Victorian Certificate of Education
2018

SUPERVISOR TO ATTACH PROCESSING LABEL HERE

Letter

STUDENT NUMBER

PHYSICS
Written examination

Thursday 31 May 2018

Reading time: 10.00 am to 10.15 am (15 minutes)
Writing time: 10.15 am to 12.45 pm (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	18	18	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 32 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}.

Question 1

Engineers are measuring the force due to Earth's magnetic field on the supply wire of a railway line. The wire runs east–west and carries a current of 2000 A. Earth's magnetic field is horizontal and due north at the place where measurements are taken.

The engineers measure the force on a 10 m length of the wire to be 1.0 N.

Which one of the following best gives the strength of Earth's magnetic field at this point?

A. 2.0×10^{-8} T

B. 5.0×10^{-5} T

C. 5.0×10^{-4} T

D. 200 T

Question 2

Data

mass of Mercury	3.34×10^{23} kg
radius of Mercury	2.44×10^{6} m
universal gravitational constant, G	6.67×10^{-11} N m^{2} kg^{-2}

The gravitational field strength at the surface of Mercury is close to

A. 9.00×10^{6} N kg^{-1}

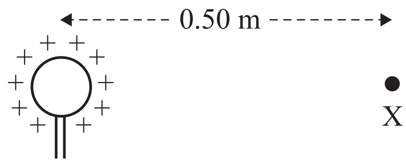
B. 9.81 N kg^{-1}

C. 3.74 N kg^{-1}

D. 3.74×10^{-2} N kg^{-1}

Question 3

A Van de Graaff generator, which is a piece of electric field demonstration equipment, consists of a small sphere that is electrically charged, as shown in the diagram below.



A particular Van de Graaff generator has a sphere that has a charge of 5.0×10^{-7} coulombs on it. Take the Coulomb's law constant to be $k = 9.0 \times 10^{9}$ N m^2 C^{-2}.

Which one of the following best gives the magnitude of the electric field at point X in the diagram above, 0.50 m from the sphere?

A. 1.8×10^{-2} V m^{-1}

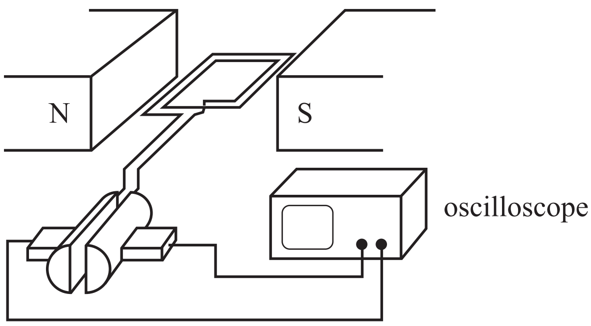
B. 3.6×10^{-2} V m^{-1}

C. 1.8×10^{4} V m^{-1}

D. 3.6×10^{4} V m^{-1}

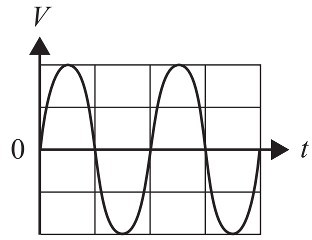
Question 4

A simple DC generator consists of two magnets that produce a uniform magnetic field, in which a square loop of wire of 100 turns rotates at constant speed, and a commutator, as shown in the diagram below.

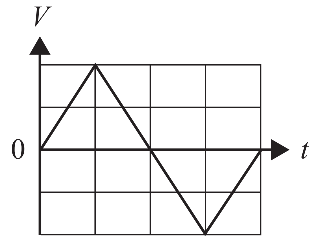


Which one of the following best shows the display observed on the oscilloscope?

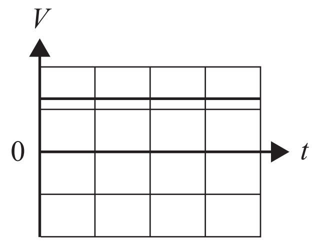
A.



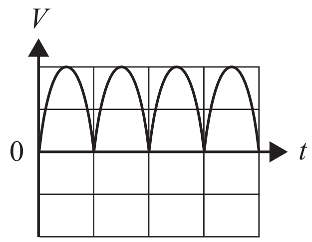
B.



C.



D.



Use the following information to answer Questions 5–7.

A step-down transformer is used to convert 240 V_{RMS} AC to 16 V_{RMS} AC.

Assume that the transformer is ideal.

Question 5

Which one of the following best gives the peak voltage of the input to the transformer?

A. 171 V

B. 240 V

C. 339 V

D. 480 V

Question 6

The ratio of turns in the primary (input) to turns in the secondary (output) is best given by

A. 15:1

B. 1:15

C. 24:1

D. 1:24

Question 7

The power input to the primary of the transformer is 30 W.

Which one of the following best gives the RMS current in the secondary (output)?

