VICTORIAN CURRICULUM AND ASSESSMENT AUTHORITY

Victorian Certificate of Education 2018

SUPERVISOR TO ATTACH PROCESSING LABEL HERE

Letter

STUDENT NUMBER

PHYSICS
Written examination

Wednesday 14 November 2018

Reading time: 9.00 am to 9.15 am (15 minutes)
Writing time: 9.15 am to 11.45 am (2 hours 30 minutes)

QUESTION AND ANSWER BOOK

Structure of book

Section	*Number of questions*	*Number of questions to be answered*	*Number of marks*
A	20	20	20
B	20	20	110
			Total 130

- Students are permitted to bring into the examination room: pens, pencils, highlighters, erasers, sharpeners, rulers, pre-written notes (one folded A3 sheet or two A4 sheets bound together by tape) and one scientific calculator.
- Students are NOT permitted to bring into the examination room: blank sheets of paper and/or correction fluid/tape.

Materials supplied
- Question and answer book of 41 pages
- Formula sheet
- Answer sheet for multiple-choice questions

Instructions
- Write your student number in the space provided above on this page.
- Check that your **name** and **student number** as printed on your answer sheet for multiple-choice questions are correct, **and** sign your name in the space provided to verify this.
- Unless otherwise indicated, the diagrams in this book are **not** drawn to scale.
- All written responses must be in English.

At the end of the examination
- Place the answer sheet for multiple-choice questions inside the front cover of this book.
- You may keep the formula sheet.

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

SECTION A – Multiple-choice questions

Instructions for Section A

Answer **all** questions in pencil on the answer sheet provided for multiple-choice 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.

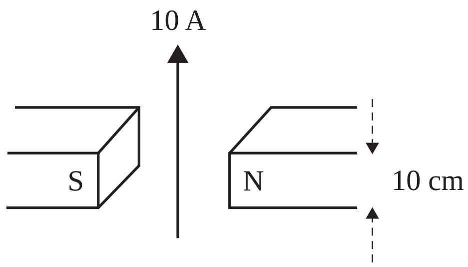
No marks will be given if more than one answer is completed for any question.

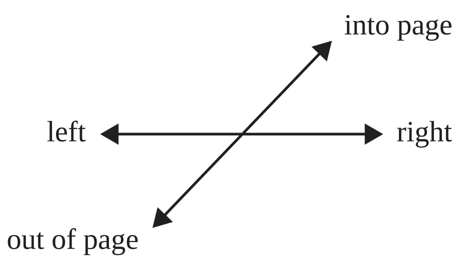
Unless otherwise indicated, the diagrams in this book are **not** drawn to scale.

Take the value of g to be 9.8 m s^{-2}.

Use the following information to answer Questions 1 and 2.

A wire carrying a current of 10 A is placed in a uniform magnetic field of B = 4.0×10^{-4} T, as shown below.
10 cm of the wire is in the field.





Question 1

Which one of the following best gives the magnitude of the force acting on the wire?

A. 4.0×10^{-2} N

B. 4.0×10^{-4} N

C. 1.6×10^{-8} N

D. 4.0×10^{-12} N

Question 2

Which one of the following best gives the direction of the force acting on the wire?

A. out of page

B. into page

C. right

D. left

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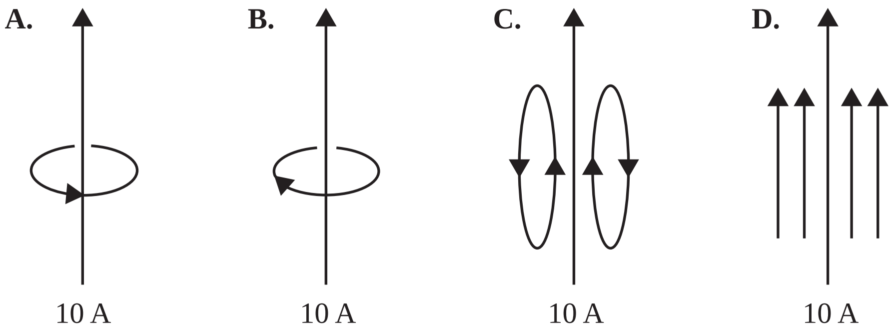
Question 3

A straight wire carries a current of 10 A.

Which one of the following diagrams best shows the magnetic field associated with this current?



Question 4

A small sphere has a charge of 2.0×10^{-6} C on it. Take $k = 8.99 \times 10^{9}$ N m^{2} C^{-2}.

The strength of the electric field due to this charge at a point 3.0 m from the sphere is best given by

A. 2.0×10^{-3} V m^{-1}

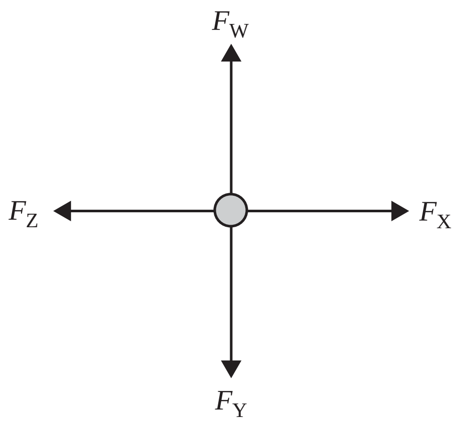
B. 6.0×10^{-3} V m^{-1}

C. 9.0×10^{-3} V m^{-1}

D. 2.0×10^{3} V m^{-1}

Question 5

Four students are pulling on ropes in a four-person tug of war. The relative sizes of the forces acting on the various ropes are $F_W = 200$ N, $F_X = 240$ N, $F_Y = 180$ N and $F_Z = 210$ N. The situation is shown in the diagram below.



Which one of the following **best** gives the magnitude of the resultant force acting at the centre of the tug-of-war ropes?

A. 28.3 N

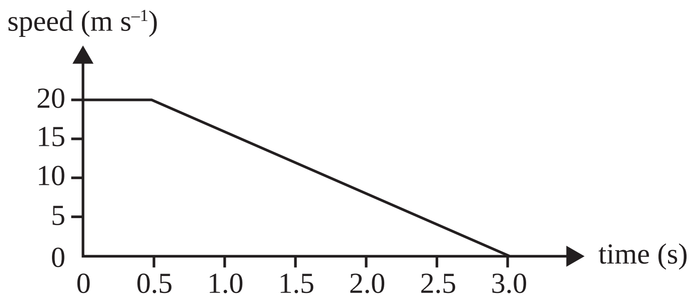
B. 30.0 N

C. 36.1 N

D. 50.0 N

Question 6

Lisa is driving a car of mass 1000 kg at 20 m s^{-1} when she sees a dog in the middle of the road ahead of her. She takes 0.50 s to react and then brakes to a stop with a constant braking force. Her speed is shown in the graph below. Lisa stops before she hits the dog.



Which one of the following is closest to the magnitude of the braking force acting on Lisa's car during her braking time?

A. 6.7 N

B. 6.7 kN

C. 8.0 kN

D. 20.0 kN

Question 7

At one point on Earth's surface at a distance R from the centre of Earth, the gravitational field strength is measured as 9.76 N kg^{-1}.

Which one of the following is closest to Earth's gravitational field strength at a distance $2R$ **above** the surface of Earth at that point?

A. 1.08 N kg^{-1}

B. 2.44 N kg^{-1}

C. 3.25 N kg^{-1}

D. 4.88 N kg^{-1}

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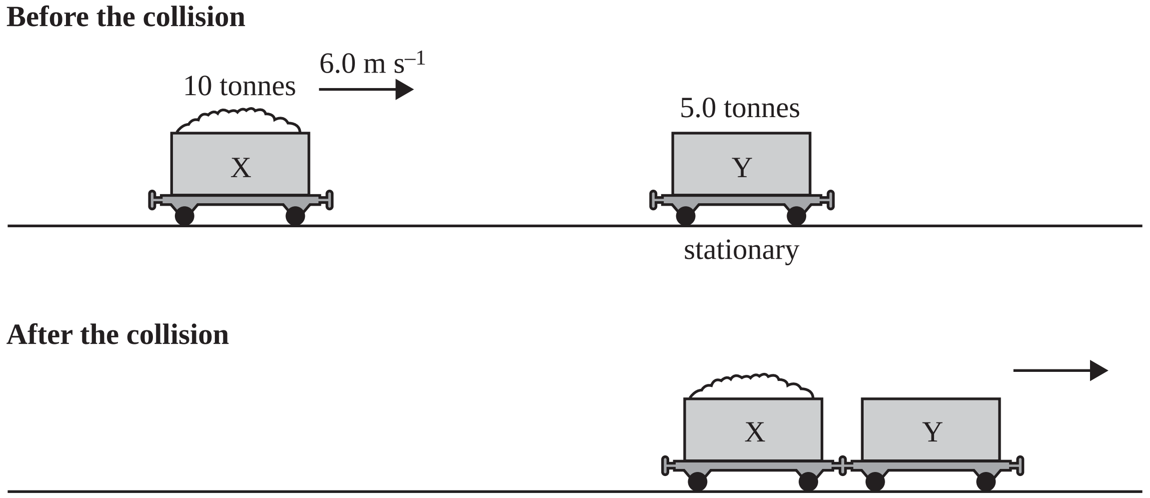
Use the following information to answer Questions 8 and 9.

