400\,\text{V}$, as required. **(1 mark: voltage drop is the difference of the two end voltages.)**

(b) $I_{\text{line}}=\dfrac{V_{\text{drop}}}{R_{\text{line}}}=\dfrac{400}{4.0}=100\,\text{A}$. (**1 mark** $I=\dfrac{V_{\text{drop}}}{R_{\text{line}}}$; **1 mark** correct value $100\,\text{A}$.)

(c) $P_{\text{loss}}=I_{\text{line}}^2R_{\text{line}}=100^2\times4.0=4.0\times10^4\,\text{W}$ (equivalently $V_{\text{drop}}\times I_{\text{line}}=400\times100$). (**1 mark** $P_{\text{loss}}=I^2R$ (or $V_{\text{drop}}I$); **1 mark** correct value $4.0\times10^4\,\text{W}$.)

Question 12 PV array: $P=5.0\times10^3\,\text{W}$ DC at $V=320\,\text{V}$.

(a) $I=\dfrac{P}{V}=\dfrac{5.0\times10^3}{320}=15.6\,\text{A}$. **(1 mark: correct value** $15.6\,\text{A}$.**)**

(b) A PV array generates direct current (DC), but the household charging circuit (and the grid) operates on alternating current (AC). The inverter converts the DC output of the array into AC at the required voltage and frequency, so the power can be used by the AC charging circuit or fed to the grid. (**1 mark** PV output is DC while the household/grid circuit is AC; **1 mark** the inverter converts DC to AC so the power is usable.)

(c) $V_{\text{RMS}}=\dfrac{V_{\text{peak}}}{\sqrt{2}}=\dfrac{340}{\sqrt{2}}=240\,\text{V}$. **(1 mark: correct value** $240\,\text{V}$.**)**

Question 13 $\lambda=650\,\text{nm}=650\times10^{-9}\,\text{m}$, $d=0.25\,\text{mm}=0.25\times10^{-3}\,\text{m}$, $L=3.0\,\text{m}$.

(a) $\Delta x=\dfrac{\lambda L}{d}=\dfrac{650\times10^{-9}\times3.0}{0.25\times10^{-3}}=7.8\times10^{-3}\,\text{m}$, as required. **(1 mark: correct substitution — with both λ and d converted to metres.)**

(b) The fringe spacing would **decrease** (the fringes move closer together). From $\Delta x=\dfrac{\lambda L}{d}$, with L and d fixed, $\Delta x\propto\lambda$, so a shorter wavelength gives a smaller fringe spacing. (**1 mark** fringe spacing decreases; **1 mark** justified by $\Delta x\propto\lambda$.)

Question 14 Work function $\phi=2.30\,\text{eV}$, $\lambda=414\,\text{nm}$.

(a) $E=\dfrac{hc}{\lambda}=\dfrac{4.14\times10^{-15}\times3.00\times10^8}{414\times10^{-9}}=3.00\,\text{eV}$. In joules, $E=\dfrac{6.63\times10^{-34}\times3.00\times10^8}{414\times10^{-9}}=4.80\times10^{-19}\,\text{J}$, as required. **(1 mark: correct photon energy in eV (and J).)**

(b) $E_{k\,\text{max}}=hf-\phi=3.00-2.30=0.70\,\text{eV}$. **(1 mark: correct value** $0.70\,\text{eV}$.**)**

(c) (i) The maximum kinetic energy is **unchanged** ($0.70\,\text{eV}$): it depends on the photon energy (frequency) and the work function, not on the intensity. (ii) The number of photoelectrons emitted per second **doubles**: doubling the intensity at the same wavelength doubles the number of photons arriving per second, and (above threshold) each photon can release one electron. (**1 mark** $E_{k\,\text{max}}$ unchanged, because it depends on frequency not intensity; **1 mark** the rate of emission doubles, because the photon arrival rate doubles.)

Question 15 $v = 4.0 \times 10^{6}\,\text{m s}^{-1}$.

(a) $\lambda = \dfrac{h}{mv} = \dfrac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 4.0 \times 10^{6}} = 1.82 \times 10^{-10}\,\text{m}$, as required. **(1 mark: correct substitution and result.)**

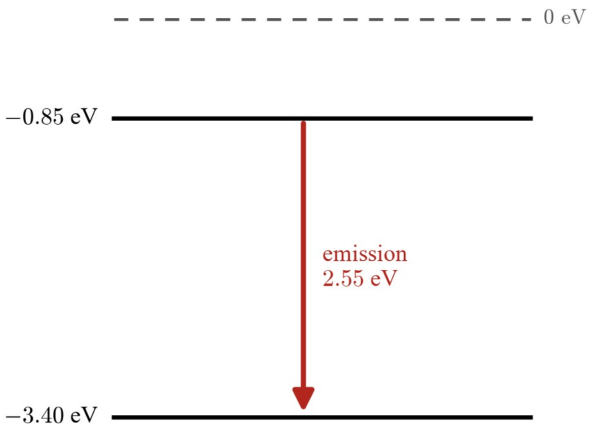
(b) Diffraction (the spreading and forming of a ring interference pattern) is a **wave** property. That a beam of electrons produces a diffraction pattern shows that electrons — normally treated as particles — also behave as waves, i.e. matter has a wave-like nature (with the de Broglie wavelength found in part **a.**). **(1 mark** diffraction is a wave behaviour; **1 mark** electrons showing diffraction demonstrates the wave-like nature of matter.)

Question 16 Transition from the $-0.85\,\text{eV}$ level to the $-3.40\,\text{eV}$ level.

(a) $E_{\text{photon}} = |-0.85 - (-3.40)| = 3.40 - 0.85 = 2.55\,\text{eV}$, as required. **(1 mark: correct energy difference.)**

(b) $\lambda = \dfrac{hc}{E} = \dfrac{4.14 \times 10^{-15} \times 3.00 \times 10^{8}}{2.55} = 4.87 \times 10^{-7}\,\text{m} = 487\,\text{nm}$. **(1 mark** $\lambda = \dfrac{hc}{E}$ (with E in eV and h in eV s); **1 mark** correct value $487\,\text{nm}$.)

(c) The arrow is drawn **downward**, from the $-0.85\,\text{eV}$ level to the $-3.40\,\text{eV}$ level (emission means the electron drops to the lower energy level).



(1 mark: downward arrow from the $-0.85\,\text{eV}$ level to the $-3.40\,\text{eV}$ level.)

Question 17 $v = 0.97\,c$, proper lifetime $t_0 = 2.2\,\mu\text{s}$.

(a) $\gamma = \dfrac{1}{\sqrt{1 - \dfrac{v^2}{c^2}}} = \dfrac{1}{\sqrt{1 - 0.97^2}} = \dfrac{1}{\sqrt{0.0591}} = 4.11$, as required. **(1 mark: correct Lorentz factor.)**

(b) The ground observer measures the dilated lifetime $t = \gamma t_0$, carrying the full-precision $\gamma = 4.113$:

$$t = 4.113 \times 2.2 = 9.05\,\mu\text{s}.$$

(1 mark $t = \gamma t_0$; **1 mark** correct value $9.05\,\mu\text{s}$.)

(c) Equal to $2.2\,\mu\text{s}$. In the frame travelling with the muon, the muon is at rest and its creation and decay occur at the same point in space; the time between them is the proper time, which is $2.2\,\mu\text{s}$. (Only an observer for whom the muon is moving measures a longer, dilated lifetime.) **(1 mark: circles *equal to* AND justifies that this is the proper time measured in the muon's own rest frame. The circled option alone scores 0.)**

Question 18 Electron and positron, each of rest mass $m = 9.11 \times 10^{-31}\,\text{kg}$, at rest.

(a) Total rest energy converted $= 2mc^2 = 2 \times 9.11 \times 10^{-31} \times (3.00 \times 10^8)^2 = 1.64 \times 10^{-13}$ J, as required. **(1 mark: correct total rest energy, using both particles.)**

(b) The two photons are identical, so each carries half the energy:

$$E_{\text{photon}} = \frac{1.64 \times 10^{-13}}{2} = 8.20 \times 10^{-14}\,\text{J}.$$

Then $f = \dfrac{E_{\text{photon}}}{h} = \dfrac{8.20 \times 10^{-14}}{6.63 \times 10^{-34}} = 1.24 \times 10^{20}\,\text{Hz}$. (**1 mark** each photon energy 8.20×10^{-14} J; **1 mark** frequency 1.24×10^{20} Hz.)

Question 19 Braking test: model $d = \dfrac{v^2}{2a}$, so a graph of d against v^2 is a straight line through the origin with gradient $\dfrac{1}{2a}$. Car mass $1700\,\text{kg}$; each d uncertain by $\pm 2\,\text{m}$.

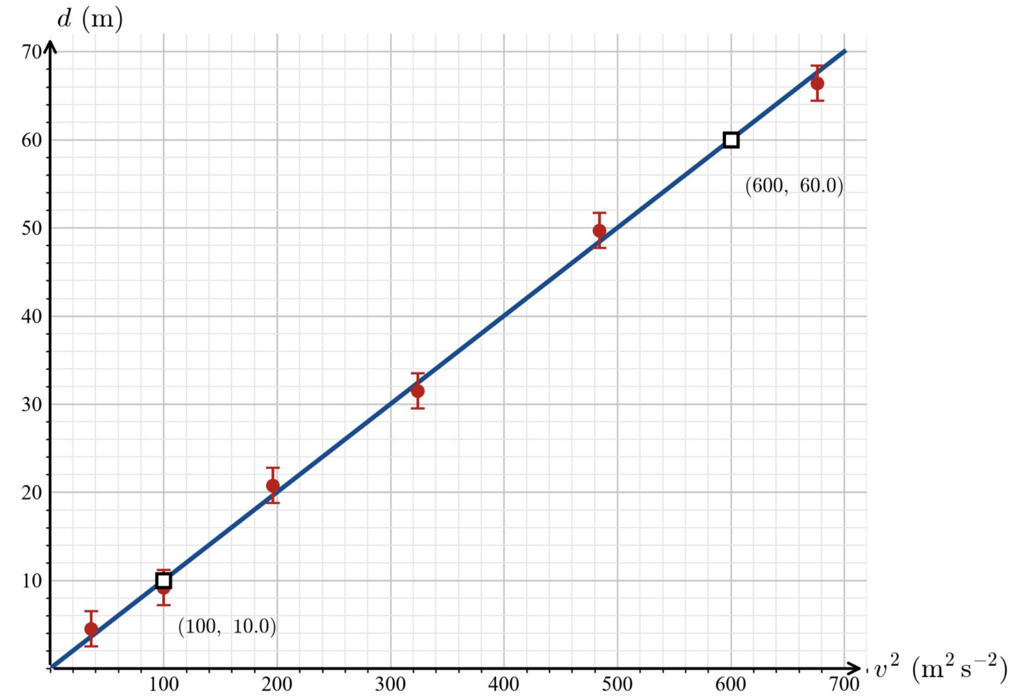
(a) Independent variable: the **initial speed** v (set by the driver). Dependent variable: the **braking distance** d (measured). A controlled variable (any one): the road surface / tyre condition, the load (mass) of the car, the braking system, or the weather (dry track). (**1 mark** IV = initial speed; **1 mark** DV = braking distance; **1 mark** one valid controlled variable, taken from the method.)

(b) Measuring from the marked line where the brakes are first applied ensures the measured distance is the actual braking distance that the model $d = \dfrac{v^2}{2a}$ describes: the start of the measured distance coincides with the start of braking. The point where the car is "first seen to slow" can only be judged by eye, and that judgement is subjective and made slightly late — braking has already begun, and the car has moved on, before an observer notices the slowing. Measuring from there would therefore start the distance too late and systematically underestimate the braking distance, reducing the validity of the investigation. (**1 mark** the marked line matches the start of braking assumed by the model; **1 mark** the "first seen to slow" point is a delayed, subjective judgement, so measuring from it would systematically underestimate the braking distance — the marked line avoids this, improving validity.)

(c) A surveyor's measuring wheel has a much finer resolution (and reads directly in metres) than counting paces, whose length varies. It therefore gives readings with a smaller uncertainty and better repeatability, improving the precision of the measured braking distances. (**1 mark** the wheel has finer resolution / smaller uncertainty than paces; **1 mark** so the data are more precise / repeatable.)

(d) Repeating each measurement and averaging reduces the effect of random errors on the result, giving a more reliable (precise) mean braking distance at each speed. **(1 mark: repeats reduce the effect of random errors / improve precision of the mean.)**

(e) The completed graph is shown below: d on the vertical axis, v^2 on the horizontal axis; each point carries a $\pm 2\,\text{m}$ uncertainty bar; a straight line of best fit is drawn through the origin, balancing the scatter of the points.



(**1 mark** correct axes (d vs v^2) with sensible scales filling the grid; **1 mark** all six points plotted correctly; **1 mark** uncertainty bars of $\pm 2\,\mathrm{m}$ drawn; **1 mark** a single straight line of best fit; **1 mark** the line balances the points and passes near the origin.)

(f) Using two well-separated points **on the line of best fit** — for example $(100, 10.0)$ and $(600, 60.0)$:

$$\text{gradient} = \frac{\Delta d}{\Delta(v^2)} = \frac{60.0 - 10.0}{600 - 100} = \frac{50.0}{500} = 0.100\,\mathrm{s^2\,m^{-1}}.$$

(**1 mark** two well-separated on-line points used (not raw data points); **1 mark** correct gradient $0.100\,\mathrm{s^2\,m^{-1}}$.)

(g) Comparing $d = \frac{1}{2a}v^2$ with a straight line through the origin, the gradient equals $\frac{1}{2a}$. Hence

$$a = \frac{1}{2 \times \text{gradient}} = \frac{1}{2 \times 0.100} = 5.0\,\mathrm{m\,s^{-2}},\ F = ma = 1700 \times 5.0 = 8.5 \times 10^3\,\mathrm{N}.$$

∴ the braking deceleration is $5.0\,\mathrm{m\,s^{-2}}$ and the braking force is $8.5 \times 10^3\,\mathrm{N}$. (**1 mark** gradient $= \frac{1}{2a} \Rightarrow a = 5.0\,\mathrm{m\,s^{-2}}$; **1 mark** $F = ma = 8.5 \times 10^3\,\mathrm{N}$.)

(h) The braking distance would **increase**. With the same braking force but a greater mass, the deceleration $a = \frac{F}{m}$ is smaller. Since $d = \frac{v^2}{2a}$, a smaller a gives a larger braking distance for the same initial speed. (**1 mark** predicts a longer braking distance; **1 mark** justified via $a = F/m$ smaller, so $d = \frac{v^2}{2a}$ larger.)

End of solutions

Practice Exam 4 — Medium

Physics — Units 3 & 4 — Practice Examination 4

- Reading time: **15 minutes**
- Writing time: **2 hours 30 minutes**
- Section A: 20 questions, 20 marks
- Section B: 19 questions, 100 marks
- Total: 120 marks

Approved materials

- One scientific calculator
- Pre-written notes (one folded A3 sheet or two A4 sheets bound together by tape)

A formula sheet is provided at the end of this examination.

Students are **not** permitted to bring mobile phones and/or any unauthorised electronic devices into the examination room.

Section A — Multiple-choice questions (20 marks)

- Answer **all** questions.
- Choose the response that is **correct** or that **best answers** the question.
- A correct answer scores 1; an incorrect answer scores 0.
- Marks will **not** be deducted for incorrect answers.
- No marks will be given if more than one answer is completed for any question.
- Unless otherwise indicated, the diagrams in this book are **not** drawn to scale.

Where required, take the magnitude of the gravitational field strength at Earth's surface to be $g = 9.81\,\text{N kg}^{-1}$.

Question 1

A cargo capsule of mass $8.0 \times 10^{3}\,\text{kg}$ moving at $6.0\,\text{m s}^{-1}$ docks with, and locks onto, a stationary station module of mass $1.2 \times 10^{4}\,\text{kg}$. The two then move off together. Which one of the following is closest to their common speed immediately after docking?

A. $2.4\,\text{m s}^{-1}$

B. $3.0\,\text{m s}^{-1}$

C. $4.0\,\text{m s}^{-1}$

D. $6.0\,\text{m s}^{-1}$

Question 2

A space tug of mass $2.5 \times 10^{3}\,\text{kg}$ is joined by a rigid coupling to a disabled satellite of mass $1.5 \times 10^{3}\,\text{kg}$. In deep space the tug's thruster exerts a steady force of $8.0 \times 10^{2}\,\text{N}$ along the line joining them; ignore all other forces. Which one of the following is closest to the force in the coupling?

A. $8.0 \times 10^{2}\,\text{N}$

B. $5.0 \times 10^{2}\,\text{N}$

C. $3.0 \times 10^{2}\,\text{N}$

D. $0.20\,\text{N}$

Question 3

A cylindrical space station spins to give its crew artificial gravity. A point on the inner rim is at radius $45\,\mathrm{m}$ and moves at $18\,\mathrm{m\ s^{-1}}$. Which one of the following is closest to the centripetal acceleration of an astronaut standing on the rim?

A. $0.40\,\mathrm{m\ s^{-2}}$

B. $7.2\,\mathrm{m\ s^{-2}}$

C. $3.6\,\mathrm{m\ s^{-2}}$

D. $3.24 \times 10^{2}\,\mathrm{m\ s^{-2}}$

Question 4

During a deep-space burn, an $800\,\mathrm{kg}$ probe speeds up in a straight line from $2.0 \times 10^{3}\,\mathrm{m\ s^{-1}}$ to $3.0 \times 10^{3}\,\mathrm{m\ s^{-1}}$. Which one of the following is closest to the work done on the probe by its thruster?

A. $4.0 \times 10^{8}\,\mathrm{J}$

B. $4.0 \times 10^{9}\,\mathrm{J}$

C. $3.6 \times 10^{9}\,\mathrm{J}$

D. $2.0 \times 10^{9}\,\mathrm{J}$

Question 5

A single thruster force acts on a probe moving in a straight line in deep space. In one graph this force is plotted against time; in a second graph the same force is plotted against the probe's displacement. Which one of the following is correct?

A. The area under the force–time graph gives the impulse on the probe; the area under the force–displacement graph gives the work done on the probe.

B. The area under the force–time graph gives the work done on the probe; the area under the force–displacement graph gives the impulse on the probe.

C. The area under both graphs gives the impulse on the probe.

D. The area under both graphs gives the change in kinetic energy of the probe.

Question 6

A probe is located $1.0 \times 10^{7}\,\mathrm{m}$ from the centre of Earth. Which one of the following is closest to the magnitude of Earth's gravitational field strength at this point?

A. $3.98 \times 10^{7}\,\mathrm{N\ kg^{-1}}$

B. $6.31 \times 10^{3}\,\mathrm{N\ kg^{-1}}$

C. $7.96\,\mathrm{N\ kg^{-1}}$

D. $3.98\,\mathrm{N\ kg^{-1}}$

Question 7

A small charged probe carries a point charge of $+4.0 \times 10^{-9}$ C. Which one of the following is closest to the magnitude of the electric field it produces at a point 0.20 m away?

A. 1.0×10^{-7} N C^{-1}

B. 1.80×10^{2} N C^{-1}

C. 8.99×10^{2} N C^{-1}

D. 2.25×10^{2} N C^{-1}

Question 8

In a cosmic-ray detector, a proton (mass 1.67×10^{-27} kg, charge 1.60×10^{-19} C) moves at 5.0×10^{5} m s^{-1} perpendicular to a uniform magnetic field of magnitude 0.30 T. Which one of the following is closest to the radius of its circular path?

A. 5.22×10^{-3} m

B. 1.74×10^{-2} m

C. 57.5 m

D. 2.40×10^{-14} m

Question 9

A charged particle moves through a uniform magnetic field, following a curved path. Which one of the following best describes the magnetic force on the particle?

A. It acts at right angles to the particle’s velocity, so it changes the direction of the velocity but not the particle’s speed.

B. It acts in the same direction as the velocity, so it increases the particle’s speed.

C. It acts in the same direction as the magnetic field.

D. It does work on the particle, steadily increasing its kinetic energy.

Question 10

A flat coil of 500 turns and area 8.0×10^{-3} m^{2} lies with its plane perpendicular to a magnetic field. The field falls uniformly from 0.60 T to 0.20 T in 0.020 s. Which one of the following is closest to the magnitude of the average emf induced in the coil?

A. 0.16 V

B. 1.6 V

C. 80 V

D. 1.0×10^{4} V

Question 11

An ideal transformer at a ground station steps $240\ \text{V}$ up to $3.6 \times 10^{3}\ \text{V}$ to drive a transmitter. The primary winding carries a current of $30\ \text{A}$. Which one of the following is closest to the current in the secondary winding?

A. $4.5 \times 10^{2}\ \text{A}$

B. $30\ \text{A}$

C. $0.13\ \text{A}$

D. $2.0\ \text{A}$

Question 12

A transmission line supplying a tracking station has a total resistance of $6.0\ \Omega$ and carries a current of $25\ \text{A}$. Which one of the following is closest to the power dissipated in the line?

A. $3.75 \times 10^{3}\ \text{W}$

B. $6.25 \times 10^{2}\ \text{W}$

C. $9.0 \times 10^{2}\ \text{W}$

D. $1.5 \times 10^{2}\ \text{W}$

Question 13

The alternating-voltage supply at a launch facility has a peak voltage of $330\ \text{V}$. Which one of the following is closest to the rms value of this voltage?

A. $4.67 \times 10^{2}\ \text{V}$

B. $2.33 \times 10^{2}\ \text{V}$

C. $1.65 \times 10^{2}\ \text{V}$

D. $3.30 \times 10^{2}\ \text{V}$

Question 14

A laser rangefinder on a Mars rover emits infrared light of wavelength $1.06 \times 10^{-6}\ \text{m}$. Which one of the following is closest to the energy of a single photon of this light?

A. $2.11 \times 10^{-31}\ \text{J}$

B. $6.25 \times 10^{-28}\ \text{J}$

C. $1.88 \times 10^{-19}\ \text{J}$

D. $1.88 \times 10^{-25}\ \text{J}$

Question 15

In an electron microscope used to inspect a heat-shield sample, electrons travel at $7.0 \times 10^6\,\mathrm{m\ s^{-1}}$. Which one of the following is closest to the de Broglie wavelength of these electrons?

A. $9.62 \times 10^{9}\,\mathrm{m}$

B. $9.47 \times 10^{-41}\,\mathrm{m}$

C. $4.23 \times 10^{-57}\,\mathrm{m}$

D. $1.04 \times 10^{-10}\,\mathrm{m}$

Question 16

An atom in a spacecraft's calibration lamp emits a photon of energy $2.48\,\mathrm{eV}$. Which one of the following is closest to the wavelength of the emitted light?

A. $2.50 \times 10^{2}\,\mathrm{nm}$

B. $5.01 \times 10^{2}\,\mathrm{nm}$

C. $1.00 \times 10^{3}\,\mathrm{nm}$

D. $3.08 \times 10^{3}\,\mathrm{nm}$

Question 17

An uncrewed probe travels at $0.80\,c$ relative to Earth. Its onboard clock records the journey as lasting 5.0 years. Which one of the following is closest to the duration of the journey as measured by observers on Earth?

A. 8.33 years

B. 13.9 years

C. 5.0 years

D. 3.0 years

Question 18

While calibrating a spacecraft's angle sensor, a technician finds that it reads 0.5° even when it is aligned so that it should read 0°. Every subsequent reading is therefore 0.5° too high. This is best described as

A. a random error; averaging many readings will remove it.

B. a mistake; the affected readings should simply be discarded.

C. a loss of precision; the readings will become more widely scattered.

D. a systematic error; repeating and averaging the readings will not reduce its effect.

Question 19

A timing circuit is used to measure a known interval of exactly $100.0\,\mathrm{ms}$. Four measurements give 96.1, 96.3, 96.2 and $96.2\,\mathrm{ms}$. These measurements are best described as

A. accurate but not precise.

B. both accurate and precise.

C. precise but not accurate.

D. neither accurate nor precise.

Question 20

For a set of moons orbiting a planet, the orbital period T and orbital radius r are related by $T^2=\frac{4\pi^2}{GM}r^3$, where M is the mass of the planet. To obtain a straight-line graph through the origin from which M can be found, a student should plot

A. T against r; the gradient equals $\frac{4\pi^2}{GM}$.

B. T^2 against r^3; the gradient equals $\frac{4\pi^2}{GM}$.

C. T^2 against r; the gradient equals $\frac{4\pi^2}{GM}$.

D. T^2 against r^3; the gradient equals $\frac{GM}{4\pi^2}$.

End of Section A

Practice Exam 4 — Section B

*Answer **all** questions in the spaces provided. Write your responses in English. In questions where more than one mark is available, appropriate working **must** be shown. Where a final answer requires a particular unit, that unit is stated in the question; give your answer in that unit. Unless otherwise indicated, the diagrams in this book are **not** drawn to scale. Take the magnitude of the gravitational field strength at Earth's surface to be $g = 9.81\ \mathrm{N\ kg^{-1}}$.*

Question 1 (6 marks)

A rocket of total mass $3.0 \times 10^4\ \mathrm{kg}$ is launched vertically from the ground. Its engines produce a constant thrust of $4.5 \times 10^5\ \mathrm{N}$. Ignore air resistance, and treat the gravitational field strength near the ground as $g = 9.81\ \mathrm{N\ kg^{-1}}$.

a. Show that the magnitude of the force due to gravity (F_g) on the rocket at launch is $2.94 \times 10^5\ \mathrm{N}$. 1 mark

b. Calculate the initial vertical acceleration of the rocket. Give your answer in $\mathrm{m\ s^{-2}}$. 2 marks

c. As the rocket rises it burns fuel, so its mass steadily decreases while the thrust stays constant. With reference to Newton's second law of motion, explain what happens to the rocket's acceleration as it rises. 3 marks

Question 2 (5 marks)

A cylindrical space station rotates about its central axis to provide artificial gravity for its crew. Astronauts stand on the inner surface at a radius of $40\ \mathrm{m}$ from the axis. The station is rotated so that a stationary astronaut experiences a centripetal acceleration equal to $g = 9.81\ \mathrm{m\ s^{-2}}$.