A. 0.50 A

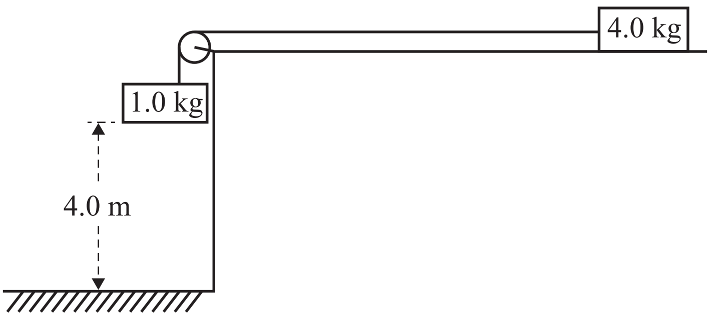
B. 1.9 A

C. 8.0 A

D. 15 A

Use the following information to answer Questions 8 and 9.

A 1.0 kg mass attached to a string is hanging 4.0 m from the ground. Assume that the string has no mass. The string is connected to a 4.0 kg mass on a horizontal frictionless table, as shown below. The masses are released from rest and an acceleration of 1.96 m s^{-2} is observed.



Question 8

The tension in the string is closest to

A. 19.6 N

B. 15.6 N

C. 9.8 N

D. 7.8 N

Question 9

Which one of the following best gives the speed of the 4.0 kg mass when the 1.0 kg mass strikes the ground after falling 4.0 m?

A. 2.0 m s^{-1}

B. 4.0 m s^{-1}

C. 8.0 m s^{-1}

D. 16 m s^{-1}

Question 10

A linear accelerator (linac) accelerates an electron beam to an energy of 100 MeV over a distance of about 10 m. After the first metre of acceleration in the linac, the electrons are travelling at approximately 99.9% of the speed of light.

The Lorentz factor, γ, for an electron travelling at this speed would be closest to

A. 22.4

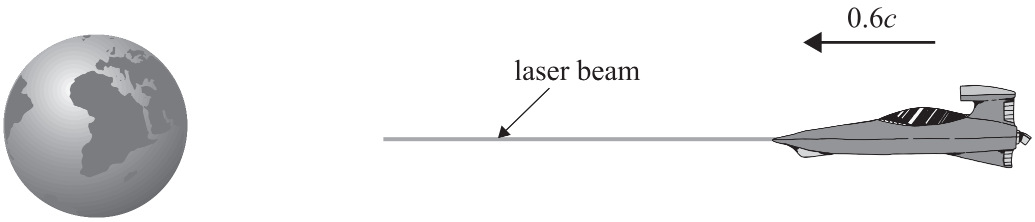
B. 44.8

C. 500

D. 1000

Question 11

An alien spaceship has entered our solar system and is heading directly towards Earth at a speed of $0.6c$, as shown in the diagram below. When it reaches a distance of 3.0×10^{11} m from Earth (in Earth's frame of reference), the aliens transmit a 'be there soon' signal via a laser beam.



How long will it take for the signal to reach Earth according to an observer on Earth?

A. 1.0 s

B. 1.7 s

C. 625 s

D. 1000 s

Question 12

A golf club strikes a stationary golf ball of mass 0.040 kg. The golf club is in contact with the ball for one millisecond. The ball moves off at 50 m s^{-1}.

The average force exerted by the club on the ball is closest to

A. 2.0 N

B. 1.0×10^3 N

C. 2.0×10^3 N

D. 1.0×10^6 N

Question 13

Which one of the following statements about the polarisation of waves is **true**?

A. Only electromagnetic waves can be polarised.

B. Both longitudinal and transverse waves can be polarised.

C. Longitudinal waves can be polarised but transverse waves cannot be polarised.

D. Transverse waves can be polarised but longitudinal waves cannot be polarised.

Question 14

Which one of the following best describes electromagnetic waves?

A. They all travel at the same speed in all mediums.

B. They all travel at the same speed in a vacuum.

C. They are not reflected by a surface.

D. They always travel in straight lines.

Question 15

Which of the following best gives the different regions of the electromagnetic spectrum in order from longest wavelength to shortest wavelength?

A. ultraviolet, visible light, infra-red, microwaves

B. microwaves, ultraviolet, visible light, infra-red

C. visible light, ultraviolet, infra-red, microwaves

D. microwaves, infra-red, visible light, ultraviolet

Question 16

When light of a specific frequency strikes a particular metal surface, photoelectrons are emitted.

If the light intensity is increased but the frequency of the light remains the same, which of the following is correct?

	Number of photoelectrons emitted	Maximum kinetic energy of the photoelectrons
A.	remains the same	remains the same
B.	remains the same	increases
C.	increases	remains the same
D.	increases	increases

Question 17

A metal surface has a work function of 2.0 eV.

The minimum energy of an incoming photon required to eject a photoelectron is

A. 3.2×10^{-19} J

B. 1.6×10^{-19} J

C. 8.0×10^{-20} J

D. 4.0×10^{-20} J

Question 18

A student measures a very small current in a circuit and obtains the result 0.000670 A.