A railway truck X of mass 10 tonnes, moving at 6.0 m s^{-1}, collides with a stationary railway truck Y of mass 5.0 tonnes. After the collision the trucks are joined together and move off as one. The situation is shown below.



Question 8

The final speed of the joined railway trucks after the collision is closest to

A. 2.0 m s^{-1}

B. 3.0 m s^{-1}

C. 4.0 m s^{-1}

D. 6.0 m s^{-1}

Question 9

The collision of the railway trucks is best described as one where

A. kinetic energy is conserved but momentum is not conserved.

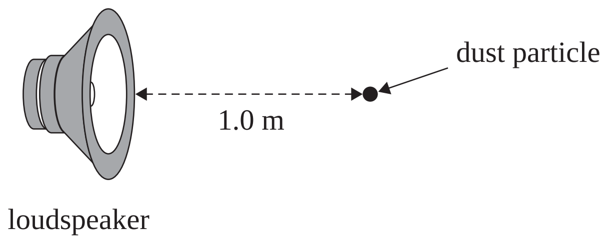
B. kinetic energy is not conserved but momentum is conserved.

C. neither kinetic energy nor momentum is conserved.

D. both kinetic energy and momentum are conserved.

Question 10

A loudspeaker is producing a sound wave of constant frequency. Consider a tiny dust particle 1.0 m in front of the loudspeaker.



Which one of the following diagrams best describes the motion of the dust particle?

Question 11

Alex hears the siren from a stationary fire engine.

Compared with the sound Alex hears from the stationary fire engine, the sound Alex will hear as the fire engine approaches him will have increased

A. speed.

B. period.

C. amplitude.

D. frequency.

D O N O T W R I T E I N T H I S A R E A

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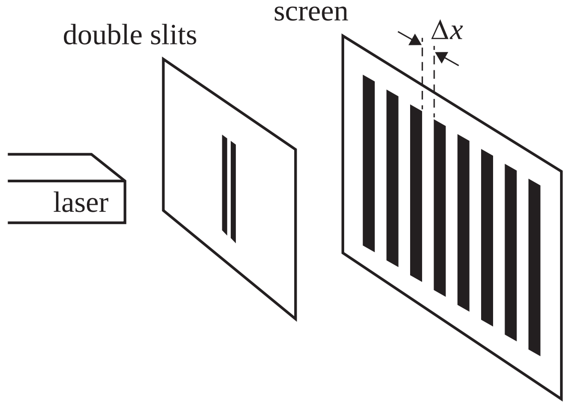
Question 12

A teacher sets up an apparatus to demonstrate Young's double-slit experiment. A pattern of bright and dark bands is observed on the screen, as shown below.



Which one of the following actions will increase the distance, Δx, between the adjacent dark bands in this interference pattern?

A. Decrease the distance between the slits and the screen.

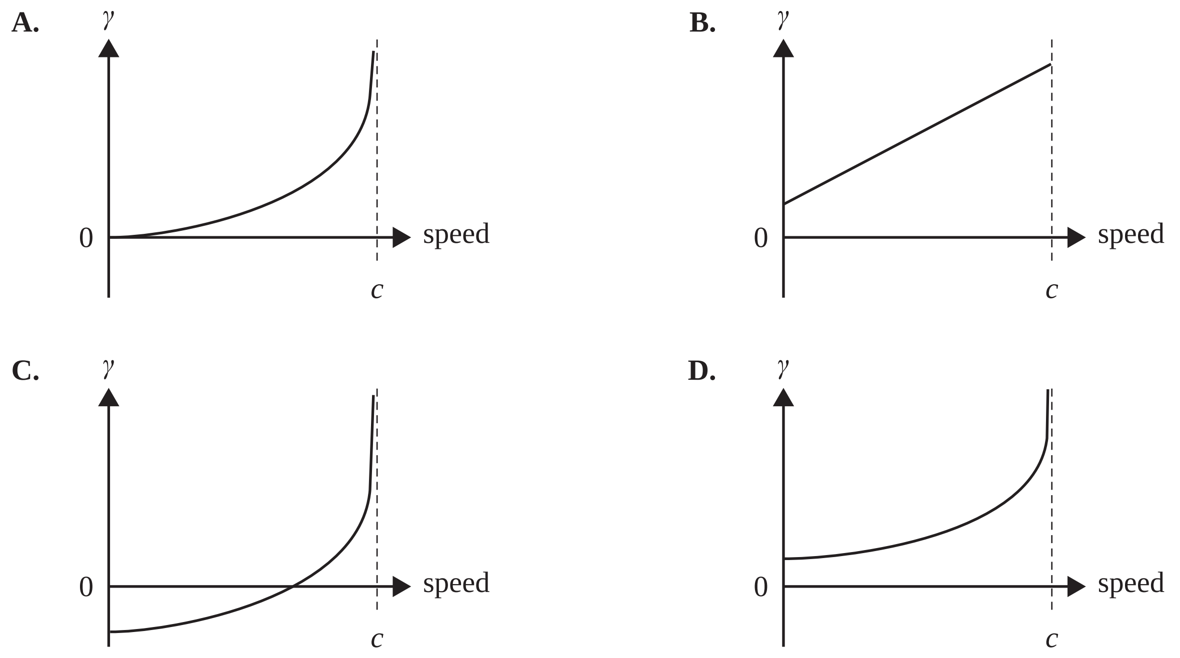
B. Decrease the wavelength of the light.

C. Decrease the slit separation.

D. Decrease the slit width.

Question 13

Which one of the following diagrams best represents the graph of γ (the Lorentz factor) versus speed for an electron that is accelerated from rest to near the speed of light, c?



Question 14

Which one of the following statements about the kinetic energy, E_k, of a proton travelling at relativistic speed is the most accurate?

A. The difference between the proton's relativistic E_k and its classical E_k cannot be determined.

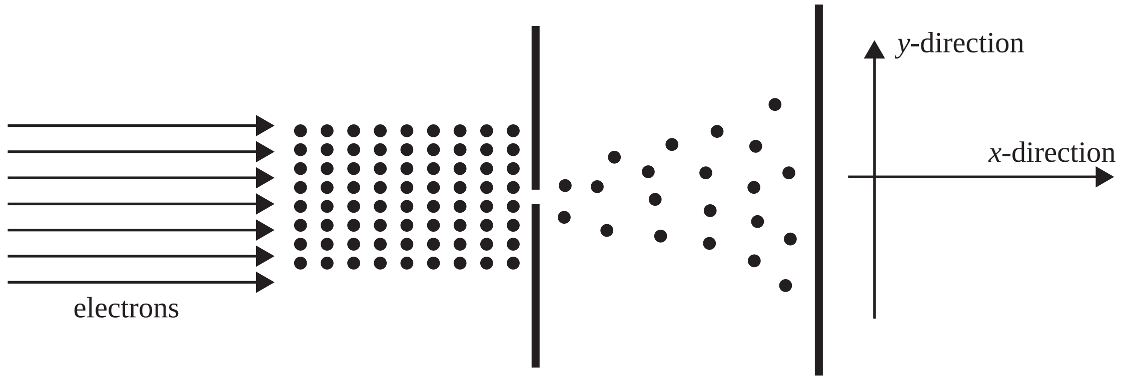
B. The proton's relativistic E_k is greater than its classical E_k.

C. The proton's relativistic E_k is the same as its classical E_k.

D. The proton's relativistic E_k is less than its classical E_k.

Question 15

When a beam of particles, such as electrons, passes through a narrow slit, diffraction effects can occur, as shown in the diagram below.



This phenomenon can be described by Heisenberg's uncertainty principle because, when electrons pass through the slit, the uncertainty in their

A. y-position does not affect the uncertainty in their y-momentum.

B. y-momentum affects the uncertainty in their x-momentum.

C. x-position affects the uncertainty in their x-momentum.

D. y-position affects the uncertainty in their y-momentum.

Question 16

Polarisation is a property of

A. all types of waves.

B. only sound waves.

C. only transverse waves.

D. only longitudinal waves.

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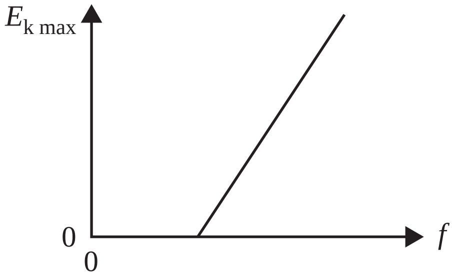
Question 17

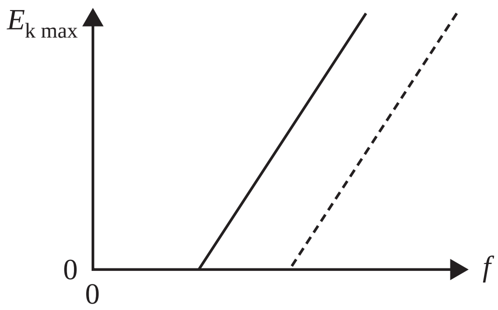
The results of a photoelectric experiment are displayed in the graph below. The graph shows the maximum kinetic energy ($E_{\text{k max}}$) of photoelectrons versus the frequency (f) of light falling on the metal surface.