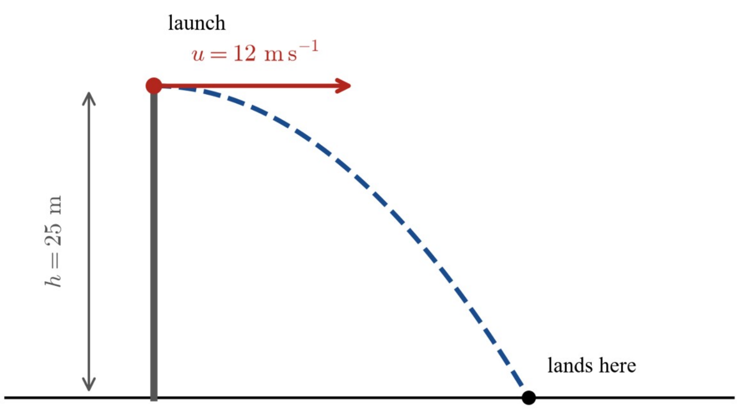
a. Show that the required speed of a point on the inner rim is $19.8\ \mathrm{m\ s^{-1}}$. 1 mark

b. Calculate the period of rotation of the station. Give your answer in s. 2 marks

c. An astronaut of mass $72\ \mathrm{kg}$ stands on the inner rim. The floor is the only surface in contact with the astronaut. Calculate the magnitude of the normal force exerted on the astronaut by the floor. Give your answer in N. 2 marks

Question 3 (5 marks)

While testing a spring-loaded deployment mechanism on Earth, engineers launch a $0.30\ \mathrm{kg}$ sensor package horizontally from the top edge of a $25\ \mathrm{m}$ test tower at a speed of $12\ \mathrm{m\ s^{-1}}$, as shown below. Ignore air resistance.



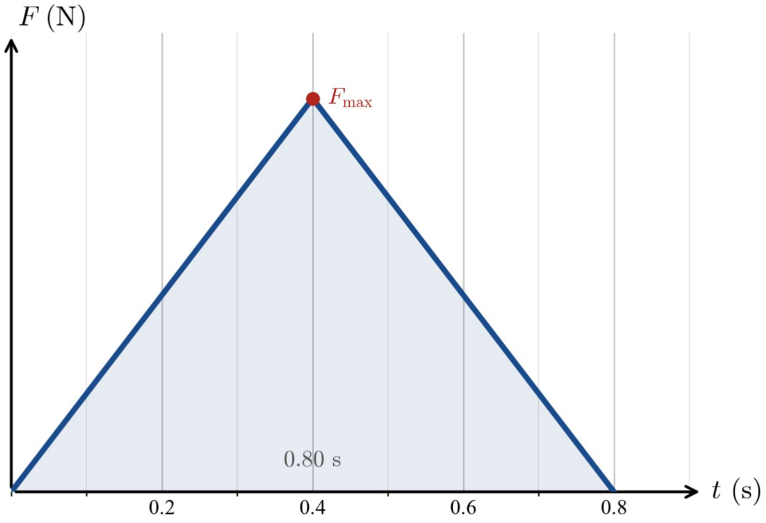
a. Show that the sensor takes $2.26\ \mathrm{s}$ to reach the ground. 1 mark

b. Calculate the horizontal distance from the base of the tower to where the sensor lands. Give your answer in m. 2 marks

c. Calculate the speed of the sensor just before it strikes the ground. Give your answer in $\mathrm{m\ s^{-1}}$. 2 marks

Question 4 (5 marks)

During a docking test, a 1.5×10^3 kg capsule approaches a station at $0.40\,\mathrm{m\,s^{-1}}$ and is brought to rest by a docking buffer. A sensor records the force exerted on the capsule by the buffer against time; the force–time graph is a triangle and the contact lasts $0.80\,\mathrm{s}$, as shown below.



a. Show that the magnitude of the impulse delivered to the capsule is $6.0 \times 10^2\,\mathrm{N\,s}$. 1 mark

b. The area under the force–time graph equals the impulse. Using this, determine the peak force recorded during the contact. Give your answer in N. 2 marks

c. Explain, in terms of impulse, why the docking buffer is designed to bring the capsule to rest slowly rather than abruptly. 2 marks

Question 5 (6 marks)

An Earth-observation satellite of mass $1.10 \times 10^3\,\mathrm{kg}$ moves in a circular orbit at an altitude of $6.30 \times 10^5\,\mathrm{m}$ above Earth's surface.

a. Show that the orbital speed of the satellite is $7.54 \times 10^3\,\mathrm{m\,s^{-1}}$. 1 mark

b. Show that the period of the orbit is $5.83 \times 10^3\,\mathrm{s}$. 1 mark

c. Calculate the centripetal acceleration of the satellite. Give your answer in $\mathrm{m\,s^{-2}}$. 2 marks

d. The satellite moves at constant speed, yet it is accelerating. Explain why, with reference to Newton's second law of motion. 2 marks

Question 6 (5 marks)

A space probe orbits a distant planet of mass $4.9 \times 10^{24}\,\mathrm{kg}$. At the probe's location, the distance from the centre of the planet is $9.0 \times 10^6\,\mathrm{m}$.

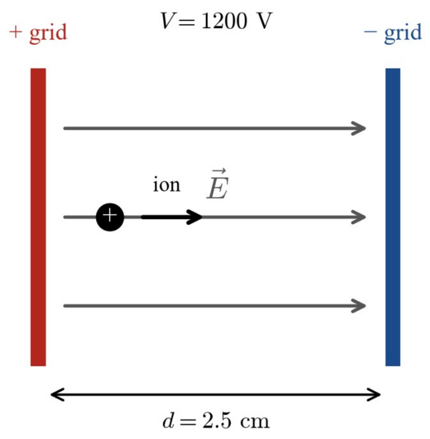
a. Show that the gravitational field strength of the planet at this radius is $4.03\,\mathrm{N\,kg^{-1}}$. 1 mark

b. The probe has a mass of $1.2 \times 10^3\,\mathrm{kg}$. Calculate the magnitude of the force due to gravity (F_g) on the probe at this radius. Give your answer in N. 2 marks

c. Explain, using the field model, why the gravitational field strength is weaker when the probe moves to a higher orbit. 2 marks

Question 7 (5 marks)

An ion thruster accelerates singly-charged xenon ions between two parallel grids that are 2.5×10^{-2} m apart, with a potential difference of 1.2×10^{3} V between them, as shown below. A xenon ion has a charge of 1.60×10^{-19} C and a mass of 2.18×10^{-25} kg.



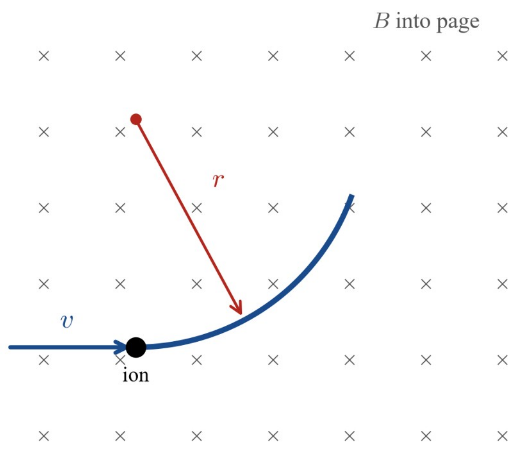
a. Show that the magnitude of the uniform electric field between the grids is 4.8×10^{4} N C^{-1}. 1 mark

b. Calculate the magnitude of the electric force on a single xenon ion in this field. Give your answer in N. 2 marks

c. A xenon ion starts from rest and is accelerated from one grid to the other through the full 1.2×10^{3} V. Calculate the speed it reaches. Give your answer in m s^{-1}. 2 marks

Question 8 (5 marks)

An instrument on a spacecraft identifies charged particles in the solar wind. Singly-charged ions of charge 1.60×10^{-19} C and mass 6.64×10^{-26} kg enter a uniform magnetic field of magnitude 0.25 T at 3.0×10^{5} m s^{-1}, at right angles to the field, as shown below.



a. Show that the magnitude of the magnetic force on one ion is 1.2×10^{-14} N. 1 mark

b. Calculate the radius of the circular path followed by the ion in the field. Give your answer in m. 2 marks

c. A second ion in the beam has the same charge and enters at the same speed, but follows a path of larger radius. Explain what this indicates about the mass of the second ion. 2 marks

Question 9 (5 marks)

A spacecraft carries a search-coil magnetometer: a flat coil of 400 turns and area $5.0 \times 10^{-3}\,\text{m}^2$. As the craft crosses a magnetic boundary, the magnetic field perpendicular to the plane of the coil increases uniformly from $2.0 \times 10^{-5}\,\text{T}$ to $8.0 \times 10^{-5}\,\text{T}$ in $0.030\,\text{s}$.

a. Show that the change in magnetic flux through one turn of the coil is $3.0 \times 10^{-7}\,\text{Wb}$. 1 mark

b. Calculate the magnitude of the average emf induced in the coil during this change. Give your answer in V. 2 marks

c. Explain, using the concept of magnetic flux and Faraday's law of induction, why an emf is induced in the coil only while the magnetic field is changing. 2 marks

Question 10 (4 marks)

A ground station uses an ideal transformer to step $240\,\text{V}$ up to $4.8 \times 10^3\,\text{V}$ to supply a high-power antenna. The primary winding has 500 turns.

a. Calculate the number of turns on the secondary winding. Give your answer as a whole number. 2 marks

b. The antenna draws a current of $5.0\,\text{A}$ from the secondary winding. Calculate the current in the primary winding. Give your answer in A. 1 mark

c. Explain why this transformer will not operate if it is connected to a steady direct-current (DC) supply. 1 mark

Question 11 (5 marks)

A remote deep-space tracking station is supplied through a transmission line of total resistance $5.0\,\Omega$. The substation feeds the line at $6.60 \times 10^3\,\text{V}$, and the tracking station operates at $6.35 \times 10^3\,\text{V}$.

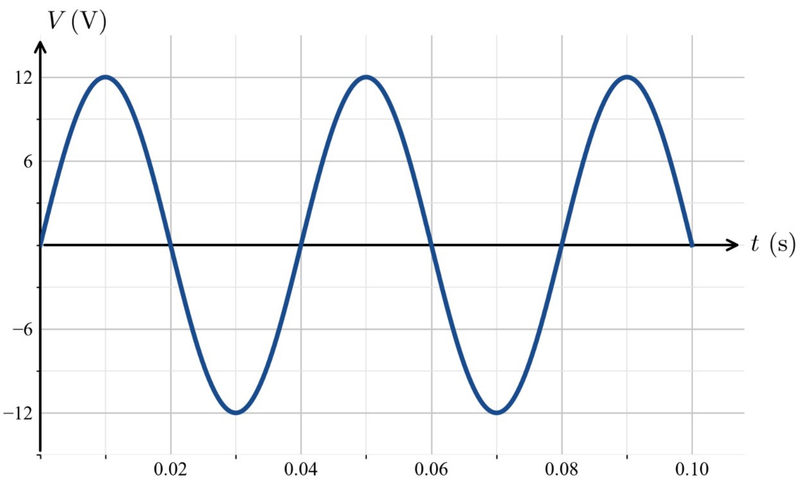
a. Show that the voltage drop along the transmission line is $2.5 \times 10^2\,\text{V}$. 1 mark

b. Calculate the current in the transmission line. Give your answer in A. 2 marks

c. Calculate the power dissipated in the transmission line. Give your answer in W. 2 marks

Question 12 (4 marks)

A test generator at a launch facility is a simple AC generator: a coil rotating in a uniform magnetic field, with the output taken from the coil through slip rings and brushes. The alternating voltage it produces is shown on the graph below.



a. State the peak voltage and the period of this alternating voltage, reading both from the graph. 1 mark

b. Calculate the frequency of the alternating voltage. Give your answer in Hz. 1 mark

c. Calculate the rms value of this voltage. Give your answer in V. 1 mark

d. Explain why taking the output through slip rings, rather than a split-ring commutator, delivers an alternating current. 1 mark

Question 13 (3 marks)

In a test of a spacecraft's laser communication system, coherent light of wavelength 6.00×10^{-7} m passes through two narrow slits separated by 0.30 mm. An interference pattern is observed on a screen 2.5 m away.

a. Show that the spacing between adjacent bright fringes on the screen is 5.0×10^{-3} m. 1 mark

b. State and explain how the fringe spacing would change if the slit separation were increased. 2 marks

Question 14 (4 marks)

A photocell used in a Sun sensor has a metal surface with a work function of 1.40 eV. Light of wavelength 6.21×10^{-7} m is shone onto the surface.

a. Show that the energy of each photon of this light is 2.00 eV (3.20×10^{-19} J). 1 mark

b. Calculate the maximum kinetic energy of the photoelectrons emitted from the surface. Give your answer in eV. 1 mark

c. The wavelength of the light is now decreased to a shorter value, while the power delivered to the surface is kept constant. State and explain the effect of this change on (i) the maximum kinetic energy of the emitted photoelectrons and (ii) the number of photoelectrons emitted per second. 2 marks

Question 15 (3 marks)

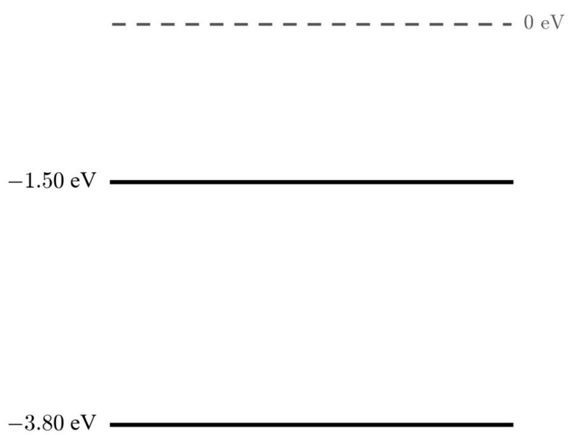
To study the crystal structure of a spacecraft alloy, a beam of electrons is accelerated to a speed of 5.0×10^{6} m s^{-1} and directed at a thin sample.

a. Show that the de Broglie wavelength of these electrons is 1.46×10^{-10} m. 1 mark

b. When the beam passes through the sample, a pattern of concentric rings is observed on a detector. Explain what this diffraction pattern demonstrates about the nature of electrons. 2 marks

Question 16 (4 marks)

An atom in a spacecraft calibration lamp has electron energy levels that include one at -1.50 eV and one at -3.80 eV, as shown in the diagram. The atom emits a photon when an electron moves from the -1.50 eV level to the -3.80 eV level.



a. Show that the energy of the emitted photon is 2.30 eV. 1 mark

b. Calculate the wavelength of the emitted light. Give your answer in nm. 2 marks

c. On the energy-level diagram, draw an arrow that represents this transition. 1 mark

Question 17 (4 marks)

An uncrewed probe travels toward a distant object at $0.80\,c$ relative to Earth. In the probe's own frame of reference, the journey lasts 6.0 years.

a. Show that the Lorentz factor γ for the probe is 1.67. 1 mark

b. Calculate the duration of the journey as measured by observers on Earth. Give your answer in years. 2 marks

c. (Circle your answer.) The length of the probe, measured by an Earth observer as it flies past, is: *less than* / *equal to* / *greater than* its length measured by an astronaut travelling with the probe. Justify your answer. No calculations are required. 1 mark

Question 18 (3 marks)

The Sun radiates energy into space at a total power of $3.8 \times 10^{26}\,\mathrm{W}$.

a. Show that the Sun converts about $4.2 \times 10^{9}\,\mathrm{kg}$ of mass into energy each second. 1 mark

b. The Sun has a mass of $2.0 \times 10^{30}\,\mathrm{kg}$. Calculate the total energy that would be released if $0.10\,\%$ of the Sun's mass were completely converted into energy. Give your answer in J. 2 marks

Question 19 (19 marks)

An aerospace team is developing an induction-based speed sensor to monitor how quickly a satellite's solar array unfolds during deployment. In the laboratory, a small bar magnet is mounted on a motorised carriage that is driven past a fixed coil of 500 turns at a series of controlled steady speeds v. A data logger records the emf induced in the coil, and the peak emf ε is read for each speed.

For this apparatus the peak emf is related to the magnet's speed by $\varepsilon = k\,v$, where k is a constant of the arrangement. The independent variable is the speed v; the dependent variable is the peak emf ε.

The recorded data are shown in the table. Each peak-emf reading has an uncertainty of $\pm 0.10\,\mathrm{V}$.

Speed v ($\mathrm{m\,s^{-1}}$)	0.20	0.40	0.60	0.80	1.00	1.20
Peak emf ε (V)	0.47	0.99	1.57	2.03	2.43	3.00

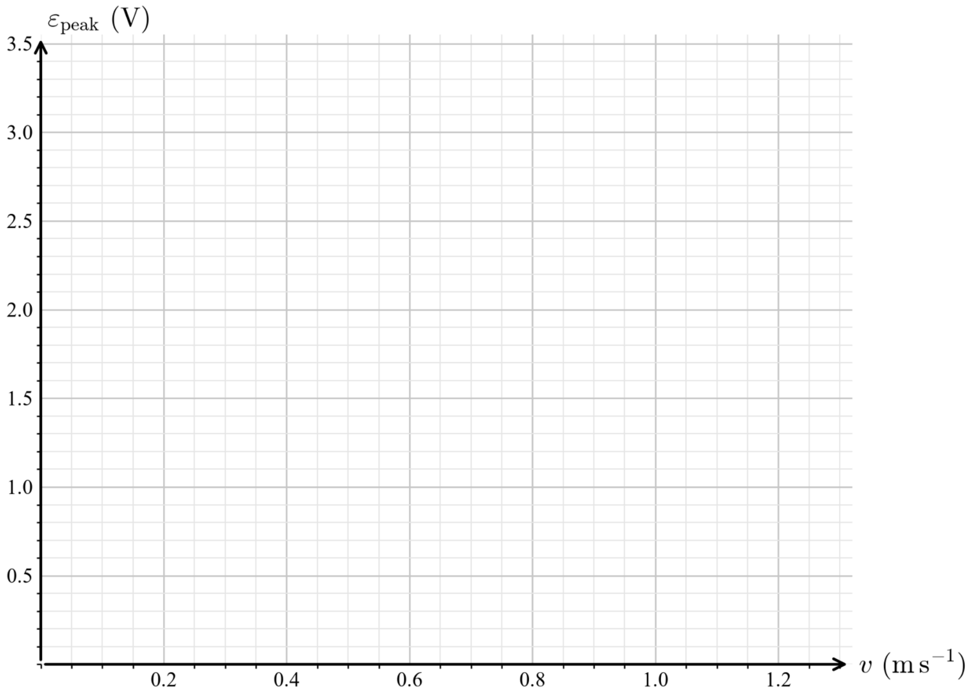
a. State the independent variable, the dependent variable, and **one** variable that should be controlled in this investigation. 3 marks

b. As the magnet moves past the coil, an emf is induced in the coil. Explain why, with reference to magnetic flux and Faraday's law of induction. 2 marks

c. The coil is connected to a data logger rather than to an analogue voltmeter. Explain why this is necessary for this investigation. 1 mark

d. The measurement at each speed is repeated three times and the results are averaged. State the purpose of repeating the measurements. 1 mark

e. On the grid provided, plot a graph of peak emf ε (vertical axis) against speed v (horizontal axis). Include uncertainty bars of $\pm 0.10\,\mathrm{V}$ on each point and draw a line of best fit. 5 marks



f. Using two well-separated points on your line of best fit, determine the gradient of the graph. Give your answer in $\mathrm{V\,s\,m^{-1}}$. 2 marks

g. For this apparatus the gradient equals $k = \dfrac{N\,\Delta\Phi_B}{d}$, where $N = 500$ is the number of turns and $d = 5.0 \times 10^{-2}\,\mathrm{m}$ is the effective distance over which the flux through the coil changes as the magnet passes. Use your gradient to determine $\Delta\Phi_B$, the change in magnetic flux through one turn of the coil. Give your answer in Wb. 3 marks

h. Predict and justify how the gradient of the graph would change if the coil were rewound with twice as many turns, with everything else unchanged.

2 marks

End of Section B

Practice Exam 4 — Formula Sheet

This formula sheet is provided for use with all practice examinations in this booklet. It covers the same items as the official VCE Physics Formula Sheet.

Motion and related energy transformations

velocity	$v=\frac{\Delta s}{\Delta t}$
acceleration	$a=\frac{\Delta v}{\Delta t}$
constant acceleration	$v=u+at$
	$s=ut+\frac{1}{2}at^2$
	$s=vt-\frac{1}{2}at^2$
	$v^2=u^2+2as$
	$s=\frac{1}{2}(u+v)t$
Newton's second law	$\Sigma F=ma$
uniform circular motion	$F_{\text{net}}=\frac{mv^2}{r}$
	$v=\frac{2\pi r}{T}$
Hooke's law	$F=-kx$
elastic potential energy	$E_s=\frac{1}{2}kx^2$
gravitational potential energy	$E_g=mg\Delta h$
kinetic energy	$E_k=\frac{1}{2}mv^2$
universal gravitation	$F_g=\frac{Gm_1m_2}{r^2}$
gravitational field	$g=\frac{GM}{r^2}$
impulse	$F\Delta t=m\Delta v$
momentum	$p=mv$

Einstein's special theory of relativity

Lorentz factor	$\gamma=\frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$
time dilation	$t=\gamma t_0$
length contraction	$L=\frac{L_0}{\gamma}$
rest energy	$E_0=mc^2$
total energy	$E_{\text{total}}=E_k+E_0=\gamma mc^2$

relativistic kinetic energy $E_k = (\gamma - 1) m c^2$

Fields and application of field concepts

uniform electric field	$E = \frac{V}{d}$
charge accelerated by a field	$\frac{1}{2} m v^2 = q V$
field of a point charge	$E = \frac{k Q}{r^2}$
electric force on a charge	$F = q E$
Coulomb's law	$F = \frac{k q_1 q_2}{r^2}$
magnetic force on a moving charge	$F = q v B$
force on a current-carrying conductor	$F = n I l B$
radius of a charged particle's path	$r = \frac{m v}{q B}$

Generation and transmission of electricity

current	$I = \frac{V}{R}$
power	$P = V I$
resistors in series	$R_T = R_1 + R_2 + \ldots$
resistors in parallel	$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$
ideal transformer	$\frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{I_2}{I_1}$
rms voltage	$V_{\text{RMS}} = \frac{1}{\sqrt{2}} V_{\text{peak}}$
rms current	$I_{\text{RMS}} = \frac{1}{\sqrt{2}} I_{\text{peak}}$
electromagnetic induction	$\varepsilon = -N \frac{\Delta \Phi_B}{\Delta t}$
magnetic flux	$\Phi_B = B_{\perp} A$
voltage drop along a line	$V_{\text{drop}} = I_{\text{line}} R_{\text{line}}$
power loss in a line	$P_{\text{loss}} = I_{\text{line}}^2 R_{\text{line}}$

Waves

wave equation	$v = f \lambda$
constructive interference	path difference $= n \lambda$
destructive interference	path difference $= \left(n + \frac{1}{2}\right) \lambda$
fringe spacing	$\Delta x = \frac{\lambda L}{d}$ when $L \gg d$

The nature of light and matter

photoelectric effect	$E_{k\,max} = hf - \phi$
photon energy	$E = hf = \frac{hc}{\lambda}$
photon momentum	$p = \frac{h}{\lambda}$
de Broglie wavelength	$\lambda = \frac{h}{p}$

Data

acceleration due to gravity at Earth's surface	$g = 9.81$ m s^{-2}
mass of the electron	$m_e = 9.11 \times 10^{-31}$ kg
magnitude of the charge of the electron	$q_e = 1.60 \times 10^{-19}$ C
Planck's constant	$h = 6.63 \times 10^{-34}$ J s
	$h = 4.14 \times 10^{-15}$ eV s
speed of light in a vacuum	$c = 3.00 \times 10^{8}$ m s^{-1}
universal gravitational constant	$G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}
mass of Earth	$M_E = 5.97 \times 10^{24}$ kg
radius of Earth	$R_E = 6.37 \times 10^{6}$ m
Coulomb constant	$k = 8.99 \times 10^{9}$ N m^2 C^{-2}

Metric (SI) multipliers

pico (p)	10^{-12}	kilo (k)	10^{3}
nano (n)	10^{-9}	mega (M)	10^{6}
micro (μ)	10^{-6}	giga (G)	10^{9}
milli (m)	10^{-3}	tera (T)	10^{12}

Unit conversions

1 tonne (t)	$= 10^{3}$ kg
1 kilowatt hour (kW h)	$= 3.6 \times 10^{6}$ J

Nomenclature

force due to gravity	F_g
force on A by B	$F_{\text{on A by B}}$
normal force	F_N

End of Formula Sheet

Practice Exam 4 — solutions

Section A — answer key

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

Question 1 — A. Momentum is conserved in the docking (an inelastic collision): $p = 8.0\times10^3\times6.0 = 4.8\times10^4\,\text{kg m s}^{-1}$, shared over the combined mass $2.0\times10^4\,\text{kg}$, so $v = \dfrac{4.8\times10^4}{2.0\times10^4} = 2.4\,\text{m s}^{-1}$. **B** takes the average of the two speeds; **C** divides the momentum by the station mass alone; **D** assumes the capsule's speed is unchanged.