The number of significant figures in the measurement 0.000670 A is

A. 2

B. 3

C. 5

D. 6

Question 19

An independent variable is best described as one that is

A. set by the researcher.

B. not relevant to the experiment.

C. fixed throughout the experiment.

D. not related to any other variables in the experiment.

Question 20

The main reason for repeating an experiment is to

A. reduce random error.

B. reduce systematic error.

C. allow for differences between researchers.

D. allow for variations in controlled variables.

END OF SECTION A

TURN OVER

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 (9 marks)

A 1500 kg weather satellite is in a circular orbit around Earth at an altitude of 850 km. The radius of Earth is 6400 km.

a. Calculate the period of the satellite in seconds. Take the mass of Earth to be 6.0×10^{24} kg and the universal gravitational constant, G, to be 6.7×10^{-11} N m^2 kg^{-2}. Show your working. 3 marks

s

b. The controllers of the satellite use its motors to move the satellite into a higher orbit.

i. Will this increase, decrease or have no effect on the speed of the satellite? Justify your answer. 3 marks

ii. Will this increase, decrease or have no effect on the gravitational potential energy of the satellite? Take the surface of Earth as the zero of gravitational potential energy. Justify your answer. 3 marks

Question 2 (6 marks)

The electron gun section of a particle accelerator accelerates electrons between two plates that are 10 cm apart and have a potential difference of 5000 V between them.

Data

mass of electron	9.1×10^{-31} kg
charge on electron	(–) 1.6×10^{-19} C

a. Calculate the electric field between the plates. Include an appropriate unit. 2 marks

b. Calculate the magnitude of the force on an electron between the plates. 2 marks

N

c. Calculate the speed of the electrons as they exit the electron gun. Ignore any relativistic effects. Assume that the initial speed of the electrons is zero. 2 marks

m s^{-1}

Question 3 (6 marks)

A uniform electric field accelerates protons from rest to a speed of 5.00×10^{7} m s^{-1}.

Data

mass of proton	1.67×10^{-27} kg
charge on proton	$+1.60 \times 10^{-19}$ C

a. The protons then pass into a region of uniform magnetic field that is at right angles to their velocity. They are bent into a circular path.

Explain why the path is circular in shape. 3 marks

b. The strength of the uniform magnetic field is 500 mT.

Calculate the magnitude of the magnetic force on the protons. 3 marks

N

Question 4 (9 marks)

Students move a square loop of wire of 100 turns and of cross-sectional area 4.0×10^{-4} m^2. The loop moves at constant speed from outside left, into, through and out of a magnetic field, as shown in Figure 1a. The area between the poles has a uniform magnetic field of magnitude 2.0×10^{-3} T. Figure 1b shows the view from above.

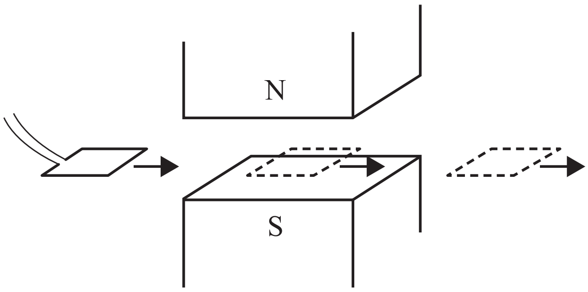


Figure 1a

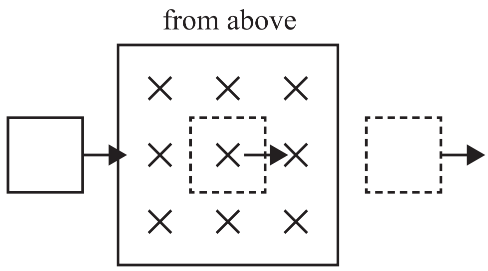


Figure 1b

a. On the axes provided below, sketch the magnetic flux, Φ_B, through the loop as it moves into, through and out of the magnetic field. 2 marks

b. On the axes provided below, sketch the EMF induced through the loop as it moves into, through and out of the magnetic field. 2 marks

c. The loop takes 2.0 s to move from completely outside to completely inside the magnetic field.

Calculate the magnitude of the induced EMF in the loop as it moves into the magnetic field. 2 marks

V

d. Determine the direction of the induced current in the loop as it moves into the magnetic field as viewed from above (clockwise or anti-clockwise). Justify your answer. 3 marks

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Question 5 (8 marks)

Students construct a model to show the transmission of electricity in transmission lines.

The apparatus is shown in Figure 2.

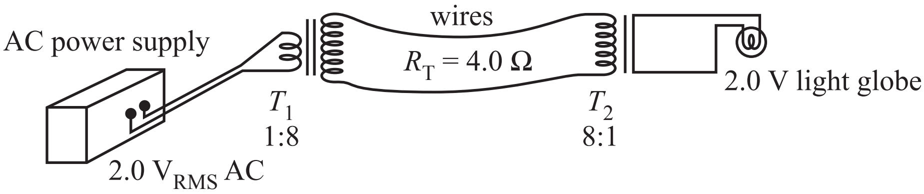

Figure 2

The students use two transformers, T_1 and T_2, with ratios of 1:8 and 8:1 respectively, and a 2.0 V_{RMS} AC power supply. Assume that the transformers are ideal. The students use a light globe that operates correctly when there is a voltage of 2.0 V across it. The wires of the transmission lines have a total resistance of 4.0 Ω. The students measure the current in these wires to be 0.50 A.

a. Calculate the power loss in the wires. 2 marks

W

b. Calculate the voltage across the light globe. 4 marks

V

c. The light globe does not operate correctly, as it should with a voltage of 2.0 V across it.