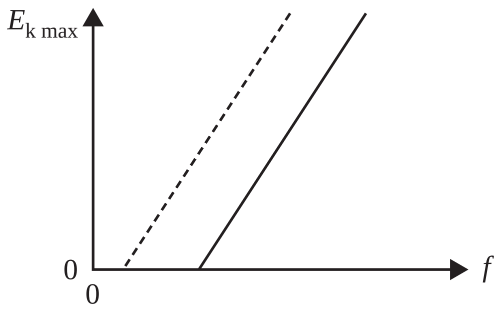
A second experiment is conducted with the original metal surface being replaced by one with a larger work function. The original data is shown with a solid line and the results of the second experiment are shown with a dashed line.

Which one of the following graphs shows the results from the second experiment?

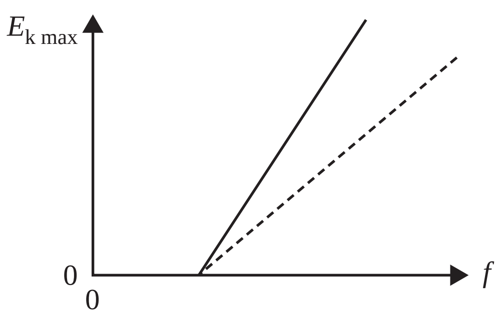
A.



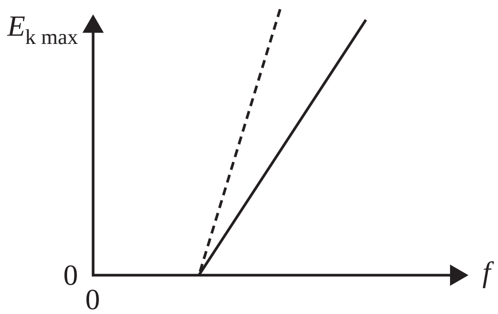
B.



C.



D.



Question 18

The experimental uncertainty in a measurement of any particular quantity is **best** described as

A. a quantitative estimate of the doubt associated with the measurement.

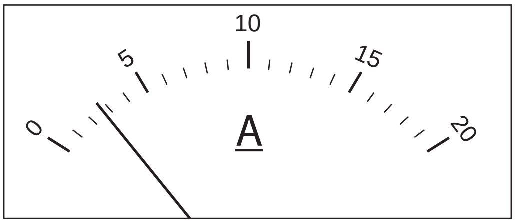
B. the degree of confidence a scientist has in their experimental technique.

C. the difference between the measurement and the true value of the quantity.

D. the result of one measurement; repeated measurements can eliminate uncertainty.

Question 19

The diagram below shows a properly calibrated ammeter with its pointer registering a current of close to 3 A.

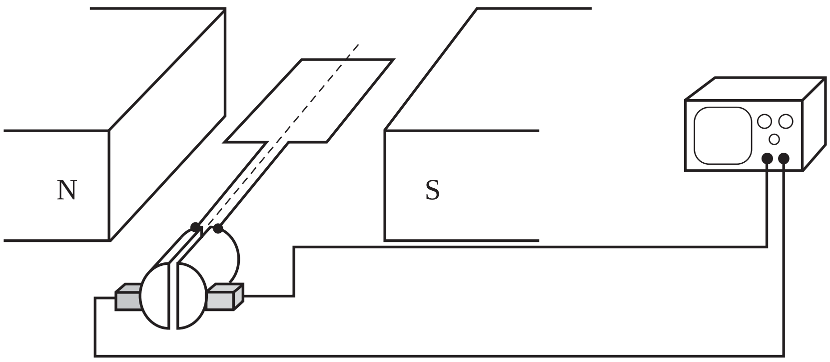


Which one of the following is the most appropriate measure of the uncertainty of this pointer reading?

A. 0.05 A
B. 0.5 A
C. 0.8 A
D. 1 A

Question 20

A group of Physics students conducts a controlled experiment to investigate the phenomenon of electromagnetic induction. The students place a coil within a uniform magnetic field, as shown in the diagram below.



The coil is spun at 50 revolutions per minute, 100 revolutions per minute and then 150 revolutions per minute, and the peak EMF is measured each time on an oscilloscope.

Which of the following **best** identifies the independent and dependent variables, and a possible controlled variable in this experiment?

	Independent variable	Dependent variable	Controlled variable
A.	speed of rotation	strength of magnetic field	peak EMF
B.	speed of rotation	peak EMF	strength of magnetic field
C.	peak EMF	speed of rotation	strength of magnetic field
D.	peak EMF	strength of magnetic field	speed of rotation

END OF SECTION A

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SECTION B

Instructions for Section B

Answer **all** questions in the spaces provided. Write using blue or black pen.
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 value of g to be 9.8 m s^{-2}.

Question 1 (5 marks)

An electric field accelerates a proton between two plates. The proton exits into a region of uniform magnetic field at right angles to its path, directed out of the page, as shown in Figure 1.

Data

mass of proton	1.7×10^{-27} kg
charge on proton	$+1.6 \times 10^{-19}$ C
accelerating voltage	10 kV
distance between plates	20 cm
strength of magnetic field	2.0×10^{-2} T

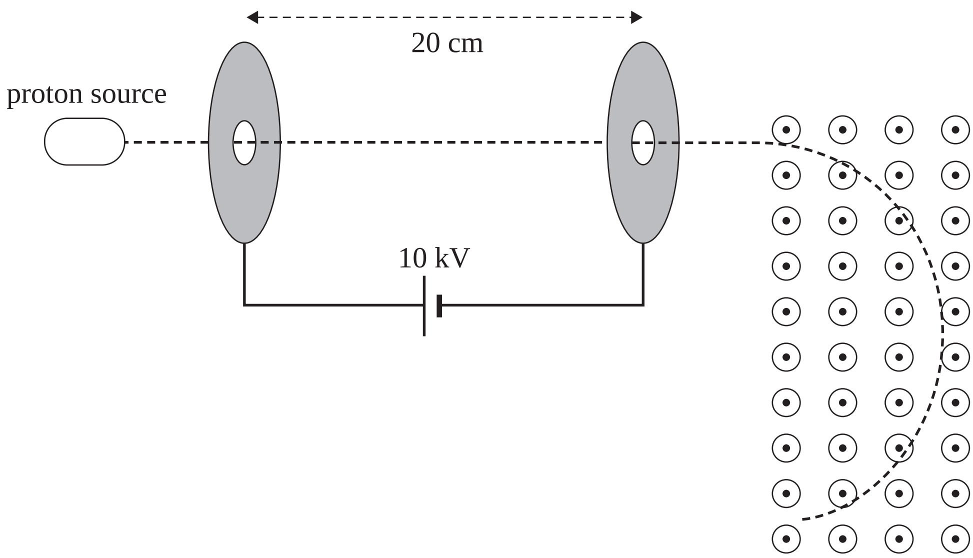

Figure 1

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a. Calculate the strength of the electric field between the plates. 1 mark

$\mathrm{V\ m^{-1}}$

b. Calculate the speed of the proton as it exits the electric field. Show your working. 2 marks

$\mathrm{m\ s^{-1}}$

c. With a different accelerating voltage, the proton exits the electric field at a speed of $1.0 \times 10^6\ \mathrm{m\ s^{-1}}$.

Calculate the radius of the path of this proton in the magnetic field. Show your working. 2 marks

m

Question 2 (6 marks)

A square loop of wire of 10 turns with a cross-sectional area of 1.6×10^{-3} m^2 passes at a constant speed into, through and out of a magnetic field of magnitude 2.0×10^{-2} T, as shown in Figure 2.

The loop takes 0.50 s to go from position X to position Y.