Question 2 — C. The whole system accelerates at $a = \dfrac{8.0\times10^2}{2.5\times10^3+1.5\times10^3} = 0.20\,\text{m s}^{-2}$. The coupling accelerates only the satellite, so $F = m_{\text{sat}}a = 1.5\times10^3\times0.20 = 3.0\times10^2\,\text{N}$. **A** quotes the whole thruster force; **B** uses the tug's mass; **D** quotes the acceleration as if it were a force.

Question 3 — B. $a = \dfrac{v^2}{r} = \dfrac{18^2}{45} = 7.2\,\text{m s}^{-2}$, directed toward the axis. **A** fails to square v (v/r); **C** uses the diameter instead of the radius ($v^2/2r$); **D** omits dividing by r.

Question 4 — D. Work done $= \Delta E_k = 1/2\,m\left(v^2-u^2\right) = 1/2\times800\times\left(\left(3.0\times10^3\right)^2-\left(2.0\times10^3\right)^2\right) = 2.0\times10^9\,\text{J}$. **A** computes $1/2\,m\left(v-u\right)^2$; **B** omits the factor $1/2$; **C** uses only the final kinetic energy $1/2\,mv^2$.

Question 5 — A. The area under a force–time graph is the impulse ($=\Delta p$); the area under a force–displacement graph is the work done ($=\Delta E_k$). **B** swaps the two — the classic impulse-versus-work trap; **C** and **D** collapse the two different areas into a single quantity.

Question 6 — D. $g = \dfrac{GM}{r^2} = \dfrac{6.67\times10^{-11}\times5.97\times10^{24}}{\left(1.0\times10^7\right)^2} = 3.98\,\text{N kg}^{-1}$. **A** divides by r instead of r^2 (a factor of r too large); **B** takes $\sqrt{GM/r}$ (an orbital speed, not a field); **C** doubles the correct value ($2GM/r^2$).

Question 7 — C. $E = \dfrac{kQ}{r^2} = \dfrac{8.99\times10^9\times4.0\times10^{-9}}{0.20^2} = 8.99\times10^2\,\text{N C}^{-1}$. **A** omits the constant k; **B** divides by r instead of r^2; **D** uses the diameter ($2r$) in place of r.

Question 8 — B. $r = \dfrac{mv}{qB} = \dfrac{1.67\times10^{-27}\times5.0\times10^5}{1.60\times10^{-19}\times0.30} = 1.74\times10^{-2}\,\text{m}$. **A** omits B; **C** inverts the expression (qB/mv); **D** computes the force qvB instead of the radius.

Question 9 — A. The magnetic force $F = qvB$ acts at right angles to the velocity, so it changes the direction of motion (providing the centripetal force) but does no work and leaves the speed unchanged. **B** and **D** wrongly have the force speed the particle up (a magnetic force does no work); **C** wrongly aligns the force with the field.

Question 10 — C. $\varepsilon = N\dfrac{\Delta\Phi_B}{\Delta t} = \dfrac{N\,A\,\Delta B}{\Delta t} = \dfrac{500 \times 8.0 \times 10^{-3} \times 0.40}{0.020} = 80\,\mathrm{V}$. **A** omits N; **B** omits dividing by Δt; **D** omits the area A.

Question 11 — D. For an ideal transformer $\dfrac{I_2}{I_1} = \dfrac{V_1}{V_2}$, so $I_2 = 30 \times \dfrac{240}{3.6 \times 10^3} = 2.0\,\mathrm{A}$. **A** inverts the ratio ($30 \times V_2 / V_1$); **B** assumes the current is unchanged; **C** squares the voltage ratio.

Question 12 — A. $P_{\text{loss}} = I_{\text{line}}^2 R_{\text{line}} = 25^2 \times 6.0 = 3.75 \times 10^3\,\mathrm{W}$. **B** uses I^2 alone (omits R); **C** computes $I\,R^2$; **D** computes $I\,R$ (the voltage drop, not a power).

Question 13 — B. $V_{\text{RMS}} = \dfrac{V_{\text{peak}}}{\sqrt{2}} = \dfrac{330}{\sqrt{2}} = 2.33 \times 10^2\,\mathrm{V}$. **A** multiplies by $\sqrt{2}$ instead of dividing; **C** divides by 2; **D** quotes the peak value unchanged.

Question 14 — C. $E = \dfrac{h\,c}{\lambda} = \dfrac{6.63 \times 10^{-34} \times 3.00 \times 10^8}{1.06 \times 10^{-6}} = 1.88 \times 10^{-19}\,\mathrm{J}$. **D** fails to keep λ in metres (loses a factor of 10^6); **B** computes h / λ (a momentum); **A** computes $h\,c\,\lambda$.

Question 15 — D. $\lambda = \dfrac{h}{m\,v} = \dfrac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 7.0 \times 10^6} = 1.04 \times 10^{-10}\,\mathrm{m}$. **A** inverts the expression ($m\,v / h$); **B** omits the mass (h / v); **C** multiplies the three quantities ($h\,m\,v$).

Question 16 — B. $\lambda = \dfrac{h\,c}{E} = \dfrac{4.14 \times 10^{-15} \times 3.00 \times 10^8}{2.48} = 5.01 \times 10^{-7}\,\mathrm{m} = 5.01 \times 10^2\,\mathrm{nm}$. **A** uses twice the photon energy; **C** uses half the energy; **D** multiplies $h\,c$ by E instead of dividing.

Question 17 — A. $\gamma = \dfrac{1}{\sqrt{1 - 0.80^2}} = \dfrac{1}{0.60} = \dfrac{5}{3} \approx 1.67$; the Earth (dilated) time is $t = \gamma\,t_0 = \dfrac{5}{3} \times 5.0 = 8.33\,\text{years}$. **B** multiplies by γ^2; **C** leaves the time unchanged; **D** divides by γ (length-contraction confusion).

Question 18 — D. A fixed offset that persists even when the true value is zero is a systematic error; because it shifts every reading by the same 0.5°, repeating and averaging will not remove it. **A** describes a random error; **B** wrongly treats a repeatable offset as a one-off mistake; **C** describes scatter (a precision issue), not a constant offset.

Question 19 — C. The four readings are tightly grouped (a spread of only $0.2\,\mathrm{ms}$, so **precise**) but all sit about $3.8\,\mathrm{ms}$ below the true $100.0\,\mathrm{ms}$ (so **not accurate**). **A** reverses the two ideas; **B** ignores the offset from the true value; **D** ignores the tight grouping.

Question 20 — B. Writing $T^2 = \dfrac{4\pi^2}{G\,M} r^3$ shows that a graph of T^2 against r^3 is a straight line through the origin with gradient $\dfrac{4\pi^2}{G\,M}$ (from which M follows). **A** (T vs r) and **C** (T^2 vs r) are curved, not straight; **D** has the correct axes but inverts the gradient.

Section B — worked solutions

Question 1 $m = 3.0 \times 10^4\,\mathrm{kg}$, thrust $= 4.5 \times 10^5\,\mathrm{N}$, $g = 9.81\,\mathrm{N\,kg^{-1}}$.

(a) $F_g = m\,g = 3.0 \times 10^4 \times 9.81 = 2.94 \times 10^5\,\mathrm{N}$, as required. **(1 mark: correct F_g.)**

(b) The net upward force is the thrust minus F_g, so by Newton's second law, carrying the unrounded $F_g = 2.943 \times 10^5\,\mathrm{N}$ from part **a**,

$$a=\frac{\text{thrust}-F_g}{m}=\frac{4.5\times10^5-2.943\times10^5}{3.0\times10^4}=\frac{1.557\times10^5}{3.0\times10^4}=5.19\,\text{m s}^{-2}.$$

(1 mark net force = thrust $-F_g$; **1 mark** correct value $5.19\,\text{m s}^{-2}$.)

(c) By Newton's second law $a=\frac{\text{thrust}-F_g}{m}$. As fuel burns the mass m decreases, so the force due to gravity $F_g=mg$ also decreases; the net upward force (thrust $-F_g$) therefore increases. At the same time this larger net force is dividing a smaller mass. Both effects act the same way, so the acceleration increases as the rocket rises. **(1 mark** cites $a=\Sigma F/m$ (Newton's second law); **1 mark** smaller mass ⇒ smaller F_g ⇒ larger net upward force; **1 mark** larger net force divided by smaller mass ⇒ increasing acceleration.)

Question 2 $r=40\,\text{m}$, required centripetal acceleration $a=9.81\,\text{m s}^{-2}$.

(a) $a=\frac{v^2}{r}$, so $v=\sqrt{ar}=\sqrt{9.81\times40}=\sqrt{392.4}=19.8\,\text{m s}^{-1}$, as required. **(1 mark: correct speed.)**

(b) $T=\frac{2\pi r}{v}=\frac{2\pi\times40}{19.81}=\frac{251.3}{19.81}=12.7\,\text{s}$. **(1 mark** $T=\frac{2\pi r}{v}$; **1 mark** correct value $12.7\,\text{s}$.)

(c) In the rotating station the only force on the astronaut is the normal force from the floor, and it provides the centripetal force:

$$F_N=\frac{mv^2}{r}=ma=72\times9.81=7.06\times10^2\,\text{N}.$$

∴ the floor exerts a normal force of $7.06\times10^2\,\text{N}$ on the astronaut, toward the axis. **(1 mark** normal force supplies the centripetal force $F_N=mv^2/r=ma$; **1 mark** correct value $7.06\times10^2\,\text{N}$.)

Question 3 Horizontal launch: $u=12\,\text{m s}^{-1}$, $h=25\,\text{m}$, $g=9.81\,\text{m s}^{-2}$.

(a) Vertically the sensor starts with zero vertical velocity, so $h=1/2\,gt^2$ and

$$t=\sqrt{\frac{2h}{g}}=\sqrt{\frac{2\times25}{9.81}}=\sqrt{5.097}=2.26\,\text{s},$$

as required. **(1 mark: correct time of flight.)**

(b) Horizontally the motion is at constant velocity: $x=ut=12\times2.258=27.1\,\text{m}$. **(1 mark** $x=ut$; **1 mark** correct value $27.1\,\text{m}$.)

(c) The horizontal velocity stays $12\,\text{m s}^{-1}$; the vertical velocity at impact is $v_y=gt=9.81\times2.258=22.15\,\text{m s}^{-1}$. Combining the components:

$$v=\sqrt{v_x^2+v_y^2}=\sqrt{12^2+22.15^2}=\sqrt{634.6}=25.2\,\text{m s}^{-1}.$$

(1 mark finds $v_y=gt$; **1 mark** correct combined speed $25.2\,\text{m s}^{-1}$.)

Question 4 $m=1.5\times10^3\,\text{kg}$, initial speed $0.40\,\text{m s}^{-1}$, brought to rest; contact time $0.80\,\text{s}$.

(a) Impulse = change in momentum $=m\Delta v=1.5\times10^3\times0.40=6.0\times10^2\,\text{N s}$, as required. **(1 mark: correct impulse.)**

(b) The area under the triangular force–time graph is $1/2\times(\text{base})\times(\text{peak force})$, and this equals the impulse:

$$1/2\times0.80\times F_{\text{peak}}=6.0\times10^2\Rightarrow F_{\text{peak}}=\frac{6.0\times10^2}{0.40}=1.50\times10^3\,\text{N}.$$

(1 mark area of triangle = impulse; **1 mark** correct value $1.50\times10^3\,\text{N}$.)

(c) The capsule undergoes a fixed change in momentum Δp (from $0.40\,\text{m s}^{-1}$ to rest), so the impulse $F\,\Delta t=\Delta p$ is fixed. Bringing it to rest over a longer contact time Δt therefore reduces the average — and hence the peak — force, since $F=\frac{\Delta p}{\Delta t}$. A smaller force is less likely to damage the capsule or station. **(1 mark** same Δp, so $F\,\Delta t=\Delta p$ is fixed; **1 mark** a longer Δt gives a smaller force.)

Question 5 Altitude $h=6.30\times10^5\,\text{m}$, so $r=R_E+h=6.37\times10^6+6.30\times10^5=7.00\times10^6\,\text{m}$; $G\,M=6.67\times10^{-11}\times5.97\times10^{24}=3.98\times10^{14}$.

(a) The gravitational force provides the centripetal force, so $\frac{G\,M\,m}{r^2}=\frac{m\,v^2}{r}$ and

$$v=\sqrt{\frac{G\,M}{r}}=\sqrt{\frac{3.98\times10^{14}}{7.00\times10^6}}=7.54\times10^3\,\text{m s}^{-1},$$

as required. (Note r includes R_E.) **(1 mark: correct substitution with $r=R_E+h$.)**

(b) $T=\frac{2\pi r}{v}=\frac{2\pi\times7.00\times10^6}{7.54\times10^3}=5.83\times10^3\,\text{s}$ (about 97 minutes), as required. **(1 mark: correct period.)**

(c) Carrying the unrounded orbital speed from part **a**, $a=\frac{v^2}{r}=\frac{(7.542\times10^3)^2}{7.00\times10^6}=\frac{5.688\times10^7}{7.00\times10^6}=8.13\,\text{m s}^{-2}$, directed toward the centre of Earth (equivalently $a=G\,M\,/\,r^2$). **(1 mark** $a=\frac{v^2}{r}$ (or $G\,M\,/\,r^2$); **1 mark** correct value $8.13\,\text{m s}^{-2}$.)

(d) Although the speed is constant, the **direction** of the velocity is continually changing, so the velocity is changing and the satellite is accelerating (centripetally, toward Earth). By Newton's second law, a changing velocity requires a net (unbalanced) force; here that net force is the gravitational force on the satellite, directed toward Earth, which provides the centripetal force. **(1 mark** velocity direction changes, so there is a centripetal acceleration; **1 mark** by Newton's second law an unbalanced (gravitational) force is required — cites the **second** law.)

Question 6 $M=4.9\times10^{24}\,\text{kg}$, $r=9.0\times10^6\,\text{m}$.

(a) $g=\frac{G\,M}{r^2}=\frac{6.67\times10^{-11}\times4.9\times10^{24}}{(9.0\times10^6)^2}=\frac{3.268\times10^{14}}{8.1\times10^{13}}=4.03\,\text{N kg}^{-1}$, as required. **(1 mark: correct substitution and result.)**

(b) $F_g=m\,g=1.2\times10^3\times4.03=4.84\times10^3\,\text{N}$ (equivalently $F_g=\frac{G\,M\,m}{r^2}$), directed toward the planet. **(1 mark** $F_g=m\,g$ (or $G\,M\,m\,/\,r^2$); **1 mark** correct value $4.84\times10^3\,\text{N}$.)

(c) The gravitational field of the planet obeys an inverse-square law, $g=\frac{G\,M}{r^2}$. At a higher orbit the distance r from the planet's centre is greater, so $g\propto\frac{1}{r^2}$ is smaller; in field-line terms the field lines are further apart (less dense) at a greater distance, representing a weaker field. **(1 mark** cites the inverse-square dependence $g=G\,M\,/\,r^2$; **1 mark** larger r gives a smaller field / field lines less dense.)

Question 7 $d=2.5\times10^{-2}\,\text{m}$, $V=1.2\times10^3\,\text{V}$, $q=1.60\times10^{-19}\,\text{C}$, $m=2.18\times10^{-25}\,\text{kg}$.

(a) $E=\frac{V}{d}=\frac{1.2\times10^3}{2.5\times10^{-2}}=4.8\times10^4\,\text{N C}^{-1}$, as required. **(1 mark: correct substitution — with d in metres.)**

(b) $F = qE = 1.60 \times 10^{-19} \times 4.8 \times 10^{4} = 7.68 \times 10^{-15}\,\mathrm{N}$. **(1 mark** $F = qE$; **1 mark** correct value $7.68 \times 10^{-15}\,\mathrm{N}$.)

(c) The work done on the ion equals its gain in kinetic energy: $qV = 1/2\,m v^2$, so

$$v = \sqrt{\frac{2qV}{m}} = \sqrt{\frac{2 \times 1.60 \times 10^{-19} \times 1.2 \times 10^{3}}{2.18 \times 10^{-25}}} = \sqrt{1.761 \times 10^{9}} = 4.20 \times 10^{4}\,\mathrm{m\ s^{-1}}.$$

(1 mark $1/2\,m v^2 = qV$; **1 mark** correct value $4.20 \times 10^{4}\,\mathrm{m\ s^{-1}}$.)

Question 8 $q = 1.60 \times 10^{-19}\,\mathrm{C}$, $m = 6.64 \times 10^{-26}\,\mathrm{kg}$, $v = 3.0 \times 10^{5}\,\mathrm{m\ s^{-1}}$, $B = 0.25\,\mathrm{T}$.

(a) $F = qvB = 1.60 \times 10^{-19} \times 3.0 \times 10^{5} \times 0.25 = 1.2 \times 10^{-14}\,\mathrm{N}$, as required. **(1 mark: correct substitution and result.)**

(b) The magnetic force provides the centripetal force, so $qvB = \frac{m v^2}{r}$ and

$$r = \frac{mv}{qB} = \frac{6.64 \times 10^{-26} \times 3.0 \times 10^{5}}{1.60 \times 10^{-19} \times 0.25} = \frac{1.992 \times 10^{-20}}{4.0 \times 10^{-20}} = 0.498\,\mathrm{m}.$$

(1 mark $r = \frac{mv}{qB}$; **1 mark** correct value $0.498\,\mathrm{m}$.)

(c) From $r = \frac{mv}{qB}$, with v, q and B unchanged, the radius is proportional to the mass ($r \propto m$). The second ion follows a larger-radius path, so it must have a **greater mass** than the first ion. **(1 mark** $r \propto m$ for fixed v, q, B; **1 mark** larger radius ⇒ greater mass.)

Question 9 $N = 400$, $A = 5.0 \times 10^{-3}\,\mathrm{m^2}$, field changes from $2.0 \times 10^{-5}\,\mathrm{T}$ to $8.0 \times 10^{-5}\,\mathrm{T}$ in $\Delta t = 0.030\,\mathrm{s}$.

(a) $\Delta \Phi_B = A\,\Delta B = 5.0 \times 10^{-3} \times (8.0 \times 10^{-5} - 2.0 \times 10^{-5}) = 5.0 \times 10^{-3} \times 6.0 \times 10^{-5} = 3.0 \times 10^{-7}\,\mathrm{Wb}$, as required. **(1 mark: correct change in flux, using the full $6.0 \times 10^{-5}\,\mathrm{T}$ change.)**

(b) $\varepsilon = N\frac{\Delta \Phi_B}{\Delta t} = \frac{400 \times 3.0 \times 10^{-7}}{0.030} = \frac{1.2 \times 10^{-4}}{0.030} = 4.0 \times 10^{-3}\,\mathrm{V}$. **(1 mark** $\varepsilon = N\frac{\Delta \Phi_B}{\Delta t}$; **1 mark** correct value $4.0 \times 10^{-3}\,\mathrm{V}$.)

(c) The magnetic flux through the coil is $\Phi_B = B_{\perp} A$. While the field is changing, the flux through the coil is changing, and by Faraday's law $\varepsilon = -N\frac{\Delta \Phi_B}{\Delta t}$ this rate of change of flux induces an emf. Once the field is steady, the flux is constant, so $\frac{\Delta \Phi_B}{\Delta t} = 0$ and no emf is induced. **(1 mark** changing field → changing flux through the coil; **1 mark** by Faraday's law the emf depends on the rate of change of flux, so a steady field gives zero emf.)

Question 10 Ideal transformer, $V_1 = 240\,\mathrm{V}$, $V_2 = 4.8 \times 10^{3}\,\mathrm{V}$, $N_1 = 500$.

(a) $\frac{N_1}{N_2} = \frac{V_1}{V_2}$, so $N_2 = N_1\frac{V_2}{V_1} = 500 \times \frac{4.8 \times 10^{3}}{240} = 500 \times 20 = 1.0 \times 10^{4}$ turns (10 000 turns). **(1 mark** correct turns ratio; **1 mark** correct value 10 000 turns.)

(b) For an ideal transformer $\frac{I_1}{I_2} = \frac{V_2}{V_1}$, so $I_1 = 5.0 \times \frac{4.8 \times 10^{3}}{240} = 5.0 \times 20 = 1.0 \times 10^{2}\,\mathrm{A}$. **(1 mark: correct value $1.0 \times 10^{2}\,\mathrm{A}$.)**

(c) A transformer works by electromagnetic induction, which requires a **changing** magnetic flux in the core. A steady DC supply produces a constant flux, so no emf is induced in the secondary and the transformer does not operate. **(1 mark: DC gives constant flux, so no induced secondary emf.)**

Question 11 $R_{\text{line}} = 5.0\,\Omega$; line fed at $6.60 \times 10^3\,\text{V}$, station at $6.35 \times 10^3\,\text{V}$.

(a) $V_{\text{drop}} = 6.60 \times 10^3 - 6.35 \times 10^3 = 2.5 \times 10^2\,\text{V}$, as required. **(1 mark: voltage drop is the difference of the two end voltages.)**

(b) $I_{\text{line}} = \dfrac{V_{\text{drop}}}{R_{\text{line}}} = \dfrac{2.5 \times 10^2}{5.0} = 50\,\text{A}$. **(1 mark** $I = \dfrac{V_{\text{drop}}}{R_{\text{line}}}$; **1 mark** correct value $50\,\text{A}$.)

(c) $P_{\text{loss}} = I_{\text{line}}^2 R_{\text{line}} = 50^2 \times 5.0 = 1.25 \times 10^4\,\text{W}$ (equivalently $V_{\text{drop}} \times I_{\text{line}} = 2.5 \times 10^2 \times 50$). **(1 mark** $P_{\text{loss}} = I^2 R$ (or $V_{\text{drop}} I$); **1 mark** correct value $1.25 \times 10^4\,\text{W}$.)

Question 12 Simple AC generator with slip rings; from the graph the peak voltage is $12\,\text{V}$ and the period is $0.040\,\text{s}$.

(a) Reading from the graph: peak voltage $V_{\text{peak}} = 12\,\text{V}$; period $T = 0.040\,\text{s}$. **(1 mark: both values read correctly from the graph.)**

(b) $f = \dfrac{1}{T} = \dfrac{1}{0.040} = 25\,\text{Hz}$. **(1 mark: correct frequency.)**

(c) $V_{\text{RMS}} = \dfrac{V_{\text{peak}}}{\sqrt{2}} = \dfrac{12}{\sqrt{2}} = 8.49\,\text{V}$. **(1 mark: correct value $8.49\,\text{V}$.)**

(d) Slip rings keep each end of the rotating coil permanently connected to the **same** output terminal. The emf induced in the coil reverses direction every half turn as it rotates; because the connections never swap, that reversing emf appears at the terminals unchanged, so the output is an alternating current. (A split-ring commutator would swap the connections every half turn, flipping the output back to one direction to give DC.) **(1 mark: slip rings tie each coil end to the same terminal, so the coil emf — which reverses every half turn — appears at the output as AC.)**

Question 13 $\lambda = 6.00 \times 10^{-7}\,\text{m}$, $d = 0.30\,\text{mm} = 3.0 \times 10^{-4}\,\text{m}$, $L = 2.5\,\text{m}$.