Describe **one** change the students could make to the model to make the light globe operate correctly. 2 marks

Question 6 (7 marks)

A rock of mass 2.0 kg is thrown horizontally from the top of a vertical cliff 20 m high with an initial speed of 25 m s^{-1}, as shown in Figure 3.

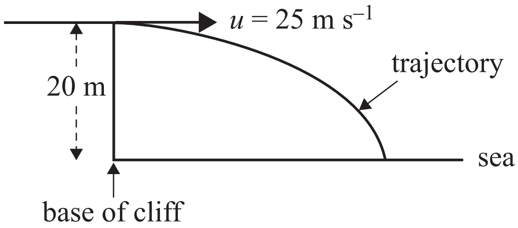

Figure 3

a. Calculate the time taken for the rock to reach the sea. Show your working. 3 marks

s

b. Calculate the horizontal distance from the base of the cliff to the point where the rock reaches the sea. Show your working. 2 marks

m

c. Calculate the kinetic energy of the rock as it reaches the surface of the sea. Show your working. 2 marks

J

Question 7 (3 marks)

Students are studying the behaviour of a golf club hitting a golf ball, treating it as a collision between the head of the golf club and the golf ball only, as shown in Figure 4.

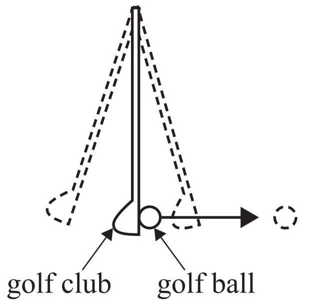

Figure 4

The students take the following measurements.

mass of head of golf club	0.50 kg
mass of golf ball	0.040 kg
initial speed of golf club	45 m s^{-1}
final speed of golf club after hitting golf ball	40 m s^{-1}

The golf ball is stationary before being hit. The ball's speed immediately after being hit is 63 m s^{-1}.

Use calculations to determine whether the collision is elastic or inelastic. Show your working.

Question 8 (5 marks)

In an experiment, a ball of mass 2.5 kg is moving in a vertical circle at the end of a string, as shown in Figure 5.

The string has a length of 1.5 m.

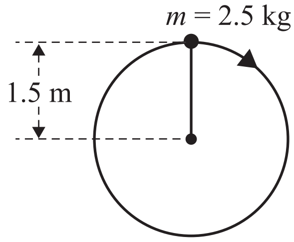

Figure 5

a. Calculate the minimum speed the ball must have at the top of its arc for the string to remain tight (under tension). 2 marks

$\boxed{\quad\quad\quad \text{m s}^{-1}}$

b. In another experiment, the ball is moving at 6.0 m s^{-1} at the top of its arc.

Calculate the speed of the ball at the lowest point. 3 marks

$\boxed{\quad\quad\quad \text{m s}^{-1}}$

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Question 9 (9 marks)

A spring launcher is used to project a rubber ball of mass 2.0 kg vertically upwards. The arrangement is shown in Figure 6.

The ball is driven by a spring, which is compressed and released. When the spring reaches the top, point X, it is held stationary, but is still partly compressed as the ball leaves the launcher. Assume that the spring has no mass.

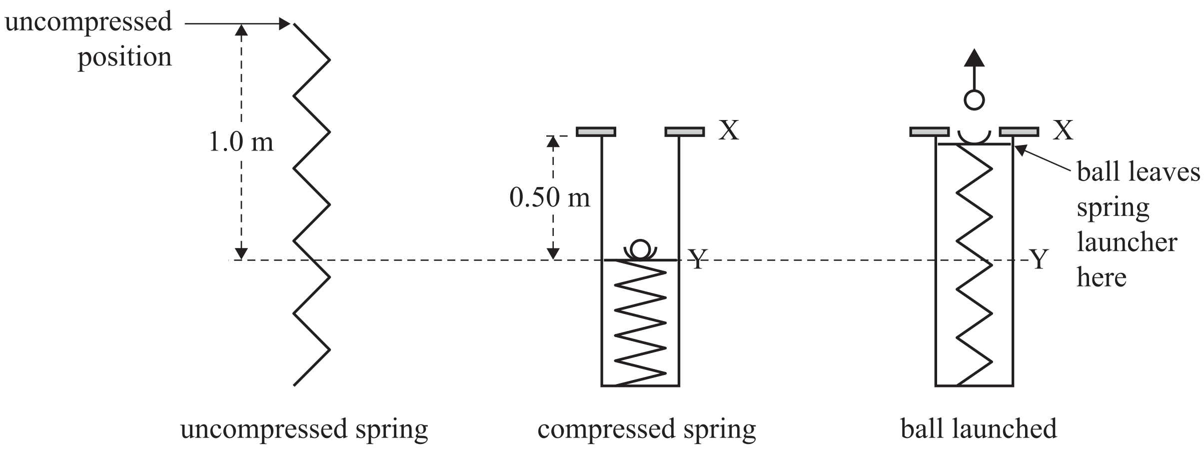

Figure 6

The force–distance graph of the spring is shown in Figure 7, on which the lower and upper positions of the spring in the spring launcher are marked.