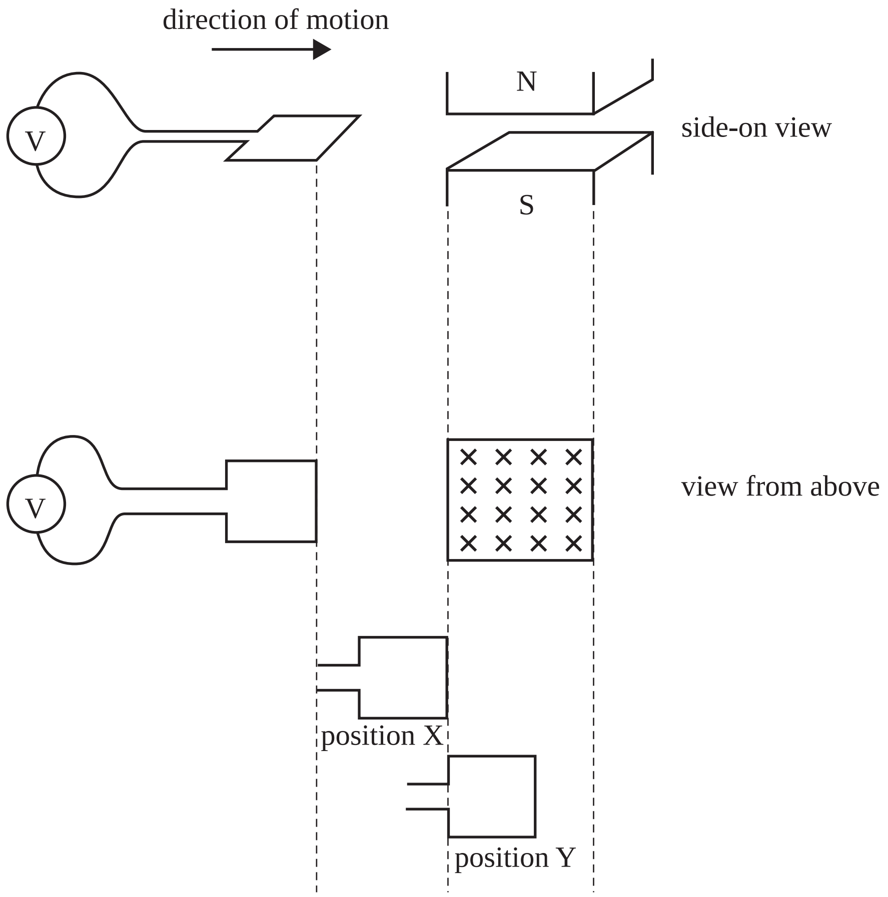
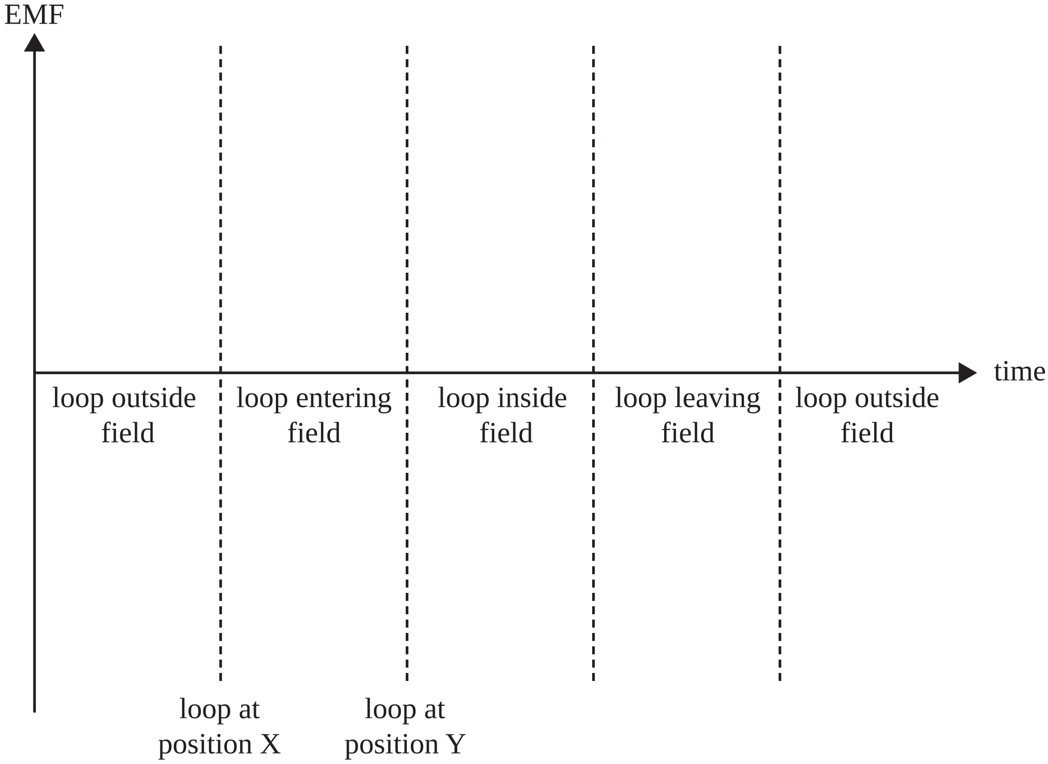


Figure 2

a. Calculate the average EMF induced in the loop as it passes from just outside the magnetic field at position X to just inside the magnetic field at position Y. Show your working. 3 marks

V

b. Sketch the EMF induced in the loop as it passes into, through and out of the magnetic field. You do not need to include values on the axes. 3 marks



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Question 3 (5 marks)

Students build a model of a simple DC motor, as shown in Figure 3.

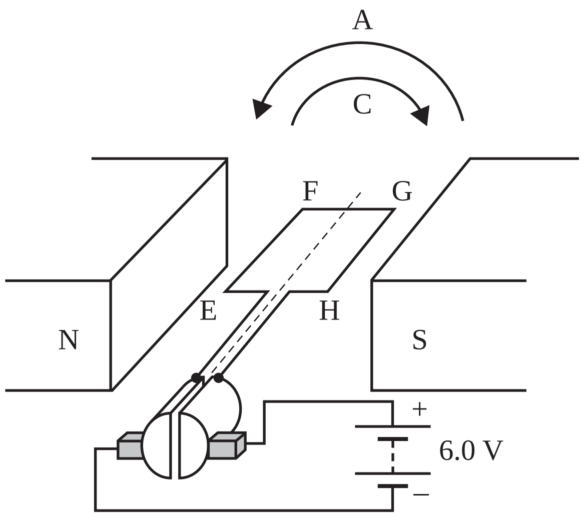

Figure 3

a. The motor is set with the coil horizontal, as shown, and the power source is applied.

Will the motor rotate in a clockwise (C) or anticlockwise (A) direction? Explain your answer. 3 marks

b. One student suggests that slip rings would be easier to make than a commutator and that they should use slip rings instead.

Explain the effect that replacing the commutator with slip rings would have on the operation of the motor, if no other change was made. 2 marks

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Question 4 (4 marks)

Figure 4 shows a simple AC alternator with the output connected to an oscilloscope and a light globe.

The oscilloscope can be considered as having a very large resistance. The coil is rotated, as shown in Figure 4.

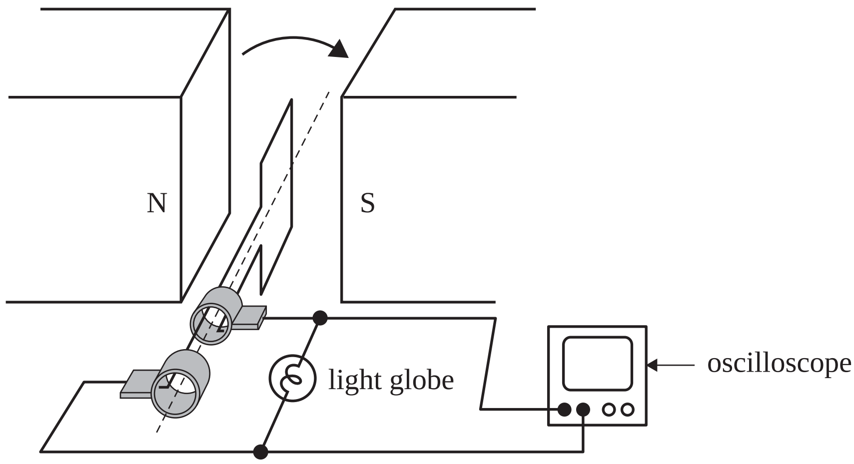

Figure 4

The output on the oscilloscope is shown in Figure 5.

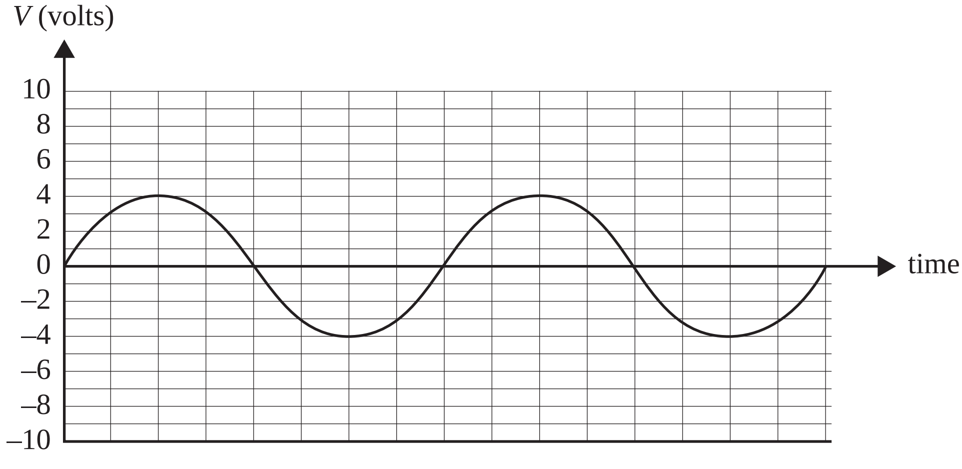

Figure 5

a. The AC alternator is to be replaced with a battery.