(a) $\Delta x = \dfrac{\lambda L}{d} = \dfrac{6.00 \times 10^{-7} \times 2.5}{3.0 \times 10^{-4}} = 5.0 \times 10^{-3}\,\text{m}$, as required. **(1 mark: correct substitution — with d converted to metres.)**

(b) The fringe spacing would **decrease** (the fringes move closer together). From $\Delta x = \dfrac{\lambda L}{d}$, with λ and L fixed, $\Delta x \propto \dfrac{1}{d}$, so a larger slit separation gives a smaller fringe spacing. **(1 mark** fringe spacing decreases; **1 mark** justified by $\Delta x \propto 1/d$.)

Question 14 Work function $\phi = 1.40\,\text{eV}$, $\lambda = 6.21 \times 10^{-7}\,\text{m}$.

(a) $E = \dfrac{hc}{\lambda} = \dfrac{4.14 \times 10^{-15} \times 3.00 \times 10^8}{6.21 \times 10^{-7}} = 2.00\,\text{eV}$. In joules, $E = \dfrac{6.63 \times 10^{-34} \times 3.00 \times 10^8}{6.21 \times 10^{-7}} = 3.20 \times 10^{-19}\,\text{J}$, as required. **(1 mark: correct photon energy in eV (and J).)**

(b) $E_{k\,\text{max}} = hf - \phi = 2.00 - 1.40 = 0.60\,\text{eV}$. **(1 mark: correct value $0.60\,\text{eV}$.)**

(c) (i) The maximum kinetic energy **increases**: a shorter wavelength means a higher frequency and so a higher photon energy hf, and since $E_{k\,\text{max}} = hf - \phi$ (with ϕ fixed) the maximum kinetic energy rises. (ii) The number of photoelectrons emitted per second **decreases**: at constant power, more energetic photons arrive at a lower rate (fewer photons per second), and each photon can release at most one electron, so fewer electrons are emitted per second. **(1**

mark $E_{k\,\max}$ increases because hf increases; **1 mark** at constant power the photon arrival rate falls, so the emission rate falls.)

Question 15 $v = 5.0 \times 10^{6}\,\text{m s}^{-1}$.

(a) $\lambda = \dfrac{h}{mv} = \dfrac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 5.0 \times 10^{6}} = 1.46 \times 10^{-10}\,\text{m}$, as required. **(1 mark: correct substitution and result.)**

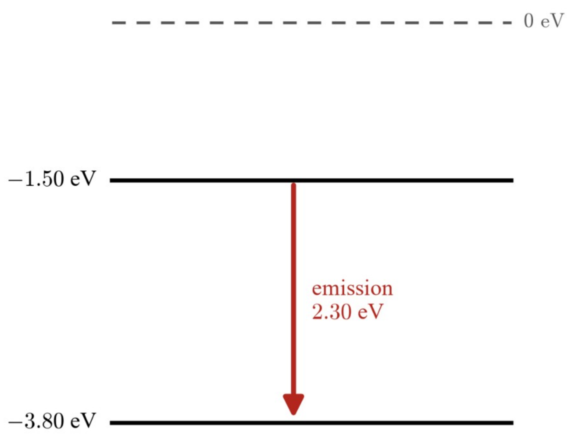
(b) Diffraction (the spreading of the beam into a ring interference pattern) is a **wave** property. That a beam of electrons produces a diffraction pattern shows that electrons — normally treated as particles — also behave as waves, i.e. matter has a wave-like nature (with the de Broglie wavelength found in part **a.**). **(1 mark** diffraction is a wave behaviour; **1 mark** electrons showing diffraction demonstrates the wave-like nature of matter.)

Question 16 Transition from the $-1.50\,\text{eV}$ level to the $-3.80\,\text{eV}$ level.

(a) $E_{\text{photon}} = |-1.50 - (-3.80)| = 3.80 - 1.50 = 2.30\,\text{eV}$, as required. **(1 mark: correct energy difference.)**

(b) $\lambda = \dfrac{hc}{E} = \dfrac{4.14 \times 10^{-15} \times 3.00 \times 10^{8}}{2.30} = 5.40 \times 10^{-7}\,\text{m} = 540\,\text{nm}$. **(1 mark** $\lambda = \dfrac{hc}{E}$ (with E in eV and h in eV s); **1 mark** correct value $540\,\text{nm}$.)

(c) The arrow is drawn **downward**, from the $-1.50\,\text{eV}$ level to the $-3.80\,\text{eV}$ level (emission means the electron drops to the lower energy level).



(1 mark: downward arrow from the $-1.50\,\text{eV}$ **level to the** $-3.80\,\text{eV}$ **level.)**

Question 17 $v = 0.80\,c$, proper journey time $t_0 = 6.0\,\text{years}$ (measured on the probe).

(a) $\gamma = \dfrac{1}{\sqrt{1 - \dfrac{v^2}{c^2}}} = \dfrac{1}{\sqrt{1 - 0.80^2}} = \dfrac{1}{\sqrt{0.36}} = 1.67$, as required. **(1 mark: correct Lorentz factor.)**

(b) The probe's clock records the proper time (the journey begins and ends at the probe). Earth observers measure the dilated time:

$$t = \gamma t_0 = 1.67 \times 6.0 = 10.0\,\text{years}.$$

(1 mark $t = \gamma t_0$ with t_0 the proper time; **1 mark** correct value $10.0\,\text{years}$.)

(c) Less than. In the Earth frame the probe is moving, so its length along the direction of motion is contracted, $L = \dfrac{L_0}{\gamma}$ with $\gamma > 1$. The astronaut travelling with the probe measures its proper (rest) length L_0, which is the greater value; the

Earth observer measures the shorter, contracted length. **(1 mark: circles *less than* AND justifies it as length contraction of the moving probe (Earth measures L_0/γ). The circled option alone scores 0.)**

Question 18 Sun's radiated power $P=3.8\times10^{26}\,\mathrm{W}$.

(a) Each second the Sun radiates $E=3.8\times10^{26}\,\mathrm{J}$. From $E=mc^2$, the mass converted per second is

$$m=\frac{E}{c^2}=\frac{3.8\times10^{26}}{(3.00\times10^8)^2}=\frac{3.8\times10^{26}}{9.0\times10^{16}}=4.2\times10^9\,\mathrm{kg},$$

as required. **(1 mark: correct mass-conversion rate.)**

(b) The mass converted is $0.10\,\%$ of $2.0\times10^{30}\,\mathrm{kg}$: $m=1.0\times10^{-3}\times2.0\times10^{30}=2.0\times10^{27}\,\mathrm{kg}$. Then

$$E=mc^2=2.0\times10^{27}\times(3.00\times10^8)^2=1.8\times10^{44}\,\mathrm{J}.$$

(1 mark finds the converted mass $2.0\times10^{27}\,\mathrm{kg}$; **1 mark** $E=mc^2=1.8\times10^{44}\,\mathrm{J}$.)

Question 19 Induction speed-sensor test: model $\varepsilon=kv$, so a graph of ε against v is a straight line through the origin of gradient k. Coil of $N=500$ turns; each peak-emf reading uncertain by $\pm0.10\,\mathrm{V}$.

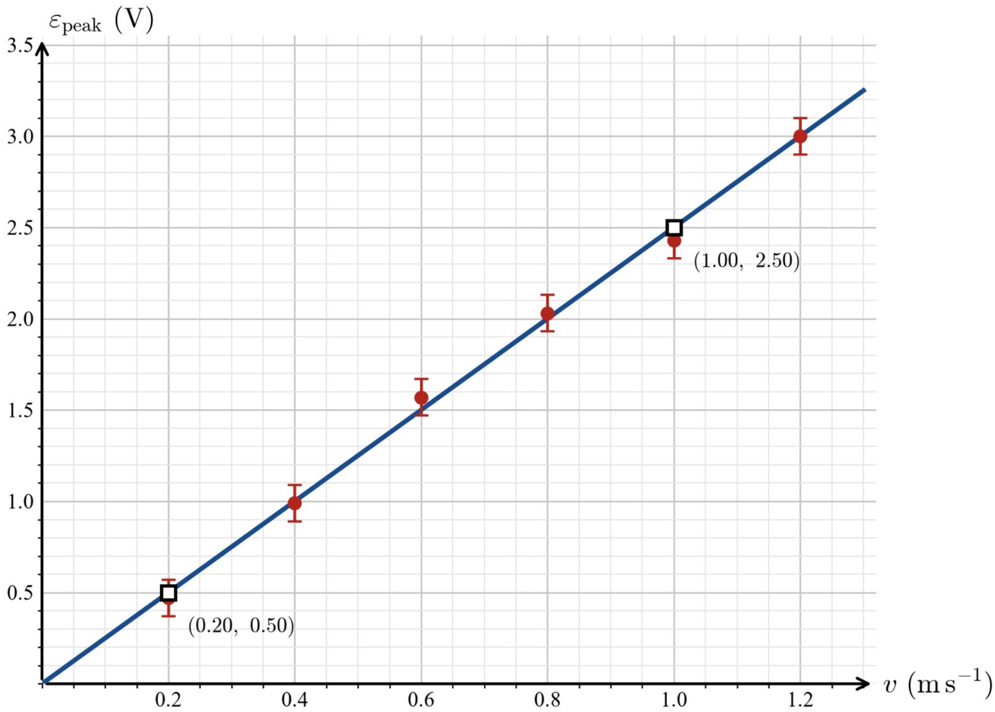
(a) Independent variable: the **speed** v of the magnet (set by the motorised carriage). Dependent variable: the **peak emf** ε (measured by the data logger). A controlled variable (any one): the coil used (its number of turns and area), the strength of the magnet, and the separation between the magnet and the coil as it passes. **(1 mark** IV = speed; **1 mark** DV = peak emf; **1 mark** one valid controlled variable, taken from the method.)

(b) As the magnet moves past the coil, the magnetic flux $\Phi_B=B_\perp A$ through the coil changes (the field of the magnet threading the coil rises and then falls). By Faraday's law, $\varepsilon=-N\dfrac{\Delta\Phi_B}{\Delta t}$, this changing flux through the coil induces an emf; the faster the flux changes, the larger the emf. **(1 mark** the moving magnet changes the flux **through the coil**; **1 mark** by Faraday's law a changing flux induces the emf.)

(c) The induced emf lasts only for the brief moment the magnet passes the coil and changes rapidly, reaching a short-lived peak. A data logger samples the voltage many times per second, so it can capture this fast, momentary peak accurately, whereas an analogue voltmeter is too slow to respond to it. **(1 mark: the data logger samples fast enough to capture the brief peak emf that a slow analogue meter would miss.)**

(d) Repeating each measurement and averaging reduces the effect of random errors on the result, giving a more reliable (precise) mean value of the peak emf at each speed. **(1 mark: repeats reduce the effect of random errors / improve precision of the mean.)**

(e) The completed graph is shown below: ε on the vertical axis, v on the horizontal axis; each point carries a $\pm0.10\,\mathrm{V}$ uncertainty bar; a straight line of best fit is drawn through the origin, balancing the scatter of the points.



(**1 mark** correct axes (ε vs v) with sensible scales filling the grid; **1 mark** all six points plotted correctly; **1 mark** uncertainty bars of ± 0.10 V drawn; **1 mark** a single straight line of best fit; **1 mark** the line balances the points and passes near the origin.)

(f) Using two well-separated points **on the line of best fit** — for example $(0.20, 0.50)$ and $(1.00, 2.50)$:

$$\text{gradient} = \frac{\Delta\varepsilon}{\Delta v} = \frac{2.50 - 0.50}{1.00 - 0.20} = \frac{2.00}{0.80} = 2.50\ \text{V s m}^{-1}.$$

(**1 mark** two well-separated on-line points used (not raw data points); **1 mark** correct gradient $2.50\ \text{V s m}^{-1}$.)

(g) The gradient equals $k = \dfrac{N\,\Delta\Phi_B}{d}$, so

$$\Delta\Phi_B = \frac{kd}{N} = \frac{2.50 \times 5.0 \times 10^{-2}}{500} = \frac{0.125}{500} = 2.5 \times 10^{-4}\ \text{Wb}.$$

∴ the flux through one turn of the coil changes by about 2.5×10^{-4} Wb as the magnet passes. (**1 mark** rearranges to $\Delta\Phi_B = \dfrac{kd}{N}$; **1 mark** substitutes the gradient, N and d; **1 mark** correct value 2.5×10^{-4} Wb.)

(h) The gradient would **double** (to about $5.0\ \text{V s m}^{-1}$). Since $k = \dfrac{N\,\Delta\Phi_B}{d}$, the gradient is proportional to the number of turns N; with $\Delta\Phi_B$ and d unchanged, doubling N doubles k, so the line becomes twice as steep. (**1 mark** predicts the gradient doubles; **1 mark** justified via $k \propto N$.)

End of solutions

Practice Exam 5 — Hard

- Reading time: **15 minutes**
- Writing time: **2 hours 30 minutes**
- Section A: 20 questions, 20 marks
- Section B: 19 questions, 100 marks
- Total 120 marks

Approved materials

- One scientific calculator
- Pre-written notes (one folded A3 sheet or two A4 sheets bound together by tape)

A formula sheet is provided at the end of this examination.

Students are **not** permitted to bring mobile phones and/or any unauthorised electronic devices into the examination room.

Section A — Multiple-choice questions (20 marks)

Answer **all** questions. Choose the response that is **correct** or that **best answers** the question. A correct answer scores 1; an incorrect answer scores 0. Marks will **not** be deducted for incorrect answers. No marks will be given if more than one answer is completed for any question. Where a numerical answer is required, use the constants given on the formula sheet. Unless otherwise indicated, the diagrams in this book are **not** drawn to scale.

Question 1

A flywheel used for short-term energy storage spins about a vertical axis. A bolt is fixed to the rim at a radius of $0.60\,\text{m}$ and the rim completes one revolution every $0.040\,\text{s}$. The speed of the bolt is closest to:

A. $47\,\text{m s}^{-1}$

B. $94\,\text{m s}^{-1}$

C. $188\,\text{m s}^{-1}$

D. $15\,\text{m s}^{-1}$

Question 2

At a biomass plant, wood pellets leave the end of a horizontal conveyor at $5.0\,\text{m s}^{-1}$ from a height of $2.0\,\text{m}$ above a hopper. Ignoring air resistance, the speed of a pellet as it reaches the hopper is closest to:

A. $8.0\,\text{m s}^{-1}$

B. $6.3\,\text{m s}^{-1}$

C. $5.0\,\text{m s}^{-1}$

D. $11.3\,\text{m s}^{-1}$

Question 3

A drop-forge hammer of mass $200\,\text{kg}$ strikes a billet at $6.0\,\text{m s}^{-1}$ and is brought to rest in $0.015\,\text{s}$. The average force exerted on the hammer by the billet is closest to:

A. $1.2\times10^{3}\,\text{N}$

B. $18\,\text{N}$

C. $8.0\times10^{4}\,\text{N}$

D. $1.6\times10^{5}\,\text{N}$

Question 4

A crane lifts a $500\,\text{kg}$ load through a height of $12\,\text{m}$. The lifting motor is $80\,\%$ efficient. The electrical energy the motor must draw is closest to:

A. $5.9\times10^{4}\,\text{J}$

B. $4.7\times10^{4}\,\text{J}$

C. $7.5\times10^{3}\,\text{J}$

D. $7.4\times10^{4}\,\text{J}$

Question 5

A space-based solar power satellite is to orbit the Earth in a circular orbit at an altitude of $800\,\text{km}$ above the surface. The orbital speed of the satellite is closest to:

A. $7.91\times10^{3}\,\text{m s}^{-1}$

B. $7.45\times10^{3}\,\text{m s}^{-1}$

C. $2.23\times10^{4}\,\text{m s}^{-1}$

D. $5.55\times10^{7}\,\text{m s}^{-1}$

Question 6

An electrostatic precipitator has two parallel plates $0.30\,\text{m}$ apart with a potential difference of $40\,\text{kV}$ between them. The electric field strength between the plates is closest to:

A. $1.3\times10^{5}\,\text{N C}^{-1}$

B. $1.2\times10^{4}\,\text{N C}^{-1}$

C. $1.3\times10^{2}\,\text{N C}^{-1}$

D. $6.7\times10^{4}\,\text{N C}^{-1}$

Question 7

In a mass spectrometer, an ion of mass $3.0 \times 10^{-26}\,\text{kg}$ and charge $1.6 \times 10^{-19}\,\text{C}$ moves at $2.0 \times 10^{5}\,\text{m s}^{-1}$ perpendicular to a uniform magnetic field of $0.50\,\text{T}$. The radius of its circular path is closest to:

A. $3.8 \times 10^{-2}\,\text{m}$

B. $1.9 \times 10^{-2}\,\text{m}$

C. $7.5 \times 10^{-2}\,\text{m}$

D. $13.3\,\text{m}$

Question 8

A straight busbar of length $2.5\,\text{m}$ carries a current of $800\,\text{A}$ at right angles to a uniform magnetic field of $0.15\,\text{T}$. The magnitude of the force on the busbar is closest to:

A. $2.0 \times 10^{3}\,\text{N}$

B. $1.2 \times 10^{2}\,\text{N}$

C. $1.3 \times 10^{4}\,\text{N}$

D. $3.0 \times 10^{2}\,\text{N}$

Question 9

A transmission line of resistance $8.0\,\Omega$ carries a current of $50\,\text{A}$. The power dissipated in the line is closest to:

A. $400\,\text{W}$

B. $20\,\text{kW}$

C. $3.2\,\text{kW}$

D. $40\,\text{kW}$

Question 10

A coil of 500 turns and area $0.020\,\text{m}^2$ sits with its plane perpendicular to a magnetic field. The field falls uniformly from $0.40\,\text{T}$ to zero in $0.10\,\text{s}$. The average emf induced in the coil is closest to:

A. $40\,\text{V}$

B. $0.08\,\text{V}$

C. $4.0\,\text{V}$

D. $2.0 \times 10^{3}\,\text{V}$

Question 11

A generator produces a sinusoidal AC output with a peak voltage of $565\,\text{V}$. The rms voltage of this output is closest to:

A. $799\,\text{V}$

B. $283\,\text{V}$

C. $400\,\text{V}$

D. $1130\,\text{V}$

Question 12

Which one of the following best explains how a DC generator produces a direct current from a single coil rotating in a magnetic field?

A. A pair of slip rings reverses the coil's connections to the external circuit every half-turn.

B. The magnetic field the coil rotates in reverses direction every half-turn.

C. The coil rotates in one direction only, so the induced emf never changes sign.

D. A split-ring commutator reverses the coil's connections to the external circuit every half-turn, keeping the output current in the same direction.

Question 13

Light of wavelength $450\,\text{nm}$ falls on a solar cell. The energy of each photon is closest to:

A. $1.38\,\text{eV}$

B. $2.76\,\text{eV}$

C. $2.76 \times 10^{-9}\,\text{eV}$

D. $4.42 \times 10^{-19}\,\text{eV}$

Question 14

In a factory inspection rig, a laser of wavelength $600\,\text{nm}$ passes through two slits $0.20\,\text{mm}$ apart onto a screen $2.5\,\text{m}$ away. The spacing between adjacent bright fringes is closest to:

A. $7.5\,\text{mm}$

B. $3.75\,\text{mm}$

C. $15\,\text{mm}$

D. $7.5\,\mu\text{m}$

Question 15

An electron in an electron microscope travels at $8.0 \times 10^{6}\,\text{m s}^{-1}$ (non-relativistic). Its de Broglie wavelength is closest to:

A. $8.3 \times 10^{-41}\,\text{m}$

B. $1.8 \times 10^{-10}\,\text{m}$

C. $9.1 \times 10^{-11}\,\text{m}$

D. $4.5 \times 10^{-11}\,\text{m}$

Question 16

In a sodium vapour lamp, an electron in a sodium atom drops from an energy level of $-3.0\,\text{eV}$ to one of $-5.0\,\text{eV}$. The wavelength of the emitted photon is closest to:

A. $414\,\text{nm}$

B. $248\,\text{nm}$

C. $155\,\text{nm}$

D. $621\,\text{nm}$

Question 17

In a particle accelerator, a proton of rest energy $938\,\text{MeV}$ is accelerated until its Lorentz factor is $\gamma = 1.25$. Its kinetic energy is closest to:

A. $188\,\text{MeV}$

B. $235\,\text{MeV}$

C. $938\,\text{MeV}$

D. $1173\,\text{MeV}$

Question 18

After an experiment, a voltmeter is checked against a calibrated standard and found to have given readings that are all $3\,\%$ too high. This is best described as:

A. a systematic error — every reading is shifted by the same proportion, and averaging cannot remove the shift.

B. a random error — the readings scatter about the true value, and averaging reduces the scatter.

C. a mistake made while reading the meter, which can be put right by discarding the affected values.

D. a loss of resolution of the meter's display.

Question 19

Five measurements of a generator's power output cluster very closely together, but all lie well above the true value. These measurements are best described as:

A. accurate but not precise.

B. neither accurate nor precise.

C. precise but not accurate.

D. both accurate and precise.

Question 20

In a transmission-line experiment, the power loss P_{loss} is measured for several line currents I. To obtain a straight line through the origin whose gradient is the line resistance R_{line}, a student should plot:

A. P_{loss} against I, with gradient R_{line}.

B. P_{loss} against $1/I^2$, with gradient R_{line}.

C. I^2 against P_{loss}, with gradient R_{line}.

D. P_{loss} against I^2, with gradient R_{line}.

Practice Exam 5 — Section B

Answer **all** questions in the spaces provided. Write your responses in English. Where an answer box is provided, write your final answer in the box. If an answer box has a unit printed in it, give your answer in that unit. In questions where more than one mark is available, appropriate working **must** be shown. Take $g = 9.81\ \mathrm{m\ s^{-2}}$ and $c = 3.00 \times 10^{8}\ \mathrm{m\ s^{-1}}$ where required; other constants are on the formula sheet. Unless otherwise indicated, the diagrams in this book are **not** drawn to scale.