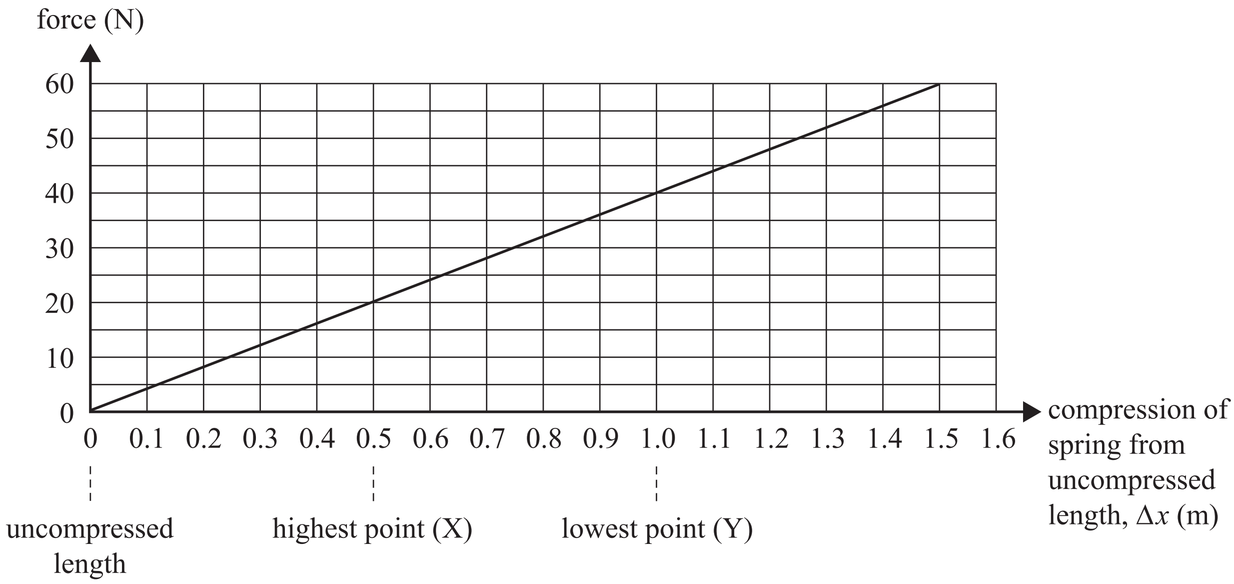

Figure 7

a. Calculate the spring constant, k, of the spring. 2 marks

$N\ m^{-1}$

b. Calculate the change in spring potential energy of the spring as it goes from the lowest point, Y, to the highest point, X. 3 marks

J

c. The spring, with a ball in place, is released from point Y. It moves up to point X, where it is stopped and the ball is launched.

Calculate the speed of the ball when it leaves the spring launcher. Show the steps involved in your working. 4 marks

$m\ s^{-1}$

Question 10 (11 marks)

Two VCE Physics students, Laura and Hal, are investigating Snell's law.

They set up their apparatus to measure the refraction of a beam of red laser light going from air into a semicircular plastic block, as shown in Figure 8.

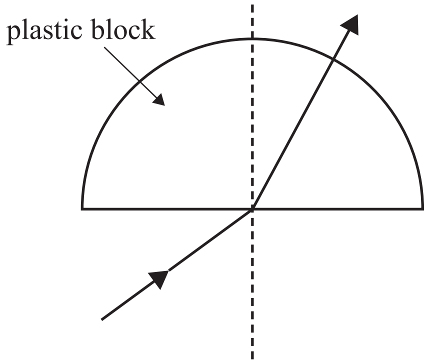

Figure 8

Using this one block, they vary the angle of incidence and measure the resulting angles of refraction.

a. List the variables involved in this experiment and classify them as controlled, dependent or independent variables. Include one of each type of variable in the table provided below. 2 marks

Variable	**Classification**

b. Laura and Hal record the data shown in the table below.