What voltage should the battery have for the light globe to light up with the same average brightness as it did with the alternator? Show your working. 2 marks

V

b. The rate of rotation of the loop is doubled.

On Figure 6 below, sketch the output that will now be seen on the oscilloscope. The original waveform is shown as a dashed line on Figure 6. 2 marks

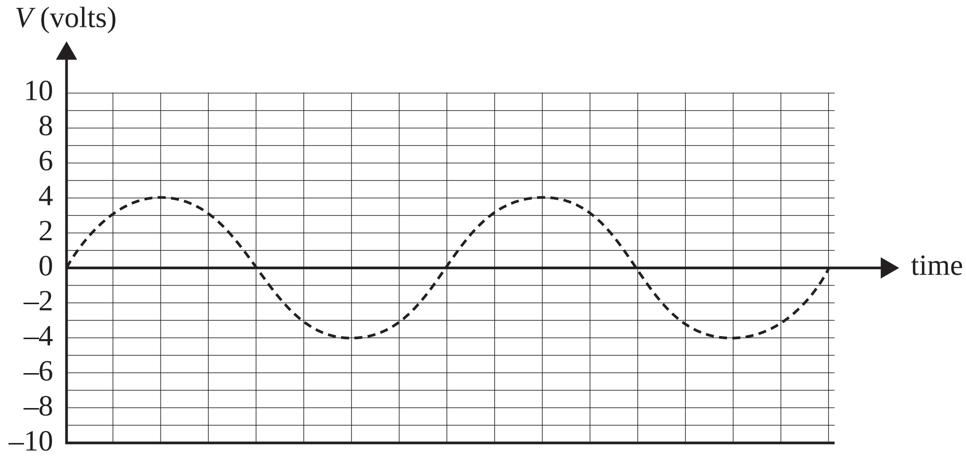

Figure 6

Question 5 (12 marks)

A Physics class is investigating power loss in transmission lines.

The students construct a model of a transmission system. They first set up the model as shown in Figure 7. The model consists of a variable voltage AC power supply, two transmission lines, each of 4.0 Ω (total resistance = 8.0 Ω), a variable ratio transformer, a light globe and meters as needed. The purpose of the model is to operate the 4.0 V light globe.

A variable ratio transformer is one in which the ratio of turns in primary windings to turns in secondary windings can be varied. The resistance of the connecting wires can be ignored.

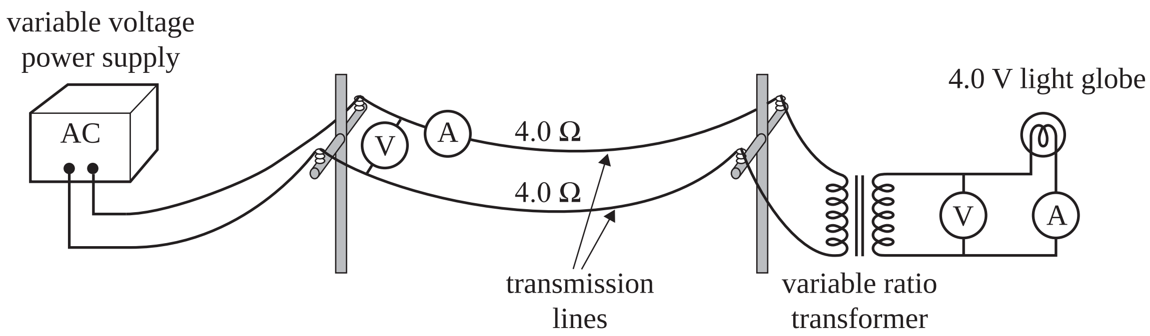

Figure 7

In their first experiment, the transformer is set on a ratio of 4:1 and the current in the transmission lines is measured to be 3.0 A. The light globe is operating correctly, with 4.0 V_{RMS} across it.

a. Calculate the power dissipated in the light globe. Show your working. 2 marks

W

b. Calculate the voltage output of the power supply. Show your working. 3 marks

V

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c. Calculate the total power loss in the transmission lines. Show your working. 2 marks

W

d. In a second experiment, the students set the variable ratio of the transformer at 8:1 and adjust the variable voltage power supply so that the light globe operates correctly, with 4.0 V_{RMS} across it.

Calculate the total power loss in the transmission lines in this second experiment. Show your working. 3 marks

W

e. Suggest **two** reasons why high voltages are often used for the transmission of electric power over long distances. 2 marks

Question 6 (7 marks)

A ball of mass 2.0 kg is dropped from a height of 2.0 m above a spring, as shown in Figure 8. The spring has an uncompressed length of 2.0 m. The ball and the spring come to rest when they are at a distance of 0.50 m below the uncompressed position of the spring.

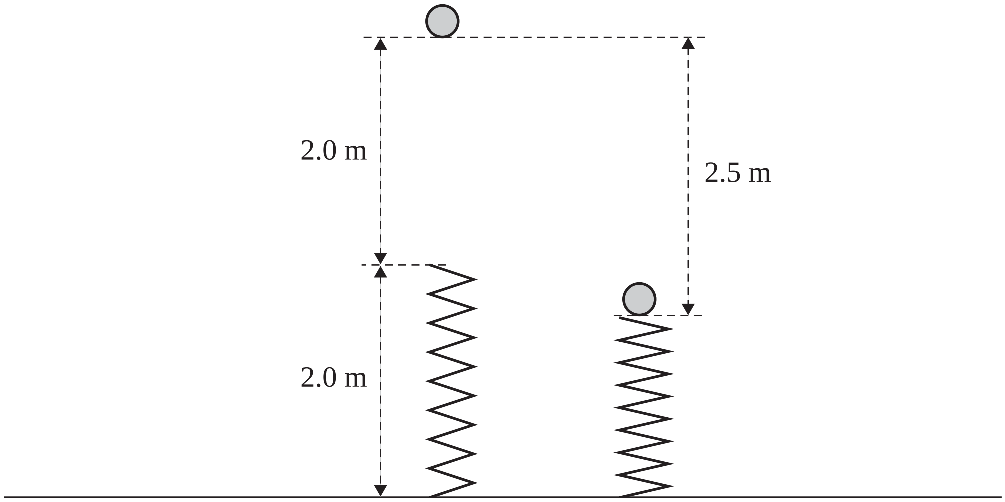

Figure 8

a. Using $g = 9.8\ \text{N kg}^{-1}$, show that the spring constant, k, is equal to $392\ \text{N m}^{-1}$. Show your working. 3 marks

b. Determine the acceleration of the ball when it reaches its maximum speed. Explain your answer. 2 marks

m s^{-2}

c. Calculate the compression of the spring when the ball reaches its maximum speed. Show your working. 2 marks

m

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Question 7 (6 marks)

A small ball of mass 0.20 kg rolls on a horizontal table at 3.0 m s^{-1}, as shown in Figure 9.

The ball hits the floor 0.40 s after rolling off the edge of the table. The radius of the ball may be ignored. In this question, take the value of g to be 10 m s^{-2}.

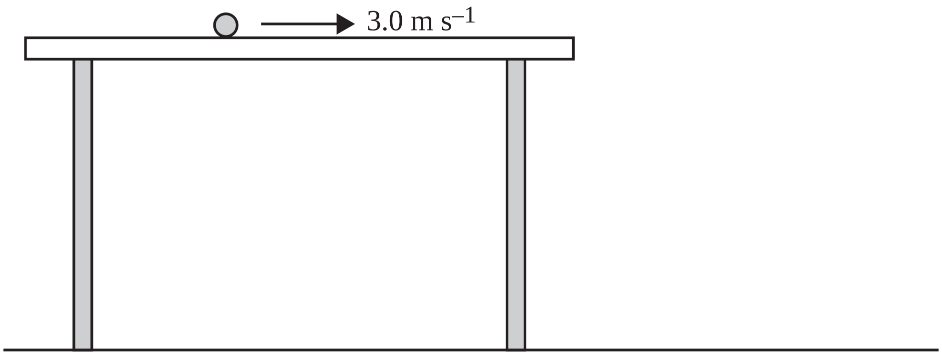

Figure 9

a. Calculate the horizontal distance from the right-hand edge of the table to the point where the ball hits the floor. 1 mark

m

b. Calculate the height of the table. Show your working. 2 marks

m

c. Calculate the speed at which the ball hits the floor. Show your working. 3 marks

m s^{-1}

Question 8 (4 marks)

Two blocks, A of mass 4.0 kg and B of mass 1.0 kg, are being pushed to the right on a smooth, frictionless surface by a 40 N force, as shown in Figure 10.