Question 1 (5 marks)

At a biomass power plant, wood pellets leave the end of a horizontal conveyor belt moving at $3.5\ \mathrm{m\ s^{-1}}$, at a height of $1.8\ \mathrm{m}$ above a collection hopper.

a. Show that the time for a pellet to fall to the level of the hopper is $0.606\ \mathrm{s}$ (to three significant figures). 1 mark

b. Calculate the horizontal distance from the end of the belt at which the pellets land. Give your answer in m. 2 marks

c. In practice the pellets are light and air resistance is not negligible. Explain how the actual landing distance would compare with your answer to part **b.** 2 marks

Question 2 (4 marks)

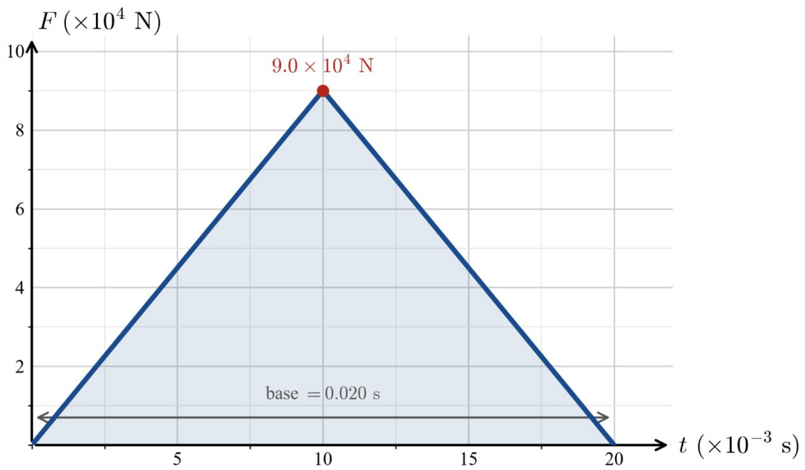
A flywheel energy-storage system stores energy in a heavy steel rim spinning about a vertical axis. A bolt of mass $0.25\ \mathrm{kg}$ is fixed to the rim at a radius of $0.55\ \mathrm{m}$. The rim completes one revolution every $0.045\ \mathrm{s}$.

a. Show that the speed of the bolt is $76.8\ \mathrm{m\ s^{-1}}$ (to three significant figures). 2 marks

b. Calculate the magnitude of the net force on the bolt, and state its direction. Give the magnitude in N. 2 marks

Question 3 (5 marks)

An industrial drop-forge hammer of mass $150\ \mathrm{kg}$ falls and strikes a hot billet, moving downwards at $5.0\ \mathrm{m\ s^{-1}}$ at the instant of contact. A force sensor records the force on the hammer during the impact; the force–time graph is shown below.



a. Use the graph to find the impulse delivered to the hammer during the impact. Give the magnitude in $\mathrm{N\ s}$. 2 marks

b. Hence find the velocity of the hammer immediately after the impact, stating both its magnitude in $\mathrm{m\ s^{-1}}$ and its direction. 2 marks

c. The impact between the hammer and the billet is inelastic. State what this tells you about the kinetic energy of the system. 1 mark

Question 4 (4 marks)

In a pumped-hydro station, 1.2×10^6 kg of water is released and falls through a vertical drop of 85 m to drive a turbine.

a. Calculate the gravitational potential energy released by this water. Give your answer in J. 2 marks

b. The turbine–generator delivers 7.6×10^8 J of electrical energy from this fall. Calculate the percentage of the released energy that is dissipated to the environment, and name one form this dissipated energy takes. 2 marks

Question 5 (4 marks)

An inclined conveyor carries a loaded skip of total mass 320 kg up a slope at 25° to the horizontal, at constant velocity. The only forces acting on the skip are the force due to gravity, the normal force, and the cable tension acting up the slope; friction is negligible.

a. With reference to Newton's first law of motion, state the magnitude of the net force on the skip. 1 mark

b. Calculate the tension in the cable. Give your answer in N. 3 marks

Question 6 (6 marks)

A proposed space-based solar power satellite is to orbit the Earth in a circular orbit of radius 4.22×10^7 m measured from the centre of the Earth.

a. Show that the orbital speed of the satellite is $3.07 \times 10^3 \text{ m s}^{-1}$ (to three significant figures). 2 marks

b. Calculate the period of the orbit. Give your answer in h. 2 marks

c. The satellite's speed remains constant even though the gravitational force of the Earth continually acts on it. Explain why the gravitational force does not change the satellite's speed. 2 marks

Question 7 (5 marks)

An electrostatic precipitator removes ash from the flue gas of a power station. It has two parallel plates 0.25 m apart with a potential difference of 5.0×10^4 V between them.

a. Show that the electric field strength between the plates is $2.00 \times 10^5 \text{ N C}^{-1}$ (to three significant figures). 1 mark

b. A charged ash particle carries a charge of 8.0×10^{-15} C. Calculate the magnitude of the electric force on it. Give your answer in N. 2 marks

c. In a separate test rig, a free electron is accelerated from rest through a potential difference of 1.2 kV. Calculate the speed the electron reaches. Give your answer in m s^{-1}. 2 marks

Question 8 (5 marks)

In a mass spectrometer used to analyse coal-ash samples, singly-charged ions (charge 1.60×10^{-19} C) travel at $1.5 \times 10^5 \text{ m s}^{-1}$ into a uniform magnetic field of 0.40 T, directed perpendicular to their velocity. An ion follows a circular arc of radius 0.078 m.

a. Calculate the magnitude of the magnetic force on the ion. Give your answer in N. 2 marks

b. Explain why the magnetic field causes the ion to move in a circular arc rather than continuing in a straight line. 1 mark

c. Calculate the mass of the ion. Give your answer in kg. 2 marks

Question 9 (5 marks)

A simple DC motor drives a pump at a water-treatment works. Its single rectangular coil has 80 loops of wire; one side of the coil has length $0.12\,\mathrm{m}$ and lies in a uniform magnetic field of $0.35\,\mathrm{T}$. The coil carries a current of $4.0\,\mathrm{A}$.

a. Calculate the magnitude of the force on one $0.12\,\mathrm{m}$ side of the coil. Give your answer in N. 2 marks

b. State the function of the split-ring commutator in this motor. 1 mark

c. State two changes, **other than** changing the current, that would each increase the torque on the coil. 2 marks

Question 10 (6 marks)

A wind farm generates electricity that is stepped up by a transformer and sent along a transmission line to a town.

a. The generator produces $940\,\mathrm{V}$, which is stepped up to $22.0\,\mathrm{kV}$ by an ideal transformer whose primary coil has 150 turns. Show that the secondary coil has 3.51×10^3 turns (to three significant figures). 1 mark

b. At the sending end the line is at $22.0\,\mathrm{kV}$, but by the time it reaches the receiving-end substation the voltage has fallen to $20.5\,\mathrm{kV}$. Given that the total resistance of the line is $6.0\,\Omega$, calculate the current in the line. Give your answer in A.

2 marks

c. Use your current to calculate the power dissipated in the transmission line, and hence express this loss as a percentage of the power arriving at the receiving-end substation. 3 marks

Question 11 (4 marks)

Inside the wind-farm generator, a coil of 250 turns and area $0.040\,\mathrm{m}^2$ sits in a magnetic field directed perpendicular to the plane of the coil. As the rotor turns, this field changes from $0.60\,\mathrm{T}$ to $0.10\,\mathrm{T}$ in $0.025\,\mathrm{s}$.

a. Calculate the average emf induced in the coil during this change. Give your answer in V. 2 marks

b. Explain, in terms of magnetic flux, why an emf is induced in the coil while the field changes from $0.60\,\mathrm{T}$ to $0.10\,\mathrm{T}$, but no emf would be induced if the field were steady at $0.60\,\mathrm{T}$. 2 marks

Question 12 (4 marks)

A large battery energy-storage system supplies an inverter that feeds sinusoidal AC into the mains grid.

a. State the function of the inverter in this system. 1 mark

b. The output voltage of the inverter is sinusoidal with a peak value of $311\,\mathrm{V}$. What is the rms voltage of this output? Give your answer in V. 2 marks

c. State what the rms value of an alternating voltage represents. 1 mark

Question 13 (4 marks)

A student investigates a small generator in which a single coil is rotated at a steady rate in a uniform magnetic field. The coil can be connected to the external circuit through a split-ring commutator or through a pair of slip rings, and the output voltage is displayed on an oscilloscope.

a. Describe the voltage–time trace shown on the oscilloscope for each of the two connections. 2 marks

b. Explain, in terms of the rate of change of magnetic flux through the coil, why the induced emf has its greatest magnitude when the plane of the coil is parallel to the magnetic field. 2 marks

Question 14 (5 marks)

A photocell used in a light sensor has a cathode with a work function of $2.2\,\mathrm{eV}$. It is illuminated by monochromatic light of wavelength $420\,\mathrm{nm}$.

a. Show that the energy of each photon is $2.96\,\text{eV}$ (to three significant figures). 2 marks

b. Calculate the maximum kinetic energy of the emitted photoelectrons, in eV and in J. 2 marks

c. The photocell is then moved twice as far from the light source, so the light falling on it is less intense. State the effect, if any, on the maximum kinetic energy of the emitted photoelectrons. 1 mark

Question 15 (4 marks)

In a quality-control rig, a laser of wavelength $640\,\text{nm}$ shines through two narrow slits $0.25\,\text{mm}$ apart onto a screen $3.0\,\text{m}$ away, producing an interference pattern.

a. State the condition, in terms of path difference, for a bright fringe to form on the screen. 1 mark

b. Calculate the spacing between adjacent bright fringes on the screen. Give your answer in mm. 2 marks

c. State and explain what happens to the fringe spacing if the laser is replaced by one of shorter wavelength. 1 mark

Question 16 (3 marks)

A sodium vapour street lamp emits its characteristic yellow light when electrons in sodium atoms make a transition between two energy levels. One such transition releases a photon of energy $2.10\,\text{eV}$.

a. What is the wavelength of the light emitted by this transition? Give your answer in nm. 2 marks

b. Explain why the lamp's spectrum consists of a set of discrete wavelengths rather than a continuous range. 1 mark

Question 17 (4 marks)

An electron microscope is used to inspect welds. Its electrons are accelerated to a speed of $6.0 \times 10^{6}\,\text{m s}^{-1}$, which may be treated as non-relativistic.

a. Calculate the momentum of one of these electrons, and use it to determine the de Broglie wavelength of the electrons. Give the wavelength in m. 2 marks

b. Explain why electrons, rather than visible light, are used to resolve very small features. 1 mark

c. A proton is moving at the same speed as these electrons. State whether the de Broglie wavelength of the proton is longer than, the same as, or shorter than that of the electrons. 1 mark

Question 18 (4 marks)

In a synchrotron light source used for materials analysis, electrons travel around the ring at $0.80\,c$. The rest energy of an electron is $8.20 \times 10^{-14}\,\text{J}$.

a. Show that the Lorentz factor for these electrons is $\gamma = 1.67$ (to three significant figures). 1 mark

b. Calculate the kinetic energy of an electron at this speed. Give your answer in MeV. 2 marks

c. A straight section of the ring is $12\,\text{m}$ long as measured in the laboratory. (Circle your answer.) An observer travelling with the electrons would measure this section to be:

longer / the same length / shorter.

Justify your choice. 1 mark

Question 19 (19 marks)

A student models the fall of water in a pumped-hydro scheme in the laboratory. A small steel sphere is released **from rest** and slides down a smooth curved guide from a release height h. As the sphere leaves the bottom of the guide, a light gate measures its speed v. The student repeats the measurement at a range of release heights.

If friction is negligible, the gravitational potential energy of the sphere at the top is fully converted to kinetic energy at the bottom, so that

$$1/2 m v^2 = m g h \Rightarrow v^2 = 2 g h.$$

The student therefore plots v^2 against h.

a. Identify the independent and dependent variables in this investigation, and give one variable that should be controlled. 3 marks

b. With reference to energy transformations, explain why v^2 is expected to be proportional to h. 2 marks

c. Explain why the guide is made as smooth as possible, referring to the effect any friction would have on the measured values of v^2. 1 mark

d. Each value of v is obtained from three trials that are then averaged. State the purpose of repeating the measurements in this way. 1 mark

The student's results are shown in the table below. Each value of v^2 has an uncertainty of $\pm 0.5\,\mathrm{m^2\,s^{-2}}$.

h (m)	0.20	0.40	0.60	0.80	1.00	1.20
v^2 ($\mathrm{m^2\,s^{-2}}$)	4.1	7.6	12.0	15.4	19.9	23.3

e. On the grid provided, plot a graph of v^2 (vertical axis) against h (horizontal axis). Include an uncertainty bar of $\pm 0.5\,\mathrm{m^2\,s^{-2}}$ on each point and draw the line of best fit.

5 marks

f. Choose two well-separated points **on your line of best fit** and use them to determine the gradient of the graph. Give your answer in $\mathrm{m^2\,s^{-2}\,m^{-1}}$. 2 marks

g. For this experiment the gradient equals $2g$, where g is the local gravitational field strength. Use your value of the gradient to find g, and comment on how it compares with the accepted value of $9.81\,\mathrm{m\,s^{-2}}$. 3 marks

h. The experiment is repeated with a steel sphere of twice the mass. Predict how the graph would change, and justify your prediction. 2 marks

Practice Exam 5 — Formula Sheet

This formula sheet is provided for use with all practice examinations in this booklet. It covers the same items as the official VCE Physics Formula Sheet.

Motion and related energy transformations

velocity	$v=\frac{\Delta s}{\Delta t}$
acceleration	$a=\frac{\Delta v}{\Delta t}$
constant acceleration	$v=u+at$
	$s=ut+\frac{1}{2}at^2$
	$s=vt-\frac{1}{2}at^2$
	$v^2=u^2+2as$
	$s=\frac{1}{2}(u+v)t$
Newton's second law	$\Sigma F=ma$
uniform circular motion	$F_{\text{net}}=\frac{mv^2}{r}$
	$v=\frac{2\pi r}{T}$
Hooke's law	$F=-kx$
elastic potential energy	$E_s=\frac{1}{2}kx^2$
gravitational potential energy	$E_g=mg\Delta h$
kinetic energy	$E_k=\frac{1}{2}mv^2$
universal gravitation	$F_g=\frac{Gm_1m_2}{r^2}$
gravitational field	$g=\frac{GM}{r^2}$
impulse	$F\Delta t=m\Delta v$
momentum	$p=mv$

Einstein's special theory of relativity

Lorentz factor	$\gamma=\frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$
time dilation	$t=\gamma t_0$
length contraction	$L=\frac{L_0}{\gamma}$
rest energy	$E_0=mc^2$
total energy	$E_{\text{total}}=E_k+E_0=\gamma mc^2$

relativistic kinetic energy $E_k = (\gamma - 1) m c^2$

Fields and application of field concepts

uniform electric field $E = \frac{V}{d}$

charge accelerated by a field $\frac{1}{2} m v^2 = q V$

field of a point charge $E = \frac{k Q}{r^2}$

electric force on a charge $F = q E$

Coulomb's law $F = \frac{k q_1 q_2}{r^2}$

magnetic force on a moving charge $F = q v B$

force on a current-carrying conductor $F = n I l B$

radius of a charged particle's path $r = \frac{m v}{q B}$

Generation and transmission of electricity

current $I = \frac{V}{R}$

power $P = V I$

resistors in series $R_T = R_1 + R_2 + \ldots$

resistors in parallel $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$

ideal transformer $\frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{I_2}{I_1}$

rms voltage $V_{\text{RMS}} = \frac{1}{\sqrt{2}} V_{\text{peak}}$

rms current $I_{\text{RMS}} = \frac{1}{\sqrt{2}} I_{\text{peak}}$

electromagnetic induction $\varepsilon = -N \frac{\Delta \Phi_B}{\Delta t}$

magnetic flux $\Phi_B = B_{\perp} A$

voltage drop along a line $V_{\text{drop}} = I_{\text{line}} R_{\text{line}}$

power loss in a line $P_{\text{loss}} = I_{\text{line}}^2 R_{\text{line}}$

Waves

wave equation $v = f \lambda$

constructive interference path difference $= n \lambda$

destructive interference path difference $= \left(n + \frac{1}{2}\right) \lambda$

fringe spacing $\Delta x = \frac{\lambda L}{d}$ when $L \gg d$

The nature of light and matter

photoelectric effect	$E_{k\,\max} = hf - \phi$
photon energy	$E = hf = \frac{hc}{\lambda}$
photon momentum	$p = \frac{h}{\lambda}$
de Broglie wavelength	$\lambda = \frac{h}{p}$

Data

acceleration due to gravity at Earth's surface	$g = 9.81$ m s^{-2}
mass of the electron	$m_e = 9.11 \times 10^{-31}$ kg
magnitude of the charge of the electron	$q_e = 1.60 \times 10^{-19}$ C
Planck's constant	$h = 6.63 \times 10^{-34}$ J s
	$h = 4.14 \times 10^{-15}$ eV s
speed of light in a vacuum	$c = 3.00 \times 10^{8}$ m s^{-1}
universal gravitational constant	$G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}
mass of Earth	$M_E = 5.97 \times 10^{24}$ kg
radius of Earth	$R_E = 6.37 \times 10^{6}$ m
Coulomb constant	$k = 8.99 \times 10^{9}$ N m^2 C^{-2}

Metric (SI) multipliers

pico (p)	10^{-12}	kilo (k)	10^{3}
nano (n)	10^{-9}	mega (M)	10^{6}
micro (μ)	10^{-6}	giga (G)	10^{9}
milli (m)	10^{-3}	tera (T)	10^{12}

Unit conversions

1 tonne (t)	$= 10^{3}$ kg
1 kilowatt hour (kW h)	$= 3.6 \times 10^{6}$ J

Nomenclature

force due to gravity	F_g
force on A by B	$F_{\text{on A by B}}$
normal force	F_N

End of Formula Sheet

Practice Exam 5 — solutions

Section A — answer key

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

Question 1 — B. $v=\frac{2\pi r}{T}=\frac{2\pi\times 0.60}{0.040}=94\,\mathrm{m\ s^{-1}}$. A uses $\pi r/T$ (circumference as πr instead of $2\pi r$), giving $47\,\mathrm{m\ s^{-1}}$; C uses the diameter in place of the radius, giving $188\,\mathrm{m\ s^{-1}}$; D uses r/T and omits the 2π, giving $15\,\mathrm{m\ s^{-1}}$.

Question 2 — A. Time to fall: $t=\sqrt{2h/g}=0.639\,\mathrm{s}$; vertical speed $v_y=gt=6.26\,\mathrm{m\ s^{-1}}$; landing speed $v=\sqrt{u^2+v_y^2}=\sqrt{5.0^2+6.26^2}=8.0\,\mathrm{m\ s^{-1}}$. B gives v_y only (ignores the horizontal component); C gives the horizontal u only (ignores the vertical); D adds the components arithmetically ($5.0+6.26=11.3$) instead of using Pythagoras.

Question 3 — C. $F=\frac{m\Delta v}{\Delta t}=\frac{200\times 6.0}{0.015}=8.0\times 10^4\,\mathrm{N}$. A quotes the impulse $m\Delta v=1.2\times 10^3\,\mathrm{N\ s}$ as if it were the force (forgets to divide by Δt); B multiplies by Δt instead of dividing ($1200\times 0.015=18$); D assumes the hammer rebounds at $6.0\,\mathrm{m\ s^{-1}}$, using $\Delta v=12\,\mathrm{m\ s^{-1}}$ ($1.6\times 10^5\,\mathrm{N}$), but the stem states it is brought to rest.

Question 4 — D. Useful work $=mgh=500\times 9.81\times 12=5.89\times 10^4\,\mathrm{J}$; input $=\frac{mgh}{0.80}=7.4\times 10^4\,\mathrm{J}$. A omits the efficiency (quotes mgh); B multiplies by 0.80 instead of dividing ($4.7\times 10^4\,\mathrm{J}$); C omits g ($500\times 12/0.80=7.5\times 10^3$).

Question 5 — B. $v=\sqrt{\frac{GM}{r}}$ with $r=R_E+800\,\mathrm{km}=7.17\times 10^6\,\mathrm{m}$: $v=7.45\times 10^3\,\mathrm{m\ s^{-1}}$. A uses $r=R_E$ and ignores the altitude (7.91×10^3); C uses $r=800\,\mathrm{km}$ alone and omits R_E (2.23×10^4 — the classic altitude error); D omits the square root, giving $GM/r=5.55\times 10^7$.

Question 6 — A. $E=\frac{V}{d}=\frac{4.0\times 10^4}{0.30}=1.3\times 10^5\,\mathrm{N\ C^{-1}}$. B multiplies instead of divides ($V\times d=1.2\times 10^4$); C fails to convert $40\,\mathrm{kV}$ to volts ($40/0.30=1.3\times 10^2$); D uses twice the plate separation ($4.0\times 10^4/0.60=6.7\times 10^4$).

Question 7 — C. $r=\frac{mv}{qB}=\frac{3.0\times 10^{-26}\times 2.0\times 10^5}{1.6\times 10^{-19}\times 0.50}=7.5\times 10^{-2}\,\mathrm{m}$. A drops B from the denominator ($mv/q=3.8\times 10^{-2}$); B places B in the numerator ($mvB/q=1.9\times 10^{-2}$); D inverts the formula ($qB/(mv)=13.3$).

Question 8 — D. $F=nIlB=1\times 800\times 2.5\times 0.15=3.0\times 10^2\,\mathrm{N}$. A omits B ($800\times 2.5=2.0\times 10^3$); B omits the length l ($800\times 0.15=1.2\times 10^2$); C divides by B instead of multiplying ($800\times 2.5/0.15=1.3\times 10^4$).

Question 9 — B. $P_{loss}=I^2 R=50^2\times 8.0=2.0\times 10^4\,\text{W}=20\,\text{kW}$. A forgets to square the current ($I\,R=400\,\text{W}$); C squares the resistance instead of the current ($I\,R^2=3.2\,\text{kW}$); D doubles the correct value ($40\,\text{kW}$), e.g. by counting both conductors of the line.

Question 10 — A. $\varepsilon=\frac{N\,\Delta\Phi_B}{\Delta t}=\frac{N\,A\,\Delta B}{\Delta t}=\frac{500\times 0.020\times 0.40}{0.10}=40\,\text{V}$. B omits N ($0.08\,\text{V}$); C omits Δt ($N\,A\,\Delta B=4.0$); D omits the area ($N\,\Delta B/\Delta t=2.0\times 10^3$).

Question 11 — C. $V_{RMS}=\frac{V_{peak}}{\sqrt{2}}=\frac{565}{\sqrt{2}}=400\,\text{V}$. A multiplies by $\sqrt{2}$ ($799\,\text{V}$); B divides by 2 ($283\,\text{V}$); D uses $2V_{peak}$ (peak-to-peak confusion, $1130\,\text{V}$).

Question 12 — D. A split-ring commutator swaps the coil's connections to the external circuit every half-turn, so the external current keeps one direction (a pulsating DC). A describes slip rings, which give AC; B is false (the field is fixed); C is false (the emf in the coil does reverse each half-turn — the commutator is what makes the output DC).

Question 13 — B. $E=\frac{h\,c}{\lambda}=\frac{4.14\times 10^{-15}\times 3.00\times 10^8}{450\times 10^{-9}}=2.76\,\text{eV}$. A uses twice the wavelength ($900\,\text{nm}$, giving $1.38\,\text{eV}$); C fails to convert nm to m ($2.76\times 10^{-9}\,\text{eV}$); D uses h in J s and reports the joule value (4.42×10^{-19}) as if it were in eV.

Question 14 — A. $\Delta x=\frac{\lambda L}{d}=\frac{600\times 10^{-9}\times 2.5}{0.20\times 10^{-3}}=7.5\,\text{mm}$. B uses twice the slit separation ($3.75\,\text{mm}$); C uses half the separation ($15\,\text{mm}$); D fails to convert $0.20\,\text{mm}$ to metres, giving $7.5\,\mu\text{m}$.

Question 15 — C. $\lambda=\frac{h}{m\,v}=\frac{6.63\times 10^{-34}}{9.11\times 10^{-31}\times 8.0\times 10^6}=9.1\times 10^{-11}\,\text{m}$. A omits the electron mass ($h/v=8.3\times 10^{-41}$); B uses $1/2\,m\,v$ in the denominator (1.8×10^{-10}); D uses $2\,m\,v$ (4.5×10^{-11}).

Question 16 — D. The photon energy is the level difference, $\Delta E=|-3.0-(-5.0)|=2.0\,\text{eV}$; $\lambda=\frac{h\,c}{\Delta E}=621\,\text{nm}$. A uses the $3.0\,\text{eV}$ level alone ($414\,\text{nm}$); B uses the $5.0\,\text{eV}$ level alone ($248\,\text{nm}$); C adds the magnitudes ($8.0\,\text{eV}$, giving $155\,\text{nm}$).

Question 17 — B. $E_k=(\gamma-1)\,m\,c^2=(1.25-1)\times 938=235\,\text{MeV}$. A uses $(1-1/\gamma)\,m\,c^2=188\,\text{MeV}$; C quotes the rest energy alone ($938\,\text{MeV}$); D uses $\gamma\,m\,c^2$ (the total energy, $1173\,\text{MeV}$) and forgets the -1.

Question 18 — A. A fixed fractional offset on every reading is a systematic error; it shifts every reading (and the mean) by the same proportion, so no amount of averaging removes it. B (random) is wrong because the offset does not scatter the readings; C (mistake) is wrong because a consistent calibration offset is not a one-off blunder that can be discarded; D confuses a calibration offset with the resolution of the display.

Question 19 — C. Tightly clustered readings indicate high precision; all lying above the true value indicates poor accuracy — precise but not accurate. A reverses the two ideas; B and D are inconsistent with the description.

Question 20 — D. Since $P_{loss}=I^2 R_{line}$, plotting P_{loss} against I^2 gives a straight line through the origin with gradient R_{line}. A plots against I (not linear); B uses $1/I^2$ (a curve/reciprocal); C swaps the axes, giving a gradient of $1/R_{line}$.

Section B — worked solutions

Question 1 (5 marks)

a. (1 mark) The vertical motion starts from rest ($u_y=0$):

$$h=1/2\,g\,t^2\Rightarrow t=\sqrt{\frac{2h}{g}}=\sqrt{\frac{2\times 1.8}{9.81}}=0.606\,\text{s}\,(3\text{ s.f.})\text{, as required.}$$

b. (2 marks) The horizontal velocity is constant at $3.5\,\text{m s}^{-1}$ [1]:

$$x = u\,t = 3.5 \times 0.606 = 2.12\,\text{m}\,[1].$$

c. (2 marks) Air resistance acts to oppose the pellet's motion, so it has a backward horizontal component that reduces the horizontal velocity as the pellet falls [1]. The pellet therefore travels a **shorter** horizontal distance than the $2.12\,\text{m}$ calculated for the no-air-resistance case [1].

∴ the pellets land less than $2.12\,\text{m}$ from the end of the belt.

Question 2 (4 marks)

a. (2 marks) The bolt travels one circumference each period:

$$v = \frac{2\pi r}{T} = \frac{2\pi \times 0.55}{0.045} = 76.8\,\text{m s}^{-1}\,(3\text{ s.f.})\text{, as required.}$$

[1 for $v = 2\pi r / T$; 1 for the value]

b. (2 marks) The net force is the centripetal force:

$$F_{\text{net}} = \frac{m v^2}{r} = \frac{0.25 \times 76.8^2}{0.55} = 2.68 \times 10^3\,\text{N}\,[1].$$

The force is directed **towards the centre of the circle** (radially inwards) [1].

Question 3 (5 marks)

a. (2 marks) The impulse is the area under the force–time graph. The graph is a triangle of base $0.020\,\text{s}$ and peak force $9.0 \times 10^4\,\text{N}$ [1]:

$$J = 1/2 \times 0.020 \times 9.0 \times 10^4 = 900\,\text{N s}\,[1].$$

b. (2 marks) The impulse equals the change in momentum, $J = m\,\Delta v$:

$$\Delta v = \frac{J}{m} = \frac{900}{150} = 6.0\,\text{m s}^{-1}\,[1].$$

The impulse acts upward (opposing the downward motion), so the hammer's velocity changes from $5.0\,\text{m s}^{-1}$ downward to $6.0 - 5.0 = 1.0\,\text{m s}^{-1}$ **upward** [1].