Angle of incidence, *i* (degrees)	**sin *i***	**Uncertainty in sin *i***	**Angle of refraction, *r* (degrees)**	**sin *r***	**Uncertainty in sin *r***
5	0.09	± 0.04	3.0	0.052	± 0.04
10	0.17	± 0.04	6.6	0.12	± 0.04
15	0.26	± 0.04	9.9	0.17	± 0.04
20	0.34	± 0.04	13.3	0.23	± 0.04
25	0.42	± 0.04	16.4	0.28	± 0.04

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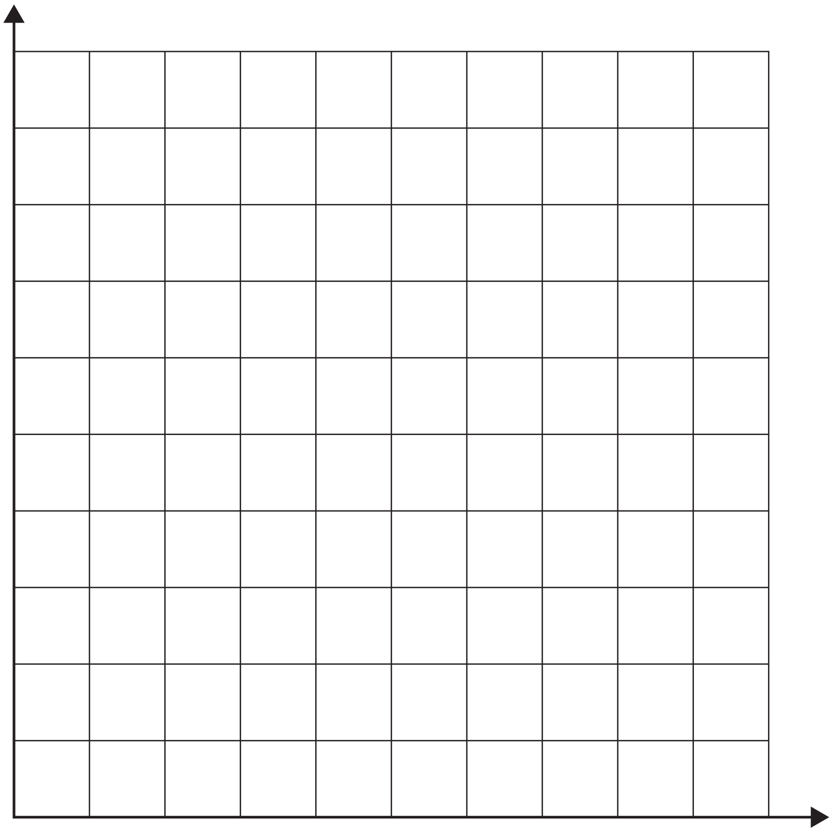
Using the data in the table on page 22, on the axes below:

- plot sin *r* versus sin *i*
- draw in uncertainty bars in both the *x* and *y* directions for each data point
- draw a line of best fit.

Include labels and scales for both axes. 6 marks



c. From the graph created in **part b.**, determine the value of the refractive index of the plastic material of the block. Give your answer to an appropriate number of significant figures. 3 marks

Question 11 (7 marks)

Students are using a microwave set to study wave interference.

The set consists of:

- a microwave transmitter that can be set to produce microwaves of wavelength 3.0 cm or 6.0 cm
- a receiver that measures the intensity of the received signal and the wavelength
- plates that can be used to give single or double slits of various widths and separations
- a ruler.

Take the speed of microwaves to be 3.0×10^8 m s^{-1}.

a. Calculate the frequency of the 3 cm microwaves. 1 mark

Hz

b. The students set up the equipment using 3.0 cm microwaves, placing the receiver at X on the second nodal line (minima) out from the centre, as shown in Figure 9.

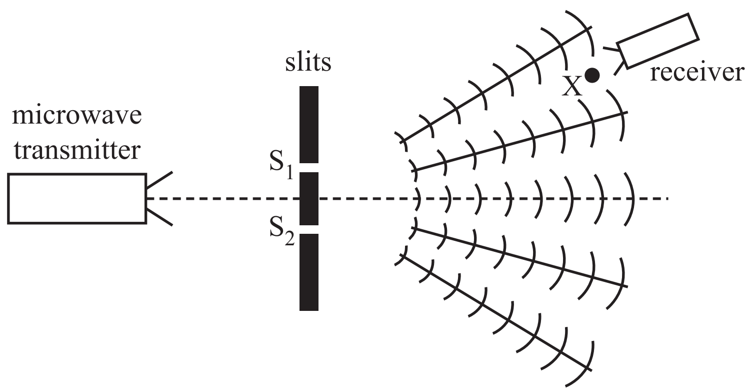


Figure 9

Calculate the path difference $S_2X - S_1X$. Show your working. 2 marks

cm

c. The students now replace the two slits with a slit of width *w*, as shown in Figure 10.

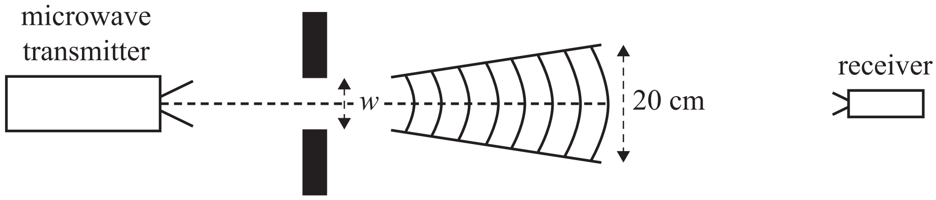


Figure 10

With the transmitter set to a wavelength of 3.0 cm, the students measure the width of the diffraction pattern to be 20 cm at a particular distance from the slit, as shown in Figure 10.