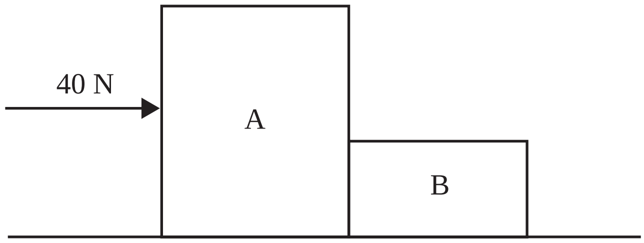

Figure 10

a. Calculate the magnitude of the force on block B by block A ($F_{\text{on B by A}}$). Show your working. 2 marks

N

b. State the magnitude and the direction of the force on block A by block B ($F_{\text{on A by B}}$). 2 marks

N

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Question 9 (8 marks)

The spacecraft *Juno* has been put into orbit around Jupiter. The table below contains information about the planet Jupiter and the spacecraft *Juno*. Figure 11 shows gravitational field strength ($N\ kg^{-1}$) as a function of distance from the centre of Jupiter.

Data

mass of Jupiter	1.90×10^{27} kg
radius of Jupiter	7.00×10^{7} m
mass of spacecraft *Juno*	1500 kg

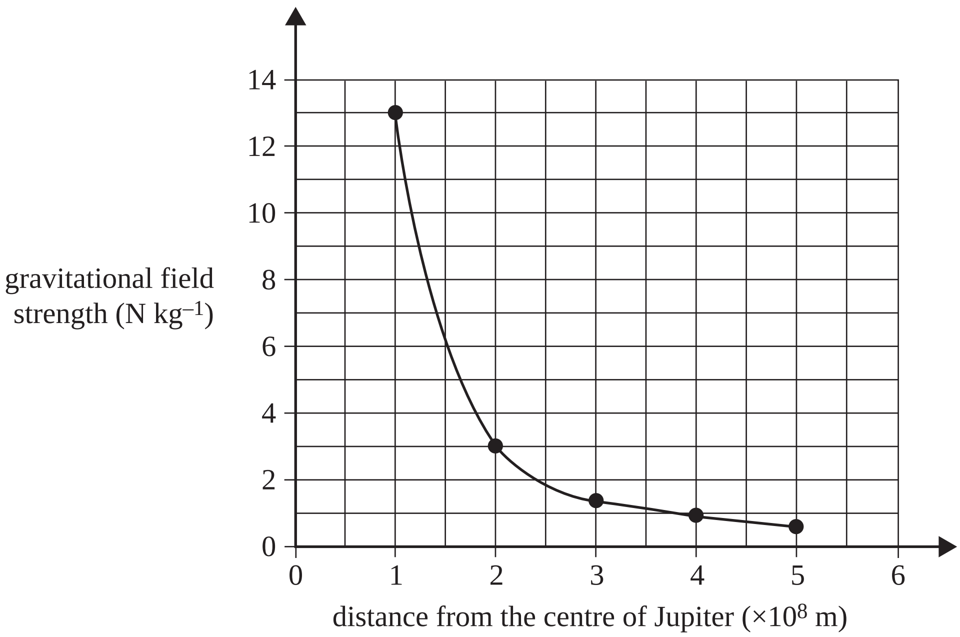

Figure 11

a. Calculate the gravitational force acting on *Juno* by Jupiter when *Juno* is at a distance of 2.0×10^{8} m from the centre of Jupiter. Show your working. 2 marks

N

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b. Use the graph in Figure 11 to estimate the magnitude of the change in gravitational potential energy of the spacecraft *Juno* as it moves from a distance of 2.0×10^8 m to a distance of 1.0×10^8 m from the centre of Jupiter. Show your working. 3 marks

J

c. Europa is a moon of Jupiter. It has a circular orbit of radius 6.70×10^8 m around Jupiter.

Calculate the period of Europa's orbit. Show your working. 3 marks

s

Question 10 (4 marks)

Members of the public can now pay to take zero gravity flights in specially modified jet aeroplanes that fly at an altitude of 8000 m above Earth's surface. A typical trajectory is shown in Figure 12. At the top of the flight, the trajectory can be modelled as an arc of a circle.

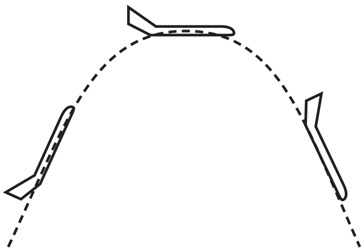

Figure 12

a. Calculate the radius of the arc that would give passengers zero gravity at the top of the flight if the jet is travelling at 180 m s^{-1}. Show your working. 2 marks

m

b. Is the force of gravity on a passenger zero at the top of the flight? Explain what 'zero gravity experience' means. 2 marks

Question 11 (4 marks)

Figure 13 shows two speakers, A and B, facing each other. The speakers are connected to the same signal generator/amplifier and the speakers are simultaneously producing the same 340 Hz sound.

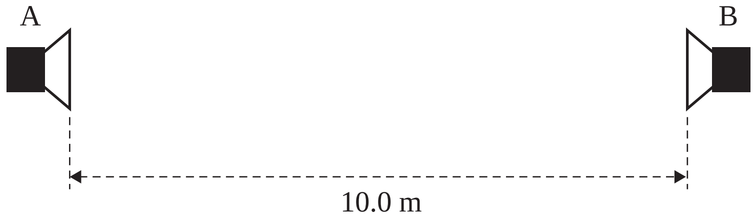

Figure 13

Take the speed of sound to be 340 m s^{-1}.

a. Calculate the wavelength of the sound. 1 mark

m

b. A student stands in the centre, equidistant from speakers A and B. He then moves towards speaker B and experiences a sequence of loud and quiet regions. He stops at the second region of quietness.

How far has the student moved from the centre? Explain your reasoning. 3 marks

m

Question 12 (5 marks)

Optical fibres are constructed using transparent materials with different refractive indices.

Figure 14 shows one type of optical fibre that has a cylindrical core and surrounding cladding. Laser light of wavelength 565 nm is shone from air into the optical fibre.

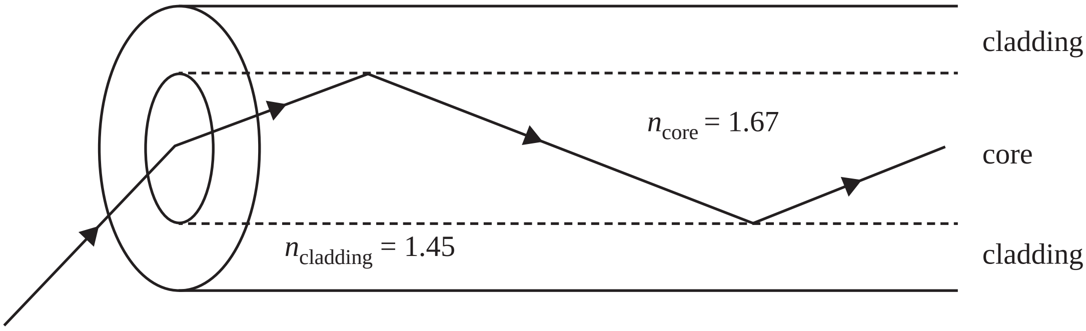

Figure 14

a. Calculate the frequency of the laser light before it enters the optical fibre. 1 mark

Hz

b. Calculate the critical angle for the laser light at the cladding–core boundary. Show your working. 2 marks

°

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c. Calculate the speed of the laser light once it enters the core of the optical fibre. Give your answer correct to three significant figures. Show your working. 2 marks

m s^{-1}

Question 13 (7 marks)

Physics students studying interference set up a double-slit experiment using a 610 nm laser, as shown in Figure 15.

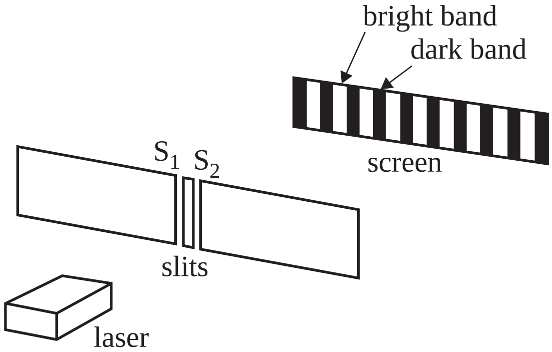

Figure 15

The light power output of the laser is 5.03×10^{-3} J s^{-1}.

a. Calculate the number of photons leaving the laser each second. Show your working. 3 marks

A section of the interference pattern observed by the students is shown in Figure 16. There is a bright band at point C, the centre point of the pattern.

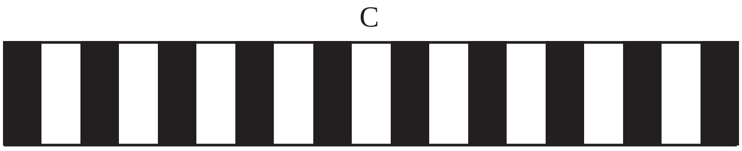

Figure 16

b. Explain why point C is in a bright band rather than in a dark band. 2 marks

c. Another point on the pattern to the right of point C is further from S_1 than S_2 by a distance of 2.14×10^{-6} m.

Mark this point on Figure 16 by writing an X above the point. You must use a calculation to justify your answer. 2 marks

Question 14 (2 marks)

Jani is stationary in a spaceship travelling at constant speed.