∴ immediately after the impact the hammer moves at $1.0\,\text{m s}^{-1}$ upward.

c. (1 mark) In an inelastic impact the total kinetic energy of the system is **not** conserved — it decreases, with the "lost" kinetic energy transformed into heat, sound and deformation of the billet. (Momentum is still conserved.)

Question 4 (4 marks)

a. (2 marks)

$$E_g = m\,g\,\Delta h = 1.2 \times 10^6 \times 9.81 \times 85 = 1.00 \times 10^9\,\text{J}\,[2].$$

[1 for substitution; 1 for the value]

b. (2 marks) Energy dissipated $= 1.00 \times 10^9 - 7.6 \times 10^8 = 2.41 \times 10^8\,\text{J}$; as a fraction of the released energy [1]:

$$\frac{2.41 \times 10^8}{1.00 \times 10^9} = 0.240 = 24\,\%\,[1].$$

The dissipated energy appears mainly as heat (also sound).

∴ about $24\,\%$ of the released energy is dissipated, largely as heat.

Question 5 (4 marks)

a. (1 mark) The skip moves at constant velocity, so by Newton's first law the forces are balanced and the net force is **zero**.

b. (3 marks) Resolving along the slope, with zero net force and negligible friction, the tension balances the component of the force due to gravity acting down the slope [1]:

$$T = m g \sin\theta = 320 \times 9.81 \times \sin 25^\circ [1]$$

$$T = 320 \times 9.81 \times 0.4226 = 1.33 \times 10^3 \,\mathrm{N} [1].$$

∴ the cable tension is $1.33 \times 10^3\,\mathrm{N}$.

Question 6 (6 marks)

a. (2 marks) For a circular orbit the gravitational force provides the centripetal force, $\frac{G M m}{r^2} = \frac{m v^2}{r}$, so $v = \sqrt{\frac{G M}{r}}$ [1]:

$$v = \sqrt{\frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24}}{4.22 \times 10^7}} = 3.07 \times 10^3 \,\mathrm{m\,s^{-1}} (3 \text{ s.f.}), \text{as required} [1].$$

b. (2 marks) The period is the circumference divided by the orbital speed:

$$T = \frac{2\pi r}{v} = \frac{2\pi \times 4.22 \times 10^7}{3.07 \times 10^3} = 8.63 \times 10^4 \,\mathrm{s} [1]$$

$$= \frac{8.63 \times 10^4}{3600} = 24.0 \,\mathrm{h} [1].$$

c. (2 marks) The gravitational force on the satellite is directed towards the centre of the Earth, perpendicular to the satellite's velocity, which is tangential to the circular orbit [1]. Since the force is perpendicular to the motion, it does no work on the satellite, so the satellite's kinetic energy — and hence its speed — remains constant [1].

Question 7 (5 marks)

a. (1 mark)

$$E = \frac{V}{d} = \frac{5.0 \times 10^4}{0.25} = 2.00 \times 10^5 \,\mathrm{N\,C^{-1}} (3 \text{ s.f.}), \text{as required.}$$

b. (2 marks)

$$F = q E = 8.0 \times 10^{-15} \times 2.00 \times 10^5 = 1.6 \times 10^{-9} \,\mathrm{N} [2].$$

[1 for $F = q E$; 1 for the value]

c. (2 marks) The work done by the field equals the kinetic energy gained, $q V = 1/2 m v^2$ [1]:

$$v = \sqrt{\frac{2 q V}{m}} = \sqrt{\frac{2 \times 1.60 \times 10^{-19} \times 1.2 \times 10^3}{9.11 \times 10^{-31}}} = 2.05 \times 10^7 \,\mathrm{m\,s^{-1}} [1].$$

Question 8 (5 marks)

a. (2 marks)

$$F = q v B = 1.60 \times 10^{-19} \times 1.5 \times 10^5 \times 0.40 = 9.6 \times 10^{-15} \,\mathrm{N} [2].$$

[1 for $F = q v B$; 1 for the value]

b. (1 mark) The magnetic force is always perpendicular to the ion's velocity and has constant magnitude (the speed does not change), so it acts as a centripetal force of fixed size, continually turning the ion into a circular path rather than speeding it up or leaving it straight.

c. (2 marks) From $r = \frac{mv}{qB}$, rearranged for mass [1]:

$$m = \frac{rqB}{v} = \frac{0.078 \times 1.60 \times 10^{-19} \times 0.40}{1.5 \times 10^{5}} = 3.33 \times 10^{-26}\,\text{kg}\,[1].$$

Question 9 (5 marks)

a. (2 marks)

$$F = nIlB = 80 \times 4.0 \times 0.12 \times 0.35 = 13.4\,\text{N}\,[2].$$

[1 for $F = nIlB$; 1 for the value]

b. (1 mark) The split-ring commutator reverses the direction of the current in the coil every half-turn, so the torque continues to turn the coil in the same direction (it prevents the coil from stopping or reversing at the vertical position).

c. (2 marks) Any two of [1 each]:

- increase the number of loops n in the coil;
- increase the strength B of the magnetic field;
- increase the area (dimensions) of the coil.

Question 10 (6 marks)

a. (1 mark) For an ideal transformer $\frac{N_1}{N_2} = \frac{V_1}{V_2}$, so

$$N_2 = N_1 \frac{V_2}{V_1} = 150 \times \frac{22\,000}{940} = 3.51 \times 10^{3}\,\text{turns (3 s.f.)}, \text{as required.}$$

b. (2 marks) The voltage dropped along the line is $V_{\text{drop}} = 22.0 - 20.5 = 1.5\,\text{kV} = 1500\,\text{V}$ [1]. Using $V_{\text{drop}} = I_{\text{line}} R_{\text{line}}$:

$$I_{\text{line}} = \frac{V_{\text{drop}}}{R_{\text{line}}} = \frac{1500}{6.0} = 250\,\text{A}\,[1].$$

c. (3 marks) Power dissipated in the line:

$$P_{\text{loss}} = I_{\text{line}}^2 R_{\text{line}} = 250^2 \times 6.0 = 3.75 \times 10^5\,\text{W} = 375\,\text{kW}\,[1].$$

Power delivered to the substation (at the receiving-end voltage):

$$P_{\text{delivered}} = V_{\text{receiving}} \times I_{\text{line}} = 20\,500 \times 250 = 5.125 \times 10^6\,\text{W}\,[1].$$

As a percentage:

$$\frac{P_{\text{loss}}}{P_{\text{delivered}}} = \frac{3.75 \times 10^5}{5.125 \times 10^6} = 7.32\,\%\,[1].$$

$\therefore$ the line dissipates $375\,\text{kW}$, about $7.32\,\%$ of the power delivered to the substation. (The line current is found from the two end voltages, not from a rated power.)

Question 11 (4 marks)

a. (2 marks) The flux change is $\Delta\Phi_B = A\,\Delta B = 0.040 \times (0.60 - 0.10) = 0.020\,\text{Wb}$ [1]:

$$\varepsilon = \frac{N \Delta \Phi_B}{\Delta t} = \frac{250 \times 0.020}{0.025} = 200\,\mathrm{V}\,[1].$$

b. (2 marks) While the field changes, the magnetic flux $\Phi_B = B_{\perp} A$ **through the coil** changes with time [1]. By Faraday's law, $\varepsilon = -N \frac{\Delta \Phi_B}{\Delta t}$, it is this **rate of change of flux** (together with the number of turns) that induces the emf; a steady field gives a constant flux, whose rate of change is zero, so no emf is induced [1].

Question 12 (4 marks)

a. (1 mark) The battery stores and delivers energy as a direct current (DC), whereas the mains grid operates on alternating current (AC); the inverter converts the DC input into the AC output the grid requires.

b. (2 marks)

$$V_{\mathrm{RMS}} = \frac{V_{\mathrm{peak}}}{\sqrt{2}} = \frac{311}{\sqrt{2}} = 220\,\mathrm{V}\,[2].$$

[1 for the relationship; 1 for the value]

c. (1 mark) The rms voltage of an AC supply is the value of a steady DC voltage that would dissipate the **same average power** in a given resistor.

Question 13 (4 marks)

a. (2 marks) With the **split-ring commutator** the trace is a pulsating **direct** voltage: it rises and falls but never changes sign, because the connections to the external circuit reverse every half-turn (DC) [1]. With the **slip rings** the trace is a **sinusoidal alternating** voltage that reverses polarity once each half-turn (AC) [1].

b. (2 marks) When the plane of the coil is parallel to the magnetic field, the flux through the coil is momentarily zero but is changing at its greatest rate [1]. Since $\varepsilon = -N \frac{\Delta \Phi_B}{\Delta t}$, the induced emf is proportional to the rate of change of flux rather than to the flux itself, so the emf has its greatest magnitude at that orientation [1].

Question 14 (5 marks)

a. (2 marks)

$$E = \frac{hc}{\lambda} = \frac{4.14 \times 10^{-15} \times 3.00 \times 10^{8}}{420 \times 10^{-9}} = 2.96\,\mathrm{eV}\ (3\text{ s.f.}),\ \text{as required.}$$

[1 for $E = hc/\lambda$; 1 for the value]

b. (2 marks) Using the photoelectric equation with the unrounded photon energy ($2.957\,\mathrm{eV}$):

$$E_{k\,\max} = hf - \phi = 2.957 - 2.2 = 0.757\,\mathrm{eV} \approx 0.76\,\mathrm{eV}\,[1].$$

Converting to joules:

$$E_{k\,\max} = 0.757 \times 1.60 \times 10^{-19} = 1.21 \times 10^{-19}\,\mathrm{J}\,[1].$$

c. (1 mark) There is **no effect**. From $E_{k\,\max} = hf - \phi$, the maximum kinetic energy depends only on the photon energy (set by the wavelength) and the work function, not on the intensity. Moving the cell further away lowers the intensity — fewer photoelectrons are emitted per second — but each photon still carries the same energy.

Question 15 (4 marks)

a. (1 mark) A bright fringe forms where the path difference from the two slits is a whole number of wavelengths: path difference $= n\lambda$, where $n = 0, 1, 2, \ldots$

b. (2 marks)

$$\Delta x = \frac{\lambda L}{d} = \frac{640 \times 10^{-9} \times 3.0}{0.25 \times 10^{-3}} = 7.68 \times 10^{-3}\,\text{m} = 7.68\,\text{mm}\,[2].$$

[1 for substitution; 1 for the value]

c. (1 mark) Since $\Delta x = \frac{\lambda L}{d}$, the fringe spacing is proportional to λ; a shorter wavelength gives a **smaller** fringe spacing, so the bright fringes move closer together.

Question 16 (3 marks)

a. (2 marks)

$$\lambda = \frac{hc}{E} = \frac{4.14 \times 10^{-15} \times 3.00 \times 10^{8}}{2.10} = 5.91 \times 10^{-7}\,\text{m} = 591\,\text{nm}\,[2].$$

[1 for $\lambda = hc/E$; 1 for the value]

b. (1 mark) The electrons in an atom can occupy only discrete (quantised) energy levels. A photon is emitted only when an electron drops from one level to another, and its energy — and therefore its wavelength — is fixed by the difference between those two levels. Only certain level differences exist, so only a few specific wavelengths are emitted, rather than a continuous range.

Question 17 (4 marks)

a. (2 marks) The electron's momentum is $p = mv = 9.11 \times 10^{-31} \times 6.0 \times 10^{6} = 5.47 \times 10^{-24}\,\text{kg m s}^{-1}$ [1]:

$$\lambda = \frac{h}{p} = \frac{6.63 \times 10^{-34}}{5.47 \times 10^{-24}} = 1.21 \times 10^{-10}\,\text{m}\,[1].$$

b. (1 mark) The resolution of an imaging system is limited to about the wavelength used. These electrons have a de Broglie wavelength ($\sim 10^{-10}\,\text{m}$) far shorter than that of visible light ($\sim 10^{-7}\,\text{m}$), so they can resolve much finer detail.

c. (1 mark) **Shorter.** The proton has a much greater mass than the electron, so at the same speed its momentum $p = mv$ is greater; since $\lambda = h/p$, the greater momentum gives the proton a shorter de Broglie wavelength.

Question 18 (4 marks)

a. (1 mark)

$$\gamma = \frac{1}{\sqrt{1-(v/c)^2}} = \frac{1}{\sqrt{1-0.80^2}} = \frac{1}{\sqrt{0.36}} = 1.67\,(3\text{ s.f.}), \text{as required.}$$

b. (2 marks)

$$E_k = (\gamma - 1)mc^2 = 0.667 \times 8.20 \times 10^{-14} = 5.47 \times 10^{-14}\,\text{J} = 0.342\,\text{MeV}\,[2].$$

[1 for $E_k = (\gamma - 1)mc^2$; 1 for the value]

c. (1 mark) **Shorter.** Working in the electrons' frame, the laboratory section moves past at $0.80c$, so its length is contracted along the direction of motion: $L = L_0/\gamma = 12/1.67 = 7.2\,\text{m}$, which is shorter than $12\,\text{m}$.

Question 19 (19 marks)

a. (3 marks) [1 each]

- Independent variable: the release height h.
- Dependent variable: the speed v at the bottom (equivalently v^2).

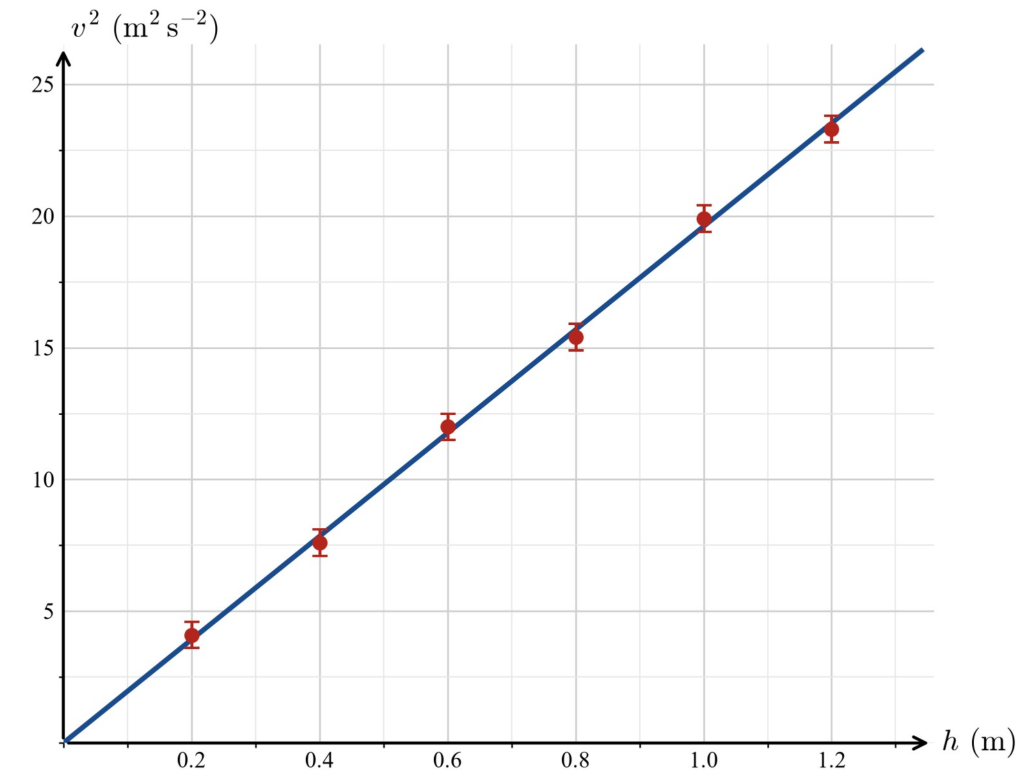
- Controlled variable (any one): the mass of the sphere / the same guide (its shape and surface) / releasing the sphere from rest each time.

b. (2 marks) If friction is negligible, all of the gravitational potential energy at the release point is converted to kinetic energy at the bottom [1]: $mgh=1/2mv^2$. The mass cancels, giving $v^2=2gh$, so v^2 is directly proportional to h (a straight line through the origin of gradient $2g$) [1].

c. (1 mark) Any friction would dissipate some of the gravitational potential energy as heat, so the sphere would arrive with less kinetic energy and a lower v^2 than $v^2=2gh$ predicts; the smoother the guide, the closer the results follow the expected proportional line (and the smaller this systematic under-reading).

d. (1 mark) Repeating each measurement and averaging reduces the effect of random errors on the mean value of v, improving the precision (reliability) of each plotted point.

e. (5 marks) The completed graph is shown below.



Marks for: axes labelled with quantity and unit, and scales that spread the data across the grid [1]; all six points plotted correctly [1]; an uncertainty bar of $\pm0.5\,m^2s^{-2}$ drawn on each point [1]; a straight line of best fit drawn to follow the trend of all the points, passing near the origin [2]. (The line of best fit drawn is $v^2=19.6h$.)

f. (2 marks) Reading two well-separated points **on the line of best fit** — for example $(0.20, 3.9)$ and $(1.20, 23.5)$ [1]:

$$\text{gradient}=\frac{\Delta(v^2)}{\Delta h}=\frac{23.5-3.9}{1.20-0.20}=\frac{19.6}{1.00}=19.6\,m^2s^{-2}m^{-1}[1].$$

(The points are read off the drawn line, not taken from the scattered data.)

g. (3 marks) The gradient equals $2g$ [1], so

$$g=\frac{\text{gradient}}{2}=\frac{19.6}{2}=9.8\,m\,s^{-2}[1].$$

This is very close to the accepted value of $9.81\,m\,s^{-2}$ (a difference of about $0.1\,\%$), so the experiment is consistent with the accepted local gravitational field strength [1].

h. (2 marks) The line would be **unchanged** [1]. The relationship $v^2 = 2gh$ contains no mass term — the mass cancels when $mgh = 1/2\, m v^2$ — so the gradient stays $2g$ and a sphere of twice the mass gives the same line of best fit [1].

Practice Exam 6 — Hard

- Reading time: **15 minutes**
- Writing time: **2 hours 30 minutes**
- Section A: 20 questions, 20 marks
- Section B: 19 questions, 100 marks
- Total 120 marks

Approved materials

- One scientific calculator
- Pre-written notes (one folded A3 sheet or two A4 sheets bound together by tape)

A formula sheet is provided at the end of this examination.

Students are **not** permitted to bring mobile phones and/or any unauthorised electronic devices into the examination room.

Section A — Multiple-choice questions (20 marks)

Answer **all** questions. Choose the response that is **correct** or that **best answers** the question. A correct answer scores 1; an incorrect answer scores 0. Marks will **not** be deducted for incorrect answers. No marks will be given if more than one answer is completed for any question. Where a numerical answer is required, use the constants given on the formula sheet. Unless otherwise indicated, the diagrams in this book are **not** drawn to scale.

Question 1

In an ultracentrifuge used to separate cell samples, a sample of mass $8.0\,\mathrm{g}$ sits at a radius of $0.12\,\mathrm{m}$ and moves at $18\,\mathrm{m\ s^{-1}}$. The magnitude of the net (centripetal) force on the sample is closest to:

A. $21.6\,\mathrm{N}$

B. $10.8\,\mathrm{N}$

C. $2.59\,\mathrm{N}$

D. $1.2\,\mathrm{N}$

Question 2

In a materials-testing laboratory, a small projectile leaves a horizontal launch rail at $12\,\mathrm{m\ s^{-1}}$ from a height of $0.80\,\mathrm{m}$ above the floor. Ignoring air resistance, the horizontal distance it travels before landing is closest to:

A. $3.43\,\mathrm{m}$

B. $1.96\,\mathrm{m}$

C. $4.85\,\mathrm{m}$

D. $9.69\,\mathrm{m}$

Question 3

On an air track, a moving glider collides with a stationary glider and the two lock together and move off as one. Which one of the following best describes this collision?

A. Both momentum and kinetic energy are conserved.

B. Momentum is conserved but the total kinetic energy decreases.

C. Kinetic energy is conserved but momentum is not.

D. Neither momentum nor kinetic energy is conserved.

Question 4

A trolley of mass $2.0\,\mathrm{kg}$, initially at rest, is pushed along a bench. The net force on the trolley increases linearly from 0 to $12\,\mathrm{N}$ over the first $6.0\,\mathrm{m}$ of its motion. Using the area under the force–distance graph, the speed of the trolley after $6.0\,\mathrm{m}$ is closest to:

A. $18\,\mathrm{m\ s^{-1}}$

B. $8.49\,\mathrm{m\ s^{-1}}$

C. $4.24\,\mathrm{m\ s^{-1}}$

D. $6.0\,\mathrm{m\ s^{-1}}$

Question 5

In a demonstration, a small ball on a light string is whirled in a vertical circle of radius $0.80\,\mathrm{m}$. The minimum speed the ball can have at the highest point while the string stays taut is closest to:

A. $2.80\,\mathrm{m\ s^{-1}}$

B. $3.96\,\mathrm{m\ s^{-1}}$

C. $7.85\,\mathrm{m\ s^{-1}}$

D. $1.98\,\mathrm{m\ s^{-1}}$

Question 6

A research satellite orbits at an altitude of $1.2 \times 10^{3}\,\mathrm{km}$ above the Earth's surface. The gravitational field strength at this altitude is closest to:

A. $9.81\,\mathrm{N\ kg^{-1}}$

B. $2.77 \times 10^{2}\,\mathrm{N\ kg^{-1}}$

C. $6.95\,\mathrm{N\ kg^{-1}}$

D. $5.26 \times 10^{7}\,\mathrm{N\ kg^{-1}}$

Question 7

Two parallel deflection plates in a laboratory apparatus are separated by $5.0\,\text{cm}$, with a potential difference of $250\,\text{V}$ between them. The electric field strength between the plates is closest to:

A. $50\,\text{N C}^{-1}$

B. $5.0 \times 10^{3}\,\text{N C}^{-1}$

C. $12.5\,\text{N C}^{-1}$

D. $5.0 \times 10^{2}\,\text{N C}^{-1}$

Question 8

An electron travelling at $5.0 \times 10^{6}\,\text{m s}^{-1}$ enters a uniform magnetic field of $0.015\,\text{T}$ at right angles to the field. The radius of its circular path is closest to:

A. $1.90 \times 10^{-3}\,\text{m}$

B. $9.49 \times 10^{-4}\,\text{m}$

C. $3.80 \times 10^{-3}\,\text{m}$

D. $4.27 \times 10^{-7}\,\text{m}$

Question 9

Which one of the following statements about the interaction of fields is correct?

A. Two masses can either attract or repel each other.

B. Two electric charges can only attract each other.

C. Two magnetic poles can only attract each other.

D. Two masses always attract, whereas two electric charges can either attract or repel.

Question 10

A coil of 200 turns and area $2.5 \times 10^{-3}\,\text{m}^{2}$ sits with its plane perpendicular to a magnetic field. The field increases uniformly by $0.40\,\text{T}$ in $0.10\,\text{s}$. The average emf induced in the coil is closest to:

A. $0.010\,\text{V}$

B. $2.0\,\text{V}$

C. $8.0 \times 10^{2}\,\text{V}$

D. $0.20\,\text{V}$

Question 11

A supply transformer at a research facility steps a transmission voltage of $22\,\text{kV}$ down to $240\,\text{V}$. Its primary coil has 5500 turns. The number of turns on the secondary coil is closest to:

A. 5.04×10^{5}

B. 6.0×10^{4}

C. 60

D. 6.0×10^{2}

Question 12

A laboratory AC source has a peak voltage of $155\,\text{V}$. The rms voltage of this source is closest to:

A. $110\,\text{V}$

B. $155\,\text{V}$

C. $219\,\text{V}$

D. $78\,\text{V}$

Question 13

In an optics experiment, light of wavelength $600\,\text{nm}$ passes through two slits $0.20\,\text{mm}$ apart onto a screen $1.5\,\text{m}$ away. The spacing between adjacent bright fringes is closest to:

A. $4.5\,\mu\text{m}$

B. $8.0 \times 10^{-11}\,\text{m}$

C. $2.25\,\text{mm}$

D. $4.5\,\text{mm}$

Question 14

In a photoelectric experiment the maximum kinetic energy of the emitted photoelectrons is $1.5\,\text{eV}$. The stopping voltage required to prevent even the fastest photoelectrons from reaching the collector is closest to:

A. $0.75\,\text{V}$

B. $1.5\,\text{V}$

C. $9.4 \times 10^{18}\,\text{V}$

D. $2.4 \times 10^{-19}\,\text{V}$

Question 15

In an electron-diffraction experiment, electrons travel at $2.5 \times 10^{6}\,\text{m s}^{-1}$ (non-relativistic). Their de Broglie wavelength is closest to:

A. $2.91 \times 10^{-10}\,\text{m}$

B. $2.65 \times 10^{-40}\,\text{m}$

C. $5.82 \times 10^{-10}\,\text{m}$

D. $1.46 \times 10^{-10}\,\text{m}$

Question 16

A photon has an energy of $3.0\,\text{eV}$. Its wavelength is closest to:

A. $6.63 \times 10^{-26}\,\text{m}$

B. $207\,\text{nm}$

C. $414\,\text{nm}$

D. $828\,\text{nm}$

Question 17

In a particle accelerator, protons travel at $0.80\,c$. The Lorentz factor γ for these protons is closest to:

A. 2.24

B. 2.78

C. 0.60

D. 1.67

Question 18

A pressure gauge is later found to read $0.5\,\text{kPa}$ higher than the true value for every reading. This is best described as:

A. a random error, whose effect is reduced by averaging repeated readings.

B. a systematic error, whose effect is not reduced by averaging repeated readings.

C. a mistake, which should be discarded as an outlier.

D. a loss of resolution of the instrument.

Question 19

A technician measures the voltage of a reference cell five times with a digital voltmeter. The five readings cluster tightly together, but their mean is $2\,\%$ above the value quoted for the cell. The readings are best described as:

A. accurate but not precise.

B. both accurate and precise.

C. precise but not accurate.

D. neither accurate nor precise.

Question 20

A student investigates how the Earth's gravitational field strength g varies with distance r from the centre of the Earth, using values deduced from the motion of orbiting satellites. To obtain a straight line whose gradient is $G\,M$, the student should plot:

A. g against r.

B. g against $1\,/\,r$.

C. $1\,/\,r^2$ against g, with gradient $G\,M$.

D. g against $1\,/\,r^2$, with gradient $G\,M$.

Practice Exam 6 — Section B

Answer **all** questions in the spaces provided. Write your responses in English. Where an answer box is provided, write your final answer in the box. If an answer box has a unit printed in it, give your answer in that unit. In questions where more than one mark is available, appropriate working **must** be shown. Take $g = 9.81\ \mathrm{m\ s^{-2}}$ and $c = 3.00 \times 10^{8}\ \mathrm{m\ s^{-1}}$ where required; other constants are on the formula sheet. Unless otherwise indicated, the diagrams in this book are **not** drawn to scale.