They then switch to a 6.0 cm wavelength on the transmitter.

What effect will this have on the width of the pattern? Explain your answer. 2 marks

d. With the transmitter reset to a wavelength of 3.0 cm, the students place the receiver on a cart.

With the cart stationary, the receiver measures the wavelength to be 3.0 cm exactly.

The cart is now set moving away from the transmitter, as shown in Figure 11.

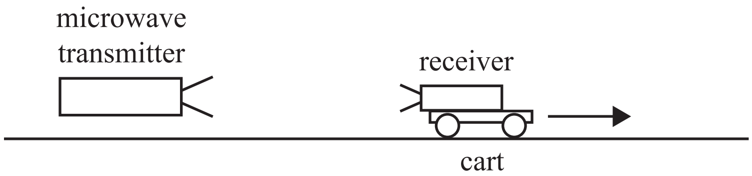


Figure 11

Will this movement increase, decrease or leave unchanged the wavelength as measured by the receiver on the cart? Explain your answer and name the physical principle involved. 2 marks

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Question 12 (3 marks)

Figure 12 shows the energy level diagram for the hydrogen atom.

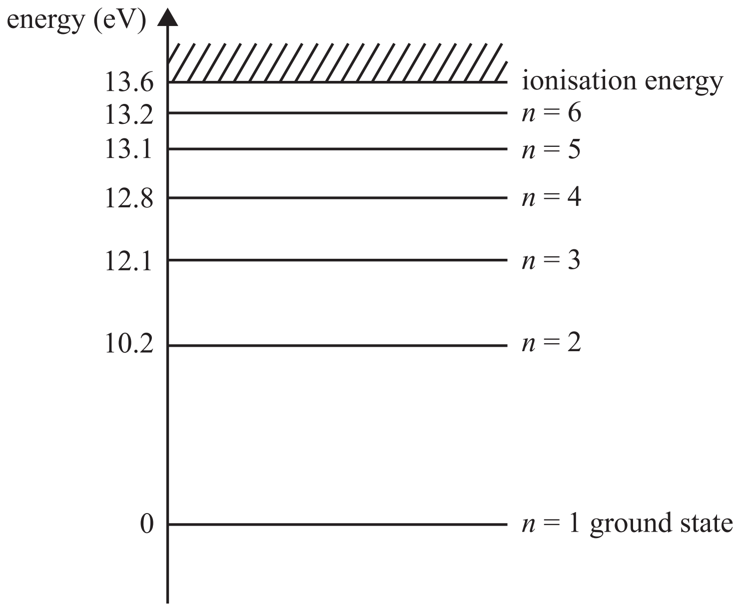

Figure 12

List the possible photon energies following emissions from the $n = 4$ state.

Question 13 (7 marks)

Electrons are accelerated through a potential difference of 4000 V and then pass through a metallic crystal. The resulting diffraction pattern is observed.

a. Calculate the de Broglie wavelength of these electrons. 3 marks

nm

b. A student, Jane, says that X-rays of a suitable wavelength could produce the same diffraction pattern.

Calculate the energy of the X-ray beam required to give a similarly spaced diffraction pattern to the electrons. Show your working. 2 marks

eV

c. Explain how electrons and X-rays can exhibit similar diffraction patterns. 2 marks

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Question 14 (3 marks)

An Earth-like planet has been discovered orbiting a distant star. A hypothetical mission to this planet is suggested. The planet is 1.0×10^{18} m from Earth. The spaceship suggested for the mission can travel at an average speed of $0.99c$. Take $\gamma = 7.1$ for this speed.

Scientists are concerned about the length of time the passengers would have to spend on the spaceship to travel to this planet.

Use principles of special relativity to estimate this time, in years, as measured on the spaceship.

years

Question 15 (2 marks)

An unstable subatomic particle, known as a π_0 meson, decays completely into electromagnetic radiation. The rest mass of this π_0 meson is 2.5×10^{-28} kg.

How much energy would be released by this π_0 meson if it decays at rest?

J

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Question 16 (6 marks)

Students are investigating the photoelectric effect.

The apparatus used by the students is shown in Figure 13. A light source shines light through a filter that only allows one frequency of light to pass through. This monochromatic light shines onto a metal plate and photoelectrons are emitted. Different filters allow different frequencies to strike the metal plate. For each frequency, the maximum kinetic energy of the emitted photoelectrons is measured by using a stopping voltage.