Does this mean that the spaceship must be in an inertial frame of reference? Justify your answer.

Question 15 (3 marks)

A stationary scientist in an inertial frame of reference observes a spaceship moving past her at a constant velocity. She notes that the clocks on the spaceship, which are operating normally, run eight times slower than her clocks, which are also operating normally. The spaceship has a mass of 10 000 kg.

Calculate the kinetic energy of the spaceship in the scientist's frame of reference. Show your working.

J

Question 16 (2 marks)

Quasars are among the most distant and brightest objects in the universe. One quasar (3C446) has a brightness that changes rapidly with time.

Scientists observe the quasar's brightness over a 20-hour time interval in Earth's frame of reference. The quasar is moving away from Earth at a speed of $0.704c$ ($\gamma = 1.41$).

Calculate the time interval that would be observed in the quasar's frame of reference. Show your working.

h

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Question 17 (7 marks)

To investigate the photoelectric effect, Sai and Kym set up an experiment.

The apparatus is shown in Figure 17.

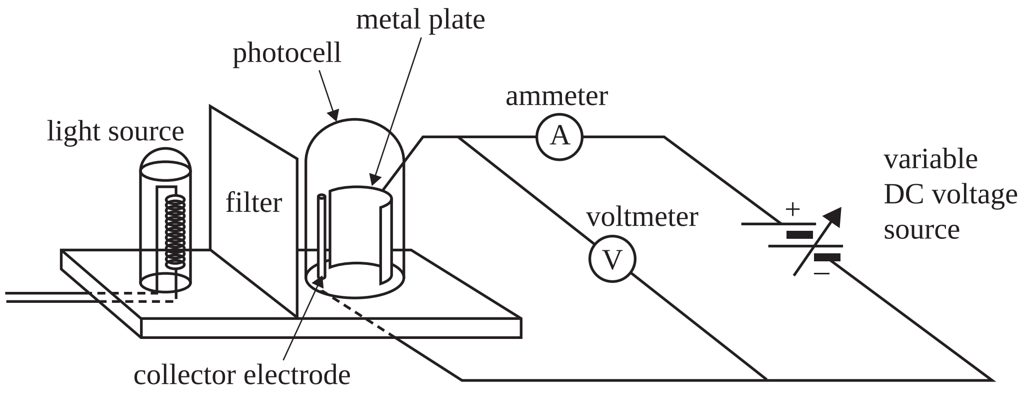
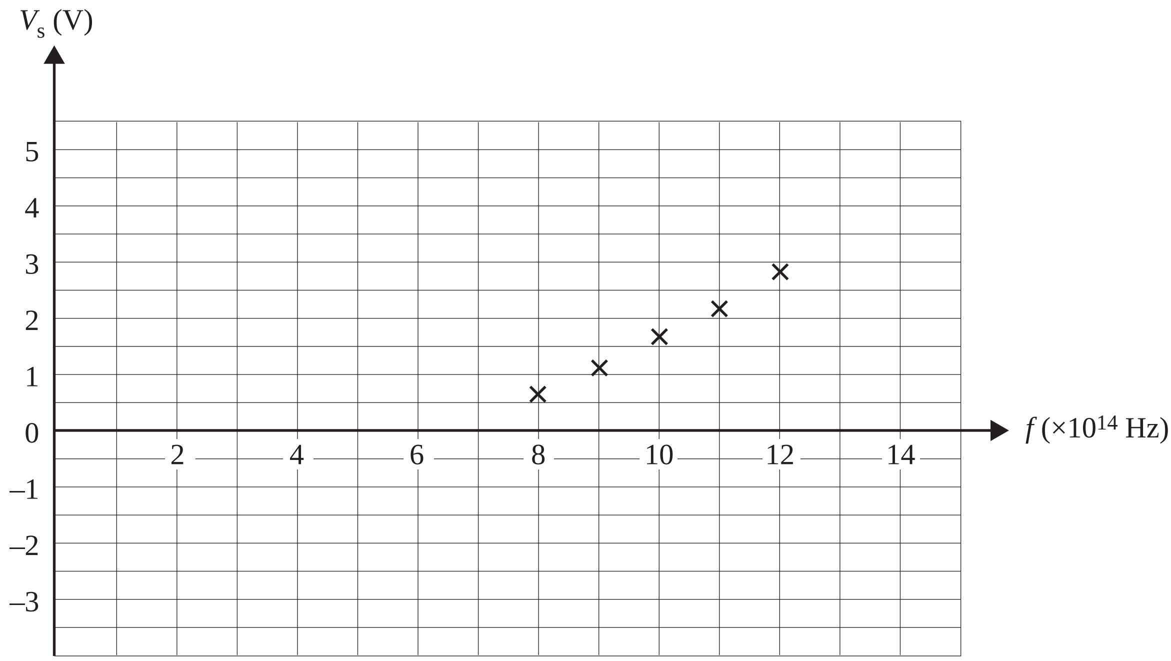


Figure 17

With the light source on and a filter in place, Sai and Kym measure the maximum kinetic energy of emitted photoelectrons by gradually changing the collector voltage until the current measured by the ammeter just falls to zero.

They record this voltage (the stopping voltage) for each frequency of the incident light and plot their results in a graph of stopping voltage, V_s, versus frequency, f ($\times 10^{14}$ Hz), of the incident light, as shown below.



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With 6.0×10^{14} Hz light, the ammeter always shows zero. Sai wants to repeat the experiment for this frequency with a much brighter light source and wants to expose the metal to the light for much longer. Kym says photoelectrons will never be ejected with this frequency of light.

a. **i.** Who is correct – Sai or Kym? Write the name in the box provided below. 1 mark

ii. What explanation might Sai give to support her opinion that by waiting longer and using a brighter light source, photoelectrons could be ejected from the metal with light of a frequency of 6.0×10^{14} Hz? 2 marks

b. Use the graph to calculate Planck's constant. Show your working. 2 marks

eV s

c. Determine the work function of the metal from the graph. Give your reasoning. 2 marks

eV

Question 18 (5 marks)

The diffraction patterns for X-rays and electrons through thin polycrystalline aluminium foil have been combined in the diagram in Figure 18, which shows an electron diffraction pattern on the left and an X-ray diffraction pattern on the right. The images are to the same scale.

The X-rays have a photon energy of 8000 eV.

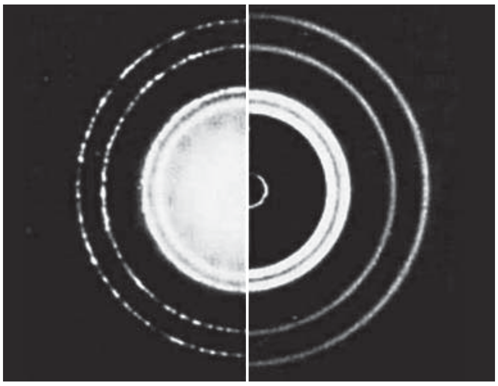


Figure 18

a. Calculate the wavelength of the electrons in nanometres. Show your working. 2 marks

nm

b. Calculate the kinetic energy of the electrons in joules. Show your working. 3 marks

J

Question 19 (4 marks)

Figure 19 shows the spectrum of light emitted from a hydrogen vapour lamp.

The spectral line, indicated by the arrow on Figure 19, is in the visible region of the spectrum.

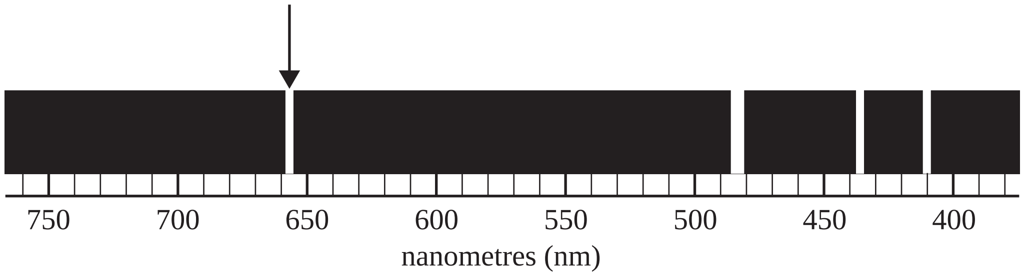


Figure 19

a. The following list gives the four visible colours that are emitted by the hydrogen atom.