Question 1 (7 marks)

To calibrate a high-speed camera, a rig launches a small steel ball at $24\ \mathrm{m\ s^{-1}}$ at an angle of 30° above the horizontal. The ball lands back at its launch height. Ignore air resistance in parts **a.–c.**

a. Show that the vertical component of the launch velocity is $12.0\ \mathrm{m\ s^{-1}}$. 1 mark

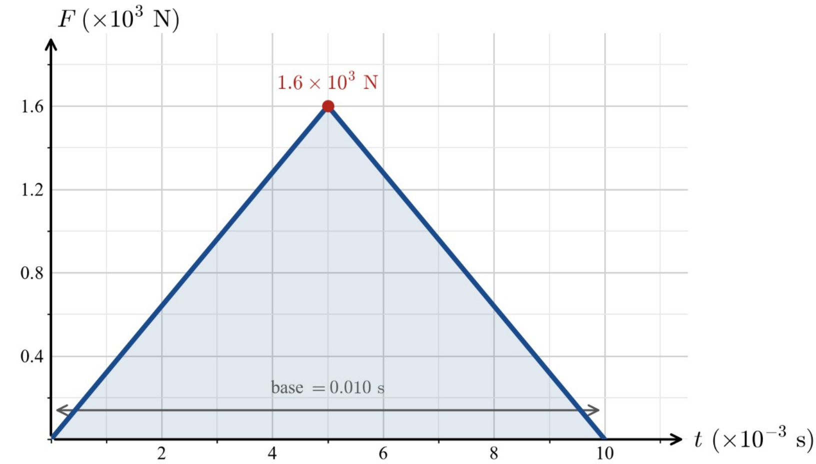
b. Calculate the maximum height reached by the ball above its launch point. Give your answer in m. 2 marks

c. Calculate the horizontal range of the ball. Give your answer in m. 2 marks

d. In a repeat with a light polystyrene ball, air resistance is no longer negligible. Explain how the range and the maximum height would each compare with your no-air-resistance answers. 2 marks

Question 2 (6 marks)

In an impact-test rig, a projectile of mass $0.40\ \mathrm{kg}$ is fired horizontally at $15\ \mathrm{m\ s^{-1}}$ into a force sensor. The sensor records the force it exerts on the projectile during the impact; the force–time graph is shown below.



a. Using the graph, determine the magnitude of the impulse delivered to the projectile by the sensor. Give your answer in $\mathrm{N\ s}$. 2 marks

b. Hence calculate the speed of the projectile immediately after the impact, and state its direction of motion. Give the speed in $\mathrm{m\ s^{-1}}$. 2 marks

c. Explain the difference between the physical quantity given by the area under a force–time graph and the physical quantity given by the area under a force–distance graph. 2 marks

Question 3 (4 marks)

In a collision experiment on an air track, a glider of mass $0.30\ \mathrm{kg}$ moving at $2.8\ \mathrm{m\ s^{-1}}$ strikes a stationary glider of mass $0.50\ \mathrm{kg}$. The two gliders couple together on impact and move off as one.

a. Calculate the common velocity of the coupled gliders immediately after the collision. Give your answer in $\mathrm{m\ s^{-1}}$. 2 marks

b. By comparing the total kinetic energy before and after the collision, show that this collision is inelastic. 2 marks

Question 4 (4 marks)

A spring-loaded injector launches a small sample carrier of mass $0.12\,\mathrm{kg}$. Before launch, the spring (spring constant $450\,\mathrm{N\,m^{-1}}$) is compressed by $0.080\,\mathrm{m}$.

a. Calculate the elastic potential energy stored in the compressed spring. Give your answer in J. 2 marks

b. The carrier leaves the injector at $4.0\,\mathrm{m\,s^{-1}}$. Calculate the energy dissipated during the launch, and name one form this dissipated energy takes. 2 marks

Question 5 (6 marks)

A scientific satellite carrying instruments orbits the Earth in a circular orbit of radius $8.0 \times 10^{6}\,\mathrm{m}$, measured from the centre of the Earth.

a. Show that the gravitational field strength at this orbital radius is $6.22\,\mathrm{N\,kg^{-1}}$ (to three significant figures). 2 marks

b. Calculate the orbital speed of the satellite. Give your answer in $\mathrm{m\,s^{-1}}$. 2 marks

c. The satellite moves at constant speed, yet it is accelerating. With reference to Newton's second law of motion, explain why. 2 marks

Question 6 (5 marks)

In the electron gun of an accelerator, electrons are accelerated from rest across a gap of $0.10\,\mathrm{m}$ by a potential difference of $2.0\,\mathrm{kV}$.

a. Show that the electric field strength between the electrodes is $2.0 \times 10^{4}\,\mathrm{N\,C^{-1}}$ (to three significant figures). 1 mark

b. Calculate the speed the electrons gain by the time they leave the gun. Give your answer in $\mathrm{m\,s^{-1}}$. 2 marks

c. Calculate the kinetic energy gained by each electron, in both eV and J. 2 marks

Question 7 (6 marks)

In a mass spectrometer, singly-charged ions (charge $1.60 \times 10^{-19}\,\mathrm{C}$) of mass $2.5 \times 10^{-26}\,\mathrm{kg}$ enter a uniform magnetic field of $0.35\,\mathrm{T}$ at a speed of $1.2 \times 10^{5}\,\mathrm{m\,s^{-1}}$, directed perpendicular to the field.

a. Explain why the ions follow a circular path while in the magnetic field. 2 marks

b. Calculate the radius of the circular path followed by an ion. Give your answer in m. 2 marks

c. A second ion enters with the same charge and speed but twice the mass. State and justify how the radius of its path compares with your answer to part **b.** 2 marks

Question 8 (4 marks)

In a synchrotron, charged particles are accelerated to high energy and steered around a ring by electric and magnetic fields.

a. A straight current-carrying conductor of length $0.25\,\mathrm{m}$ inside one of the ring's magnets carries a current of $15\,\mathrm{A}$ at right angles to a uniform magnetic field of $0.80\,\mathrm{T}$. Calculate the magnitude of the magnetic force on this conductor. Give your answer in N. 2 marks

b. In the synchrotron, the electric field and the magnetic field play different roles. Explain the role of each, referring to whether it does work on the particles. 2 marks

Question 9 (6 marks)

A search coil of 800 turns and area $1.5 \times 10^{-3}\,\mathrm{m^2}$ is used to measure a magnetic field. The coil sits with its plane perpendicular to a field of $0.25\,\mathrm{T}$, which is then switched off so that it falls to zero in $0.020\,\mathrm{s}$.

a. Calculate the magnetic flux through one turn of the coil while the field is $0.25\,\mathrm{T}$. Give your answer in Wb. 1 mark

b. Calculate the average emf induced in the coil while the field is switched off. Give your answer in V. 2 marks

c. A student writes: "An emf appears in the coil simply because there is a magnetic field near it." Explain, as a complete chain of reasoning, why an emf is actually induced. 2 marks

d. State how the flux through one turn would change if the coil were tilted so that its plane was no longer perpendicular to the field. 1 mark

Question 10 (7 marks)

A research facility draws its power from a distant substation. An ideal transformer steps $250\,\mathrm{V}$ up to the transmission voltage using a primary of 500 turns and a secondary of 2.20×10^4 turns. The power then travels along a transmission line of total resistance $6.0\,\Omega$.

a. Show that the transmission voltage produced by the transformer is $11.0\,\mathrm{kV}$ (to three significant figures). 1 mark

b. Along the transmission line the voltage falls from $11.0\,\mathrm{kV}$ at the sending end to $10.4\,\mathrm{kV}$ at the facility. Calculate the current in the line. Give your answer in A. 2 marks

c. Calculate the power dissipated in the transmission line. Give your answer in W. 2 marks

d. Express this line loss as a percentage of the power delivered to the facility, and explain why transmitting at high voltage keeps this loss small. 2 marks

Question 11 (3 marks)

A single coil rotating at a steady rate in a uniform magnetic field can be connected to an external circuit through either a split-ring commutator or two slip rings.

a. Describe how the output voltage differs between the split-ring commutator connection and the slip-ring connection. 2 marks

b. State the orientation of the coil, relative to the magnetic field, at which the induced emf is momentarily zero. 1 mark

Question 12 (3 marks)

A remote field station is powered by a photovoltaic array that feeds an inverter, which supplies AC to the station's equipment.

a. Explain why the inverter is needed. 1 mark

b. The inverter's AC output has a peak voltage of $325\,\mathrm{V}$. Calculate the rms voltage of this output. Give your answer in V. 2 marks

Question 13 (3 marks)

In an optics laboratory, a helium–neon laser of wavelength $633\,\mathrm{nm}$ shines through two narrow slits $0.25\,\mathrm{mm}$ apart onto a screen $2.0\,\mathrm{m}$ away, producing an interference pattern.

a. Calculate the spacing between adjacent bright fringes on the screen. Give your answer in mm. 2 marks

b. State how the fringe spacing would change if the slit separation were increased. 1 mark

Question 14 (4 marks)

A photocathode with a work function of $2.10\,\mathrm{eV}$ is illuminated with ultraviolet light of wavelength $350\,\mathrm{nm}$.

a. Show that the energy of each photon is $3.55\,\mathrm{eV}$ (to three significant figures). 2 marks

b. Calculate the maximum kinetic energy of the emitted photoelectrons. Give your answer in eV. 1 mark

c. The intensity of the $350\,\mathrm{nm}$ light is then doubled. State the effect, if any, on the maximum kinetic energy of the photoelectrons. 1 mark

Question 15 (3 marks)

In an electron-diffraction experiment, electrons are accelerated to a speed of $4.0\times10^{6}\,\mathrm{m\ s^{-1}}$, which may be treated as non-relativistic.

a. Calculate the de Broglie wavelength of these electrons. Give your answer in m. 2 marks

b. A photon has the same wavelength as one of these electrons. State how the momentum of the photon compares with the momentum of the electron. 1 mark

Question 16 (3 marks)

A metal-vapour lamp is analysed with a spectrometer. One emission line arises when an electron in an atom drops from an energy level of $-1.5\,\mathrm{eV}$ to a level of $-4.0\,\mathrm{eV}$.

a. Calculate the wavelength of the light emitted in this transition. Give your answer in nm. 2 marks

b. Explain why the lamp emits light at only certain discrete wavelengths rather than as a continuous spectrum. 1 mark

Question 17 (4 marks)

In a muon storage ring, muons circulate at a speed of $0.994\,c$. A muon has a proper (rest-frame) half-life of $2.2\,\mu\mathrm{s}$.

a. Show that the Lorentz factor for these muons is $\gamma=9.14$ (to three significant figures). 1 mark

b. Calculate the half-life of these muons as measured in the laboratory frame. Give your answer in $\mu\mathrm{s}$. 2 marks

c. A straight section of the ring is $15\,\mathrm{m}$ long as measured in the laboratory. (Circle your answer.) An observer travelling with the muons would measure this section to be:

longer / the same length / shorter.

Justify your choice. 1 mark

Question 18 (3 marks)

In a particle-physics experiment, an electron and a positron, both effectively at rest, meet and annihilate, producing photons. The rest mass of each particle is $9.11\times10^{-31}\,\mathrm{kg}$.

a. Calculate the total energy released in the annihilation. Give your answer in J. 2 marks

b. Explain why at least two photons must be produced, rather than a single photon. 1 mark

Question 19 (19 marks)

A student investigates the photoelectric effect. Monochromatic light of known frequency f is shone onto a clean metal photocathode in an evacuated tube, and the maximum kinetic energy $E_{k\,\max}$ of the emitted photoelectrons is found from the stopping voltage. The measurement is repeated for a range of frequencies.

If the photon energy is $E=hf$ and the metal has work function φ, the photoelectric equation predicts

$$E_{k\,\max}=hf-\varphi\,,$$

so a graph of $E_{k\,\max}$ against f should be a straight line of gradient h.

a. Identify, for this investigation, the independent variable, the dependent variable, and one variable that should be controlled. 3 marks

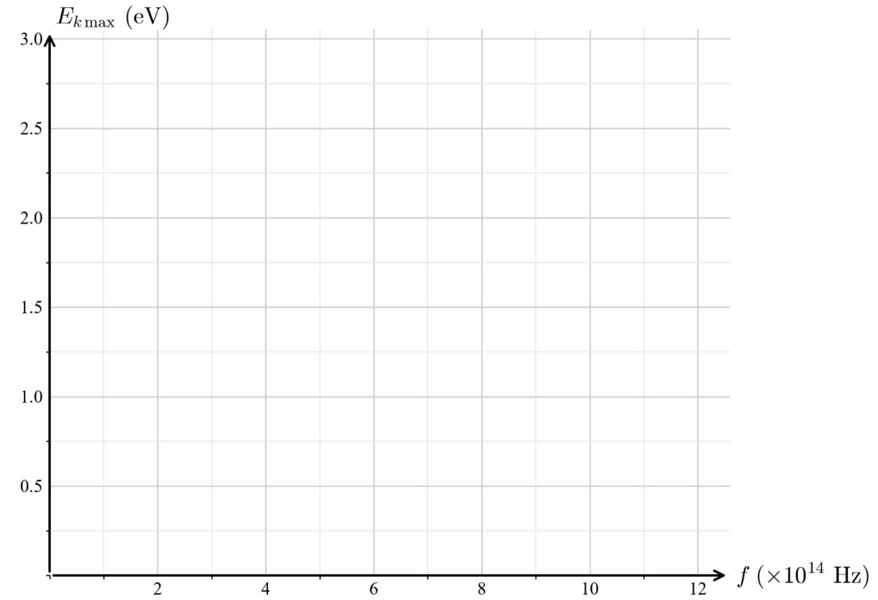
b. Explain, in terms of photon energy and the work function, why no photoelectrons are emitted when the light's frequency is below a threshold value, no matter how intense the light. 2 marks

c. At each frequency the student measures the stopping voltage three times and averages the results. State the purpose of taking repeated measurements. 1 mark

The student's results are shown in the table below. Each value of $E_{k\,\max}$ has an uncertainty of $\pm 0.10\,\text{eV}$.

f ($\times 10^{14}$ Hz)	6.0	7.0	8.0	9.0	10.0	11.0
$E_{k\,\max}$ (eV)	0.49	0.98	1.39	1.70	2.12	2.52

d. On the grid provided, plot a graph of $E_{k\,\max}$ (vertical axis) against f (horizontal axis). Include an uncertainty bar of $\pm 0.10\,\text{eV}$ on each point and draw a line of best fit. 5 marks



e. Using two well-separated points that lie **on your line of best fit**, determine the gradient of the line. Give your answer in eV s. 2 marks

f. The gradient of this graph is equal to Planck's constant h. Use your gradient to determine a value for h in J s, and compare it with the accepted value 6.63×10^{-34} J s. 2 marks

g. Use the graph to determine the threshold frequency of the metal, and hence its work function φ in eV. 2 marks

h. Predict, with justification, how the line of best fit would change if the experiment were repeated with a metal of higher work function.

2 marks

Practice Exam 6 — Formula Sheet

This formula sheet is provided for use with all practice examinations in this booklet. It covers the same items as the official VCE Physics Formula Sheet.

Motion and related energy transformations

velocity	$v=\frac{\Delta s}{\Delta t}$
acceleration	$a=\frac{\Delta v}{\Delta t}$
constant acceleration	$v=u+at$
	$s=ut+\frac{1}{2}at^2$
	$s=vt-\frac{1}{2}at^2$
	$v^2=u^2+2as$
	$s=\frac{1}{2}(u+v)t$
Newton's second law	$\Sigma F=ma$
uniform circular motion	$F_{\text{net}}=\frac{mv^2}{r}$
	$v=\frac{2\pi r}{T}$
Hooke's law	$F=-kx$
elastic potential energy	$E_s=\frac{1}{2}kx^2$
gravitational potential energy	$E_g=mg\Delta h$
kinetic energy	$E_k=\frac{1}{2}mv^2$
universal gravitation	$F_g=\frac{Gm_1m_2}{r^2}$
gravitational field	$g=\frac{GM}{r^2}$
impulse	$F\Delta t=m\Delta v$
momentum	$p=mv$

Einstein's special theory of relativity

Lorentz factor	$\gamma=\frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$
time dilation	$t=\gamma t_0$
length contraction	$L=\frac{L_0}{\gamma}$
rest energy	$E_0=mc^2$
total energy	$E_{\text{total}}=E_k+E_0=\gamma mc^2$

relativistic kinetic energy	$E_k = (\gamma - 1) m c^2$

Fields and application of field concepts

uniform electric field	$E = \frac{V}{d}$
charge accelerated by a field	$\frac{1}{2} m v^2 = q V$
field of a point charge	$E = \frac{k Q}{r^2}$
electric force on a charge	$F = q E$
Coulomb's law	$F = \frac{k q_1 q_2}{r^2}$
magnetic force on a moving charge	$F = q v B$
force on a current-carrying conductor	$F = n I l B$
radius of a charged particle's path	$r = \frac{m v}{q B}$

Generation and transmission of electricity

current	$I = \frac{V}{R}$
power	$P = V I$
resistors in series	$R_T = R_1 + R_2 + \ldots$
resistors in parallel	$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$
ideal transformer	$\frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{I_2}{I_1}$
rms voltage	$V_{\text{RMS}} = \frac{1}{\sqrt{2}} V_{\text{peak}}$
rms current	$I_{\text{RMS}} = \frac{1}{\sqrt{2}} I_{\text{peak}}$
electromagnetic induction	$\varepsilon = -N \frac{\Delta \Phi_B}{\Delta t}$
magnetic flux	$\Phi_B = B_{\perp} A$
voltage drop along a line	$V_{\text{drop}} = I_{\text{line}} R_{\text{line}}$
power loss in a line	$P_{\text{loss}} = I_{\text{line}}^2 R_{\text{line}}$

Waves

wave equation	$v = f \lambda$
constructive interference	path difference $= n \lambda$
destructive interference	path difference $= \left(n + \frac{1}{2}\right) \lambda$
fringe spacing	$\Delta x = \frac{\lambda L}{d}$ when $L \gg d$

The nature of light and matter

photoelectric effect	$E_{k\,\max} = hf - \phi$
photon energy	$E = hf = \frac{hc}{\lambda}$
photon momentum	$p = \frac{h}{\lambda}$
de Broglie wavelength	$\lambda = \frac{h}{p}$

Data

acceleration due to gravity at Earth's surface	$g = 9.81$ m s^{-2}
mass of the electron	$m_e = 9.11 \times 10^{-31}$ kg
magnitude of the charge of the electron	$q_e = 1.60 \times 10^{-19}$ C
Planck's constant	$h = 6.63 \times 10^{-34}$ J s
	$h = 4.14 \times 10^{-15}$ eV s
speed of light in a vacuum	$c = 3.00 \times 10^{8}$ m s^{-1}
universal gravitational constant	$G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}
mass of Earth	$M_E = 5.97 \times 10^{24}$ kg
radius of Earth	$R_E = 6.37 \times 10^{6}$ m
Coulomb constant	$k = 8.99 \times 10^{9}$ N m^2 C^{-2}

Metric (SI) multipliers

pico (p)	10^{-12}	kilo (k)	10^{3}
nano (n)	10^{-9}	mega (M)	10^{6}
micro (μ)	10^{-6}	giga (G)	10^{9}
milli (m)	10^{-3}	tera (T)	10^{12}

Unit conversions

1 tonne (t)	= 10^{3} kg
1 kilowatt hour (kW h)	= 3.6×10^{6} J

Nomenclature

force due to gravity	F_g
force on A by B	$F_{\text{on A by B}}$
normal force	F_N

End of Formula Sheet

Practice Exam 6 — solutions

Section A — answer key

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

Question 1 — A. $F=\frac{mv^2}{r}=\frac{0.008\times18^2}{0.12}=21.6\,\mathrm{N}$. B halves the result ($1/2\,mv^2/r=10.8\,\mathrm{N}$); C forgets to divide by r ($mv^2=2.59\,\mathrm{N}$); D forgets to square the speed ($mv/r=1.2\,\mathrm{N}$).

Question 2 — C. Time to fall: $t=\sqrt{2h/g}$; range $R=ut=12\times\sqrt{2\times0.80/9.81}=4.85\,\mathrm{m}$. A drops the factor of 2 ($u\sqrt{h/g}=3.43\,\mathrm{m}$); B omits the square root ($u\times2h/g=1.96\,\mathrm{m}$); D doubles the fall time ($2u\sqrt{2h/g}=9.69\,\mathrm{m}$).

Question 3 — B. When the gliders couple they undergo a perfectly inelastic collision: momentum is conserved (isolated system) but the total kinetic energy decreases. A is wrong because kinetic energy is not conserved in an inelastic collision; C reverses the two ideas (momentum, not KE, is the conserved quantity); D is wrong because momentum is still conserved.

Question 4 — D. The area under the force–distance graph is the work done: $W=1/2\times6.0\times12=36\,\mathrm{J}=\Delta E_k$, so $v=\sqrt{2W/m}=\sqrt{36}=6.0\,\mathrm{m\ s^{-1}}$. A treats the area as an impulse ($\Delta p=36$, $v=\Delta p/m=18\,\mathrm{m\ s^{-1}}$) — the force–distance-vs-force–time trap; B omits the $1/2$ in the triangle's area ($72\,\mathrm{J}\Rightarrow8.49\,\mathrm{m\ s^{-1}}$); C omits the $1/2$ in $1/2\,mv^2$ ($\sqrt{W/m}=4.24\,\mathrm{m\ s^{-1}}$).

Question 5 — A. At the highest point the minimum speed is reached when the force due to gravity alone supplies the centripetal force: $mg=mv^2/r\Rightarrow v=\sqrt{gr}=\sqrt{9.81\times0.80}=2.80\,\mathrm{m\ s^{-1}}$. B uses $\sqrt{2gr}=3.96$; C omits the square root ($gr=7.85$); D uses the radius as a diameter ($\sqrt{gr/2}=1.98$).

Question 6 — C. $g=\frac{GM}{r^2}$ with $r=R_E+1.2\times10^3\,\mathrm{km}=7.57\times10^6\,\mathrm{m}$, giving $6.95\,\mathrm{N\ kg^{-1}}$. A ignores the altitude ($r=R_E$, the surface value 9.81); B uses the altitude alone as r ($GM/\left(1.2\times10^6\right)^2=2.77\times10^2$); D forgets to square r ($GM/r=5.26\times10^7$).

Question 7 — B. $E=\frac{V}{d}=\frac{250}{0.050}=5.0\times10^3\,\mathrm{N\ C^{-1}}$. A fails to convert $5.0\,\mathrm{cm}$ to metres ($250/5.0=50$); C multiplies instead of dividing ($V\times d=12.5$); D slips the decimal in the separation ($250/0.50=5.0\times10^2$).