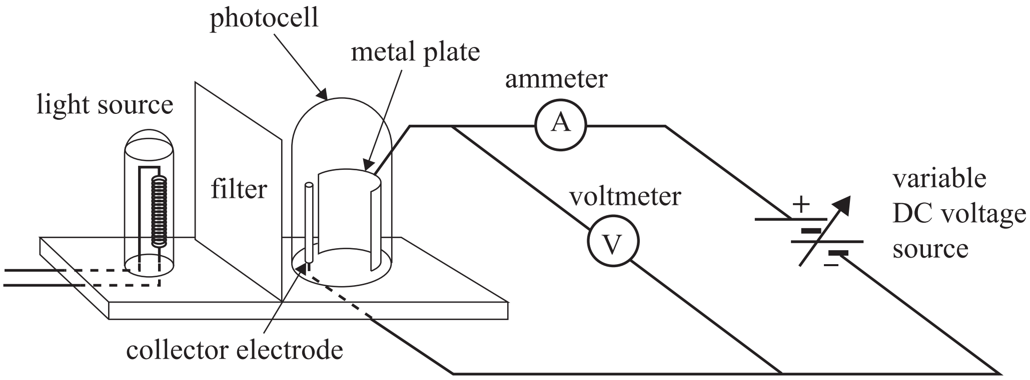

Figure 13

The graph of the data the students collected for the maximum kinetic energy of emitted photoelectrons versus frequency is shown in Figure 14. A line of best fit has been drawn.

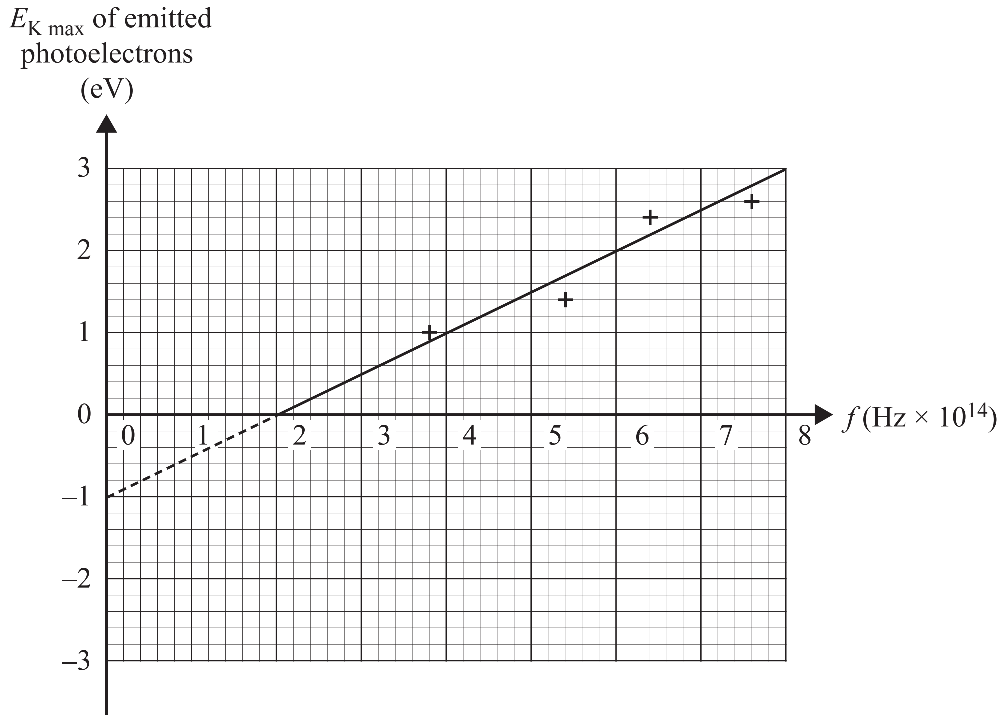

Figure 14

DO NOT WRITE IN THIS AREA

a. Determine the value of Planck's constant, *h*, that the students would have obtained from this graph. 2 marks

eV s

b. Determine the value of the minimum frequency, or cut-off frequency, f_0, that the students would have obtained from this graph. 1 mark

Hz

c. Determine the value of the work function of the metal in the plate that the students would have obtained from this graph. 1 mark

eV

d. The students replace the photocell with one that has a different metal plate with a work function of 2.5 eV.

On Figure 14, draw in the graph they would now expect. 2 marks

Question 17 (6 marks)

The results of photoelectric effect experiments provide evidence for the particle-like nature of light.

Outline **one** aspect of the results that would provide this evidence. Your response should explain:

- why a wave model of light cannot satisfactorily explain this aspect of the results
- how the photon theory does explain this aspect of the results.

Question 18 (3 marks)

Explain how the diffraction pattern produced by a stream of electrons passing through a narrow slit can illustrate Heisenberg's uncertainty principle.

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	$F = IlB$
radius of a charged particle in a magnetic field	$r = \frac{mv}{qB}$

Generation and transmission of electricity

voltage; power	$V = RI; \quad P = VI = I^2R$
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	$V_{RMS} = \frac{1}{\sqrt{2}}V_{peak} \qquad I_{RMS} = \frac{1}{\sqrt{2}}I_{peak}$
electromagnetic induction	EMF: $\varepsilon = -N\frac{\Delta\Phi}{\Delta t}$ flux: $\Phi = BA$
transmission losses	$V_{drop} = I_{line}R_{line} \qquad P_{loss} = I^2_{line}R_{line}$

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	$E_{\text{K max}} = hf - W$
photon energy	$E = hf$
photon momentum	$p = \dfrac{h}{\lambda}$
de Broglie wavelength	$\lambda = \dfrac{h}{p}$
Heisenberg's uncertainty principle	$\Delta p_x \Delta x \geq \dfrac{h}{4\pi}$

Data

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

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