Circle the colour that corresponds to the spectral line indicated by the arrow on Figure 19. 1 mark

violet blue-violet blue-green red

b. Explain why the visible spectrum of light emitted from a hydrogen vapour lamp gives **discrete** spectral lines, as shown in Figure 19. 3 marks

Question 20 (10 marks)

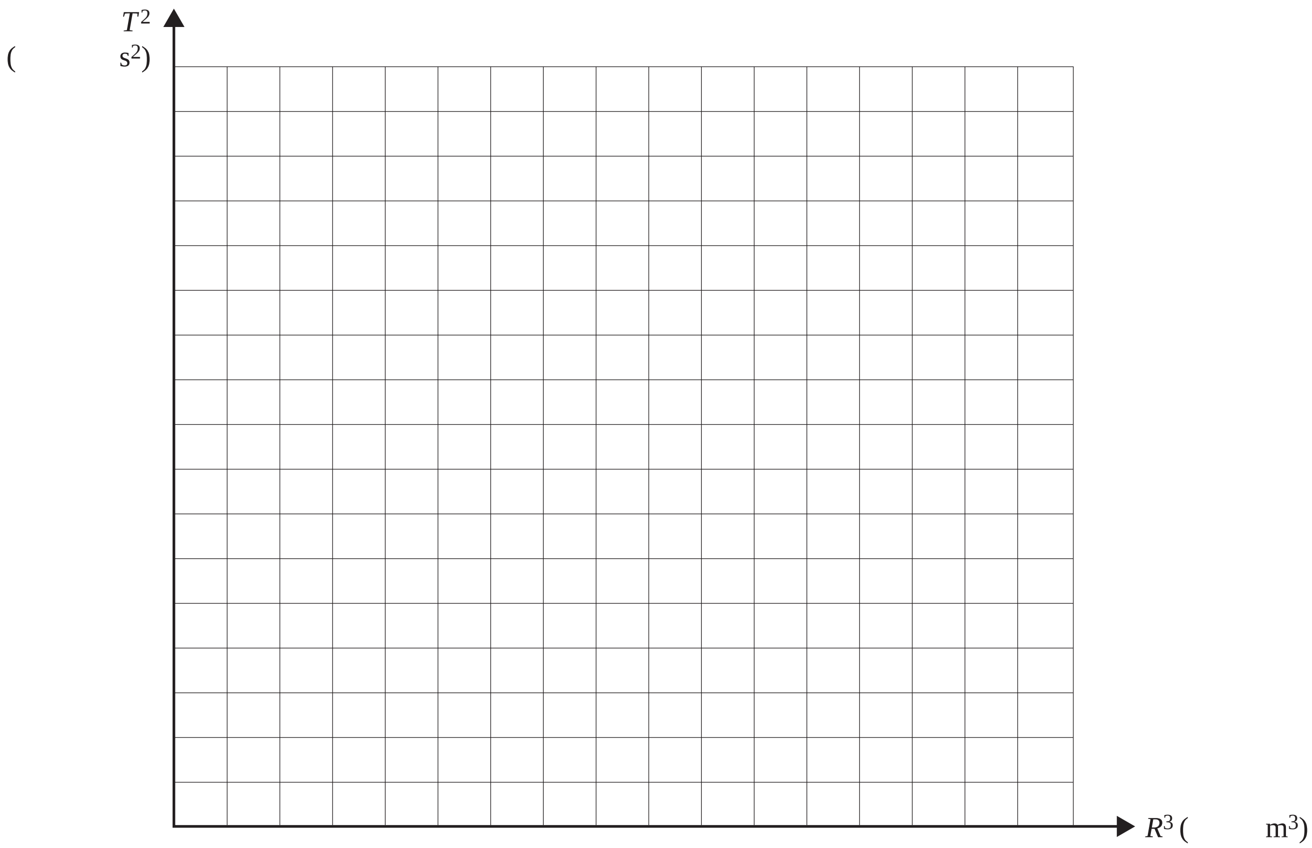
Some students have collected data on the orbital period, T, and orbital radius, R, of five of Saturn's moons. The results are shown in the table below. Assume that the moons are in circular orbits.

Moon	**Orbital period (s)**	**Orbital radius (m)**	T^2 **(10^{10} s^2)**	R^3 **(10^{24} m^3)**
Mimas	8.14×10^4	1.86×10^8	0.66	6.40
Enceladus	1.18×10^5	2.38×10^8	1.39	13.5
Tethys	1.63×10^5	2.95×10^8	2.66	25.7
Dione	2.36×10^5	3.77×10^8	5.57	53.6
Rhea	3.90×10^5	5.27×10^8	15.2	146

a. On the axes provided below:

- plot a graph of the observational data T^2 versus R^3
- include a scale on each axis
- draw a line of best fit.

5 marks



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b. Calculate the gradient of the line of best fit drawn in **part a.** Show your working. 2 marks

$s^2\ m^{-3}$

c. Use the value of the gradient calculated in **part b.** to determine the mass of Saturn. Show your working. 3 marks

kg

END OF QUESTION AND ANSWER BOOK

VICTORIAN CURRICULUM AND ASSESSMENT AUTHORITY

Victorian Certificate of Education
2018

PHYSICS

Written examination

FORMULA SHEET

Instructions

This formula sheet is provided for your reference. A question and answer book is provided with this formula sheet.

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

Physics formulas

Motion and related energy transformations

velocity; acceleration	$v = \frac{\Delta s}{\Delta t}; \quad a = \frac{\Delta v}{\Delta t}$
equations for constant acceleration	$v = u + at$ $s = ut + \frac{1}{2}at^2$ $s = vt - \frac{1}{2}at^2$ $v^2 = u^2 + 2as$ $s = \frac{1}{2}(v + u)t$
Newton's second law	$\Sigma F = ma$
circular motion	$a = \frac{v^2}{r} = \frac{4\pi^2 r}{T^2}$
Hooke's law	$F = -k\Delta x$
elastic potential energy	$\frac{1}{2}k(\Delta x)^2$
gravitational potential energy near the surface of Earth	$mg\Delta h$
kinetic energy	$\frac{1}{2}mv^2$
Newton's law of universal gravitation	$F = G\frac{M_1 M_2}{r^2}$
gravitational field	$g = G\frac{M}{r^2}$
impulse	$F\Delta t$
momentum	mv
Lorentz factor	$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$
time dilation	$t = t_o\gamma$
length contraction	$L = \frac{L_o}{\gamma}$
rest energy	$E_{rest} = mc^2$
relativistic total energy	$E_{total} = \gamma mc^2$
relativistic kinetic energy	$E_k = (\gamma - 1)mc^2$

Fields and application of field concepts

electric field between charged plates	$E = \frac{V}{d}$
energy transformations of charges in an electric field	$\frac{1}{2}mv^2 = qV$
field of a point charge	$E = \frac{kq}{r^2}$
force on an electric charge	$F = qE$
Coulomb's law	$F = \frac{kq_1q_2}{r^2}$
magnetic force on a moving charge	$F = qvB$
magnetic force on a current carrying conductor	$F = nIlB$
radius of a charged particle in a magnetic field	$r = \frac{mv}{qB}$

Generation and transmission of electricity

voltage; power	$V = RI$; $P = VI = I^2R$
resistors in series	$R_T = R_1 + R_2$
resistors in parallel	$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$
ideal transformer action	$\frac{V_1}{V_2} = \frac{N_1}{N_2} = \frac{I_2}{I_1}$
AC voltage and current	$V_{RMS} = \frac{1}{\sqrt{2}}V_{peak}$ $I_{RMS} = \frac{1}{\sqrt{2}}I_{peak}$
electromagnetic induction	EMF: $\varepsilon = -N\frac{\Delta\Phi_B}{\Delta t}$ flux: $\Phi_B = B_\perp A$
transmission losses	$V_{drop} = I_{line} R_{line}$ $P_{loss} = I^2_{line} R_{line}$

Wave concepts

wave equation	$v = f\lambda$
constructive interference	path difference = $n\lambda$
destructive interference	path difference = $\left(n - \frac{1}{2}\right)\lambda$
fringe spacing	$\Delta x = \frac{\lambda L}{d}$
Snell's law	$n_1 \sin\theta_1 = n_2 \sin\theta_2$
refractive index and wave speed	$n_1 v_1 = n_2 v_2$

The nature of light and matter

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

Data

acceleration due to gravity at Earth's surface	$g = 9.8\ \mathrm{m\ s^{-2}}$
mass of the electron	$m_{\mathrm{e}} = 9.1 \times 10^{-31}\ \mathrm{kg}$
magnitude of the charge of the electron	$e = 1.6 \times 10^{-19}\ \mathrm{C}$
Planck's constant	$h = 6.63 \times 10^{-34}\ \mathrm{J\ s}$ $h = 4.14 \times 10^{-15}\ \mathrm{eV\ s}$
speed of light in a vacuum	$c = 3.0 \times 10^{8}\ \mathrm{m\ s^{-1}}$
gravitational constant	$G = 6.67 \times 10^{-11}\ \mathrm{N\ m^2\ kg^{-2}}$
mass of Earth	$M_{\mathrm{E}} = 5.98 \times 10^{24}\ \mathrm{kg}$
radius of Earth	$R_{\mathrm{E}} = 6.37 \times 10^{6}\ \mathrm{m}$
Coulomb constant	$k = 8.99 \times 10^{9}\ \mathrm{N\ m^2\ C^{-2}}$

Prefixes/Units

p = pico = 10^{-12}	n = nano = 10^{-9}	μ = micro = 10^{-6}	m = milli = 10^{-3}
k = kilo = 10^{3}	M = mega = 10^{6}	G = giga = 10^{9}	t = tonne = 10^{3} kg

END OF FORMULA SHEET