Question 8 — A. $r=\frac{mv}{qB}=\frac{9.11\times10^{-31}\times5.0\times10^6}{1.60\times10^{-19}\times0.015}=1.90\times10^{-3}\,\mathrm{m}$. B uses $2B$ in the denominator (9.49×10^{-4}); C uses $1/2\,B$ (3.80×10^{-3}); D multiplies by B instead of dividing ($mvB/q=4.27\times10^{-7}$).

Question 9 — D. Masses only ever attract one another, whereas electric charges (like magnetic poles) can either attract or repel. A, B and C each misassign these behaviours.

Question 10 — B. $\varepsilon = \frac{N A \Delta B}{\Delta t} = \frac{200 \times 2.5 \times 10^{-3} \times 0.40}{0.10} = 2.0\,\text{V}$. A omits N ($0.010\,\text{V}$); C omits the area A ($N \Delta B / \Delta t = 8.0 \times 10^{2}$); D omits Δt ($N A \Delta B = 0.20$).

Question 11 — C. $N_2 = N_1 \frac{V_2}{V_1} = 5500 \times \frac{240}{22\,000} = 60$ turns. A inverts the ratio ($5500 \times 22\,000 / 240 = 5.04 \times 10^{5}$); B keeps $22\,\text{kV}$ as "22" ($5500 \times 240 / 22 = 6.0 \times 10^{4}$); D drops a zero from the primary voltage ($5500 \times 240 / 2200 = 6.0 \times 10^{2}$).

Question 12 — A. $V_{\text{RMS}} = \frac{V_{\text{peak}}}{\sqrt{2}} = \frac{155}{\sqrt{2}} = 110\,\text{V}$. B quotes the peak value (155); C multiplies by $\sqrt{2}$ (219); D halves the peak (78).

Question 13 — D. $\Delta x = \frac{\lambda L}{d} = \frac{600 \times 10^{-9} \times 1.5}{0.20 \times 10^{-3}} = 4.5\,\text{mm}$. A leaves the slit separation in mm ($d = 0.20\,\text{m} \Rightarrow 4.5\,\mu\text{m}$); B swaps d and L ($\lambda d / L = 8.0 \times 10^{-11}\,\text{m}$); C doubles the slit separation ($2.25\,\text{mm}$).

Question 14 — B. The stopping voltage V_s satisfies $e V_s = E_{k\,\max}$, so for $E_{k\,\max} = 1.5\,\text{eV}$ the stopping voltage is $V_s = 1.5\,\text{V}$ — the numerical value in eV equals the stopping voltage in volts. A halves the kinetic energy; C divides the eV value by e again (9.4×10^{18}); D multiplies by e, quoting the kinetic energy in joules (2.4×10^{-19}) rather than a voltage.

Question 15 — A. $\lambda = \frac{h}{m v} = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 2.5 \times 10^{6}} = 2.91 \times 10^{-10}\,\text{m}$. B omits the mass ($h / v = 2.65 \times 10^{-40}$); C uses $1/2\,m v$ as the momentum (5.82×10^{-10}); D uses $2 m v$ (1.46×10^{-10}).

Question 16 — C. $\lambda = \frac{h c}{E} = \frac{4.14 \times 10^{-15} \times 3.00 \times 10^{8}}{3.0} = 4.14 \times 10^{-7}\,\text{m} = 414\,\text{nm}$. A uses h in J s with E in eV ($6.63 \times 10^{-26}\,\text{m}$); B uses $2E$ ($207\,\text{nm}$); D uses $E/2$ ($828\,\text{nm}$).

Question 17 — D. $\gamma = \frac{1}{\sqrt{1 - (v/c)^2}} = \frac{1}{\sqrt{1 - 0.80^2}} = \frac{1}{\sqrt{0.36}} = \frac{1}{0.60} = 1.67$. A forgets to square the ratio ($1 / \sqrt{1 - 0.80} = 2.24$); B omits the square root ($1 / (1 - 0.64) = 2.78$); C gives the reciprocal ($\sqrt{0.36} = 0.60$).

Question 18 — B. A fixed offset applied to every reading is a systematic error; because it shifts every reading (and the mean) the same way, averaging repeated readings does not remove it. A (random) is wrong because the offset is not scattered; C (mistake/outlier) is wrong because it is consistent, not a one-off; D confuses a calibration offset with the instrument's resolution.

Question 19 — C. Precision describes how closely repeated measurements agree with one another, and accuracy how close they are to the accepted value. The tightly clustered readings are precise; a mean sitting 2% above the quoted value is not accurate. A reverses the two ideas; B ignores the offset from the quoted value; D ignores the tight clustering.

Question 20 — D. Since $g = \frac{G M}{r^2}$, plotting g against $1/r^2$ gives a straight line through the origin with gradient $G M$. A (g vs r) and B (g vs $1/r$) are curves, not straight lines; C swaps the axes, giving a gradient of $1 / G M$.

Section B — worked solutions

Question 1 (7 marks)

a. (1 mark) The vertical component of the launch velocity is

$$u_y = u \sin 30^\circ = 24 \times 0.5 = 12.0\,\text{m s}^{-1}, \text{as required.}$$

b. (2 marks) At the maximum height the vertical velocity is zero, so $v_y^2 = u_y^2 - 2gH$ with $v_y = 0$ [1]:

$$H = \frac{u_y^2}{2g} = \frac{12.0^2}{2 \times 9.81} = 7.34\,\mathrm{m}\,[1].$$

c. (2 marks) The ball returns to launch height after a time $t = \frac{2u_y}{g} = \frac{2 \times 12.0}{9.81} = 2.446\,\mathrm{s}$; the horizontal velocity is constant at $u_x = 24\cos 30^\circ = 20.78\,\mathrm{m\ s^{-1}}$ [1]:

$$R = u_x t = 20.78 \times 2.446 = 50.8\,\mathrm{m}\,[1].$$

d. (2 marks) Air resistance acts to oppose the ball's motion, continuously removing kinetic energy [1]. The range is therefore **shorter** than $50.8\,\mathrm{m}$ and the maximum height is **lower** than $7.34\,\mathrm{m}$ compared with the no-air-resistance case (the trajectory also becomes asymmetric, falling more steeply than it rises) [1].

Question 2 (6 marks)

a. (2 marks) The impulse is the area under the force–time graph, a triangle of base $0.010\,\mathrm{s}$ and peak $1.6 \times 10^3\,\mathrm{N}$ [1]:

$$J = 1/2 \times 0.010 \times 1.6 \times 10^3 = 8.0\,\mathrm{N\ s}\,[1].$$

b. (2 marks) The impulse equals the change in momentum, $J = m\Delta v$, so $\Delta v = \frac{J}{m} = \frac{8.0}{0.40} = 20\,\mathrm{m\ s^{-1}}$ [1]. Taking the incoming direction as positive, the sensor's force opposes the motion, so the velocity changes from $+15\,\mathrm{m\ s^{-1}}$ to $15 - 20 = -5.0\,\mathrm{m\ s^{-1}}$: the projectile **rebounds at** $5.0\,\mathrm{m\ s^{-1}}$ [1].

c. (2 marks) The area under a force–time graph is the **impulse**, equal to the change in momentum ($J = \Delta p$, in N s) [1]. The area under a force–distance graph is the **work done**, equal to the change in kinetic energy ($W = \Delta E_k$, in J) [1]. They are different physical quantities with different units.

Question 3 (4 marks)

a. (2 marks) Momentum is conserved and the gliders couple, so $m_A u_A = (m_A + m_B)v$ [1]:

$$v = \frac{0.30 \times 2.8}{0.30 + 0.50} = \frac{0.84}{0.80} = 1.05\,\mathrm{m\ s^{-1}}\,[1].$$

b. (2 marks) Kinetic energy before: $E_{k,i} = 1/2\, m_A u_A^2 = 1/2 \times 0.30 \times 2.8^2 = 1.18\,\mathrm{J}$; kinetic energy after: $E_{k,f} = 1/2(m_A + m_B)v^2 = 1/2 \times 0.80 \times 1.05^2 = 0.44\,\mathrm{J}$ [1]. Since the total kinetic energy decreases ($1.18\,\mathrm{J} \rightarrow 0.44\,\mathrm{J}$) while momentum is conserved, the collision is **inelastic** [1] (the "lost" kinetic energy becomes heat, sound and deformation).

Question 4 (4 marks)

a. (2 marks)

$$E_s = 1/2\, k x^2 = 1/2 \times 450 \times 0.080^2 = 1.44\,\mathrm{J}\,[2].$$

[1 for $E_s = 1/2\, k x^2$; 1 for the value]

b. (2 marks) The kinetic energy at launch is $E_k = 1/2\, m v^2 = 1/2 \times 0.12 \times 4.0^2 = 0.96\,\mathrm{J}$ [1]:

$$E_{\text{dissipated}} = E_s - E_k = 1.44 - 0.96 = 0.48\,\mathrm{J}\,[1],$$

appearing mainly as heat (also sound) due to friction in the injector.

Question 5 (6 marks)

a. (2 marks)

$$g = \frac{G\,M}{r^2} = \frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24}}{(8.0 \times 10^6)^2} = 6.22\,\text{N kg}^{-1}\,(3\text{ s.f.}),\text{as required.}$$

[1 for $g = G\,M/r^2$; 1 for the value]

b. (2 marks) For a circular orbit the gravitational force provides the centripetal force, so $v = \sqrt{\frac{G\,M}{r}}$ [1]:

$$v = \sqrt{\frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24}}{8.0 \times 10^6}} = 7.06 \times 10^3\,\text{m s}^{-1}[1].$$

c. (2 marks) The satellite's speed is constant, but the direction of its velocity changes continuously, so its velocity is changing and it is accelerating (a centripetal acceleration directed towards the Earth) [1]. By Newton's second law, $\Sigma F = m\,a$, this acceleration must be produced by an unbalanced net force — the gravitational force of the Earth on the satellite, directed towards the Earth's centre; a non-zero net force gives a non-zero acceleration even at constant speed [1].

Question 6 (5 marks)

a. (1 mark)

$$E = \frac{V}{d} = \frac{2.0 \times 10^3}{0.10} = 2.0 \times 10^4\,\text{N C}^{-1}\,(3\text{ s.f.}),\text{as required.}$$

b. (2 marks) The work done by the field equals the kinetic energy gained, $q\,V = 1/2\,m\,v^2$ [1]:

$$v = \sqrt{\frac{2\,q\,V}{m}} = \sqrt{\frac{2 \times 1.60 \times 10^{-19} \times 2.0 \times 10^3}{9.11 \times 10^{-31}}} = 2.65 \times 10^7\,\text{m s}^{-1}[1].$$

c. (2 marks) The kinetic energy gained equals the work done, $E_k = q\,V$. Since the electron is accelerated through $2.0 \times 10^3\,\text{V}$, $E_k = 2.0 \times 10^3\,\text{eV}$ [1]. In joules:

$$E_k = q\,V = 1.60 \times 10^{-19} \times 2.0 \times 10^3 = 3.2 \times 10^{-16}\,\text{J}[1].$$

Question 7 (6 marks)

a. (2 marks) The magnetic force $F = q\,v\,B$ is always perpendicular to the ion's velocity, so it does no work and the speed stays constant [1]. A force of constant magnitude, always perpendicular to the velocity, acts as a centripetal force, continually turning the ion into a circular path [1].

b. (2 marks)

$$r = \frac{m\,v}{q\,B} = \frac{2.5 \times 10^{-26} \times 1.2 \times 10^5}{1.60 \times 10^{-19} \times 0.35} = 5.36 \times 10^{-2}\,\text{m}[2].$$

[1 for $r = m\,v/(q\,B)$; 1 for the value]

c. (2 marks) From $r = \frac{m\,v}{q\,B}$, with v, q and B unchanged, the radius is directly proportional to the mass [1]. Doubling the mass therefore **doubles** the radius, to $2 \times 5.36 \times 10^{-2} = 0.107\,\text{m}$ [1].

Question 8 (4 marks)

a. (2 marks)

$$F = n\,I\,l\,B = 1 \times 15 \times 0.25 \times 0.80 = 3.0\,\text{N}[2].$$

[1 for $F = n I l B$; 1 for the value]

b. (2 marks) The electric field does work on the charged particles, exerting a force along their direction of motion that increases their speed and kinetic energy (linear acceleration) [1]. The magnetic field exerts a force perpendicular to the velocity, so it does no work; it changes only the direction of motion, providing the centripetal force that steers the particles around the ring [1].

Question 9 (6 marks)

a. (1 mark)

$$\Phi_B = B_\perp A = 0.25 \times 1.5 \times 10^{-3} = 3.75 \times 10^{-4}\,\text{Wb}.$$

b. (2 marks) The flux through the coil falls to zero, so $\Delta\Phi_B = 3.75 \times 10^{-4}\,\text{Wb}$ [1]:

$$\varepsilon = \frac{N\,\Delta\Phi_B}{\Delta t} = \frac{800 \times 3.75 \times 10^{-4}}{0.020} = 15.0\,\text{V}\,[1].$$

c. (2 marks) Switching off the field means the magnetic flux **through the coil** changes with time [1]. By Faraday's law, $\varepsilon = -N\dfrac{\Delta\Phi_B}{\Delta t}$, it is this rate of change of flux (together with the number of turns) that induces the emf — the mere presence of a magnetic field is not enough; the flux must be changing [1].

d. (1 mark) Tilting the coil so its plane is no longer perpendicular to the field reduces the flux through it, because only the field component perpendicular to the coil's area contributes ($\Phi_B = B_\perp A$); the flux would be less than $3.75 \times 10^{-4}\,\text{Wb}$.

Question 10 (7 marks)

a. (1 mark) For an ideal transformer $\dfrac{V_2}{V_1} = \dfrac{N_2}{N_1}$, so

$$V_2 = V_1 \frac{N_2}{N_1} = 250 \times \frac{2.20 \times 10^4}{500} = 1.10 \times 10^4\,\text{V} = 11.0\,\text{kV (3 s.f.)}\text{, as required.}$$

b. (2 marks) The voltage dropped along the line is $V_{\text{drop}} = 11.0 - 10.4 = 0.6\,\text{kV} = 600\,\text{V}$ [1]. Using $V_{\text{drop}} = I_{\text{line}} R_{\text{line}}$:

$$I_{\text{line}} = \frac{V_{\text{drop}}}{R_{\text{line}}} = \frac{600}{6.0} = 100\,\text{A}\,[1].$$

c. (2 marks)

$$P_{\text{loss}} = I_{\text{line}}^2 R_{\text{line}} = 100^2 \times 6.0 = 6.0 \times 10^4\,\text{W}\,[2].$$

[1 for $P_{\text{loss}} = I^2 R$; 1 for the value]

d. (2 marks) The power delivered to the facility is $P = V_{\text{facility}} I_{\text{line}} = 10\,400 \times 100 = 1.04 \times 10^6\,\text{W}$, so the line loss is $\dfrac{6.0 \times 10^4}{1.04 \times 10^6} = 5.77\,\%$ [1]. Transmitting at high voltage means that, for a given power ($P = V I$), the line current is small; since $P_{\text{loss}} = I_{\text{line}}^2 R_{\text{line}}$, a small current makes the line loss very small [1].

Question 11 (3 marks)

a. (2 marks) With a **split-ring commutator** the connections to the external circuit reverse every half-turn, so the output never changes sign — a pulsating **direct** voltage (DC) [1]. With **slip rings** the connections never swap, so the output is a sinusoidal **alternating** voltage (AC) that reverses direction once each half-turn [1].

b. (1 mark) The emf is momentarily zero when the coil's plane is **perpendicular to the magnetic field** (the coil is face-on to the field, so the flux is at its maximum and its rate of change is instantaneously zero).

Question 12 (3 marks)

a. (1 mark) The photovoltaic array produces a direct current (DC), whereas the station's AC equipment (and the mains standard) requires alternating current; the inverter converts the DC output into AC.

b. (2 marks)

$$V_{\text{RMS}} = \frac{V_{\text{peak}}}{\sqrt{2}} = \frac{325}{\sqrt{2}} = 230\,\text{V}\,[2].$$

[1 for the relationship; 1 for the value]

Question 13 (3 marks)

a. (2 marks)

$$\Delta x = \frac{\lambda L}{d} = \frac{633 \times 10^{-9} \times 2.0}{0.25 \times 10^{-3}} = 5.06 \times 10^{-3}\,\text{m} = 5.06\,\text{mm}\,[2].$$

[1 for substitution; 1 for the value]

b. (1 mark) Since $\Delta x = \frac{\lambda L}{d}$, the fringe spacing is inversely proportional to d; increasing the slit separation would **decrease** the fringe spacing (the bright fringes move closer together).

Question 14 (4 marks)

a. (2 marks)

$$E = \frac{hc}{\lambda} = \frac{4.14 \times 10^{-15} \times 3.00 \times 10^{8}}{350 \times 10^{-9}} = 3.55\,\text{eV}\,(3\text{ s.f.})\text{, as required.}$$

[1 for $E = hc/\lambda$; 1 for the value]

b. (1 mark) Using the unrounded photon energy ($3.549\,\text{eV}$):

$$E_{k\,\text{max}} = hf - \varphi = 3.549 - 2.10 = 1.45\,\text{eV}.$$

c. (1 mark) There is **no effect** on the maximum kinetic energy — it depends only on the frequency of the light (and the work function), not on the intensity. Doubling the intensity doubles the number of photoelectrons emitted per second, but not their maximum kinetic energy.

Question 15 (3 marks)

a. (2 marks) The electron's momentum is $p = mv = 9.11 \times 10^{-31} \times 4.0 \times 10^{6} = 3.64 \times 10^{-24}\,\text{kg m s}^{-1}$ [1]:

$$\lambda = \frac{h}{p} = \frac{6.63 \times 10^{-34}}{3.64 \times 10^{-24}} = 1.82 \times 10^{-10}\,\text{m}\,[1].$$

b. (1 mark) The momenta are **equal**: for both a photon and the electron $p = h/\lambda$, so equal wavelengths mean equal momenta.

Question 16 (3 marks)

a. (2 marks) The photon energy equals the difference between the two levels, $\Delta E = |-1.5 - (-4.0)| = 2.5\,\text{eV}$ [1]:

$$\lambda = \frac{hc}{\Delta E} = \frac{4.14 \times 10^{-15} \times 3.00 \times 10^{8}}{2.5} = 4.97 \times 10^{-7}\,\text{m} = 497\,\text{nm}\,[1].$$

b. (1 mark) The electrons in an atom can occupy only discrete (quantised) energy levels. A photon is emitted only when an electron drops from one level to another, and its energy — and hence its wavelength — is fixed by the difference between those levels. Only certain level differences exist, so only certain wavelengths are emitted, giving a line spectrum rather than a continuous one.

Question 17 (4 marks)

a. (1 mark)

$$\gamma=\frac{1}{\sqrt{1-(v/c)^2}}=\frac{1}{\sqrt{1-0.994^2}}=\frac{1}{\sqrt{0.011964}}=9.14\,(3\text{ s.f.}),\text{as required.}$$

b. (2 marks) The laboratory (dilated) half-life is $t=\gamma t_0$, using the full-precision $\gamma=9.142$ [1]:

$$t=9.142\times 2.2=20.1\,\mu\text{s}[1].$$

(Using the displayed $\gamma=9.14$ gives $20.1\,\mu\text{s}$ to three significant figures as well.)

c. (1 mark) **Shorter.** Working in the muons' frame, the ring section moves past at $0.994\,c$, so its length is contracted along the direction of motion: $L=L_0/\gamma=15/9.142=1.64\,\text{m}$, which is shorter than $15\,\text{m}$.

Question 18 (3 marks)

a. (2 marks) Both particles are at rest, so the released energy equals the total rest energy of the electron and positron [1]:

$$E=2m_ec^2=2\times 9.11\times 10^{-31}\times(3.00\times 10^8)^2=1.64\times 10^{-13}\,\text{J}[1].$$

(This is $2\times 0.512=1.02\,\text{MeV}$.)

b. (1 mark) Before the annihilation the electron and positron are at rest, so the total momentum is zero. A single photon would carry momentum ($p=E/c\neq 0$), which cannot equal zero, so momentum could not be conserved. At least two photons, travelling in opposite directions, are required so that their momenta cancel.

Question 19 (19 marks)

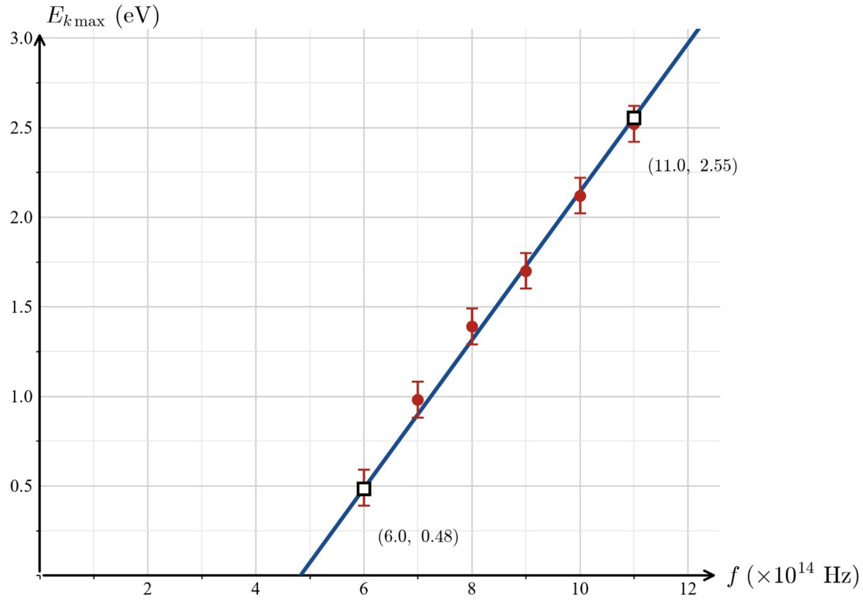
a. (3 marks) [1 each]

- Independent variable: the frequency f of the incident light.
- Dependent variable: the maximum kinetic energy $E_{k\max}$ of the photoelectrons (found from the stopping voltage).
- Controlled variable (any one): the photocathode metal (same surface) / the apparatus and its geometry / the method used to determine the stopping voltage.

b. (2 marks) Each photon delivers its whole energy $E=hf$ to a single electron [1]. If hf is less than the work function φ, no electron receives enough energy to escape the metal, so below the threshold frequency f_0 (where $hf_0=\varphi$) no photoelectrons are emitted no matter how intense the light — a brighter beam simply delivers more photons, each still too weak to free an electron [1].

c. (1 mark) Repeating the measurement and averaging reduces the effect of random errors on each value of $E_{k\max}$, improving the precision (reliability) of each plotted point.

d. (5 marks) The completed graph is shown below: $E_{k\max}$ on the vertical axis and f on the horizontal axis; each point carries an uncertainty bar of $\pm 0.10\,\text{eV}$; a single straight line of best fit ($E_{k\max}=0.414f-2.0$ in the plotted units) follows the trend of all six points.



Marks for: axes labelled with quantity and unit, and scales that spread the data across the grid [1]; all six points plotted correctly [1]; an uncertainty bar of $\pm 0.10\,\text{eV}$ drawn on each point [1]; a single straight line of best fit drawn to follow the trend of all six points [2].

e. (2 marks) Reading two well-separated points **on the line of best fit** — for example $(6.0\times 10^{14}\,\text{Hz}, 0.48\,\text{eV})$ and $(11.0\times 10^{14}\,\text{Hz}, 2.55\,\text{eV})$ [1]:

$$\text{gradient} = \frac{\Delta E_{k\,max}}{\Delta f} = \frac{(2.55-0.48)\,\text{eV}}{(11.0-6.0)\times 10^{14}\,\text{Hz}} = 4.14\times 10^{-15}\,\text{eV s}\,[1].$$

(The points are read off the drawn line, not taken from the scattered data.)

f. (2 marks) The gradient is Planck's constant. Converting to joule-seconds [1]:

$$h = 4.14\times 10^{-15}\,\text{eV s}\times 1.60\times 10^{-19}\,\text{J eV}^{-1} = 6.62\times 10^{-34}\,\text{J s}\,[1].$$

This differs from the accepted value $6.63\times 10^{-34}\,\text{J s}$ by only about $0.2\,\%$, so the result is consistent with the accepted value of Planck's constant.

g. (2 marks) Extending the line of best fit to cut the horizontal axis ($E_{k\,max}=0$) gives the threshold frequency $f_0 \approx 4.8\times 10^{14}\,\text{Hz}$ [1]. The work function is then

$$\varphi = hf_0 = 4.14\times 10^{-15}\times 4.83\times 10^{14} = 2.0\,\text{eV}\,[1].$$

(Equivalently, extrapolating the line to $f=0$ gives a vertical intercept of $-\varphi = -2.0\,\text{eV}$.)

h. (2 marks) The gradient would be **unchanged**: it equals Planck's constant h, a universal constant that does not depend on the metal [1]. A higher work function only shifts the whole line — it moves down and to the right, giving a more negative vertical intercept ($-\varphi$) and a higher threshold frequency f_0 [1].