VICTORIAN CURRICULUM AND ASSESSMENT AUTHORITY

Victorian Certificate of Education
2017

SUPERVISOR TO ATTACH PROCESSING LABEL HERE

Letter

STUDENT NUMBER

PHYSICS
Written examination

Wednesday 15 November 2017

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	19	19	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 39 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

A group of students is considering how to create a magnetic monopole.

Which one of the following is correct?

A. Break a bar magnet in half.

B. Pass a current through a long solenoid.

C. Pass a current through a circular loop of wire.

D. It is not known how to create a magnetic monopole.

Question 2

Millikan, a famous scientist, measured the size of the electron charge by balancing an upwards electric force with a gravitational force on a small oil drop. In a repeat of this experiment, an oil drop with a charge of 9.6×10^{-19} C was placed in an electric field of 10^4 V m^{-1}.

Which one of the following is closest to the electrical force on the oil drop?

A. 9.6×10^{-14} N

B. 9.6×10^{-15} N

C. 9.6×10^{-22} N

D. 9.6×10^{-23} N

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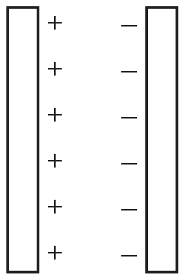
Question 3

Two large charged plates with equal and opposite charges are placed close together, as shown in the diagram below. A distance of 5.0 mm separates the plates. The electric field between the plates is equal to 1000 N C^{-1}.



Which one of the following is closest to the voltage difference between the plates?

A. 5.0 V

B. 200 V

C. 5000 V

D. 5 000 000 V

Use the following information to answer Questions 4 and 5.

Students doing a VCE Physics practical investigation use a step-down transformer with 240 V_{RMS} AC to 12 V_{RMS} AC.

Question 4

Which one of the following best gives the ratio of the number of turns, $N_{primary}$: $N_{secondary}$?

A. 1:4

B. 1:20

C. 4:1

D. 20:1

Question 5

The transformer delivers 48 W_{RMS} to a resistor. Assume that the transformer is ideal.

Which one of the following best gives the peak current in the secondary coil?

A. 0.2 A

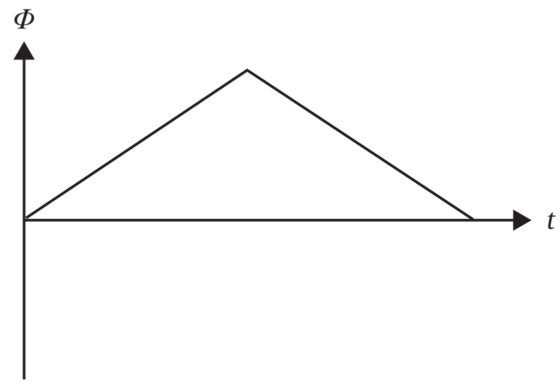
B. 4.0 A

C. 5.7 A

D. 11.3 A

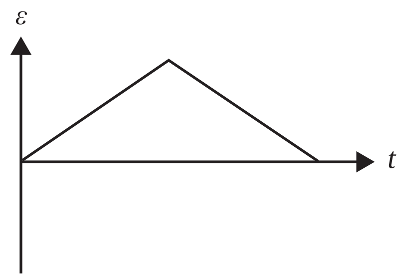
Question 6

The graph below shows the change in magnetic flux (Φ) through a coil of wire as a function of time (t).



Which one of the following graphs best represents the induced EMF (ε) across the coil of wire as a function of time (t)?

A.



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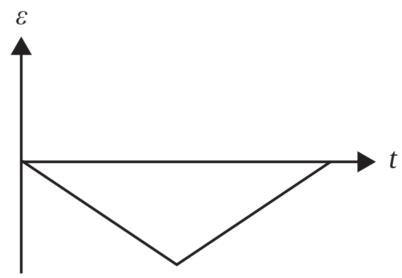
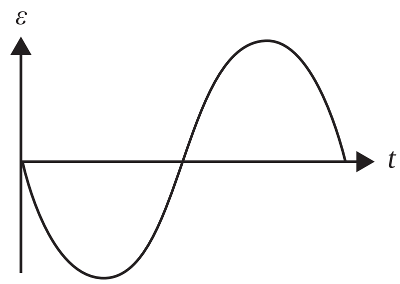
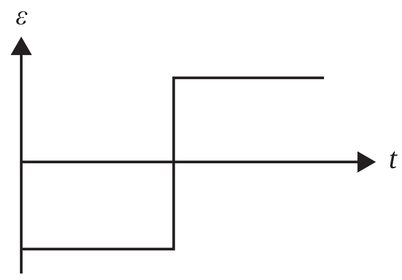


C.



D.



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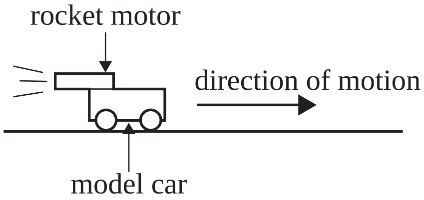
Use the following information to answer Questions 7–9.

A model car of mass 2.0 kg is propelled from rest by a rocket motor that applies a constant horizontal force of 4.0 N, as shown below. Assume that friction is negligible.



Question 7

Which one of the following best gives the magnitude of the acceleration of the model car?

A. 0.50 m s^{-2}

B. 1.0 m s^{-2}

C. 2.0 m s^{-2}

D. 4.0 m s^{-2}

Question 8

Which one of the following best gives the magnitude of the impulse given to the car by the rocket motor in the first 5.0 s?

A. 4.0 N s

B. 8.0 N s

C. 20 N s

D. 40 N s

Question 9

With the same rocket motor, the car accelerates from rest for 10 s.

Which one of the following best gives the final speed?

A. 6.3 m s^{-1}

B. 10 m s^{-1}

C. 20 m s^{-1}

D. 40 m s^{-1}

Question 10

A student sits inside a windowless box that has been placed on a smooth-riding train carriage. He conducts a series of motion experiments to investigate frames of reference.

Which one of the following observations is correct?

A. The results when the train accelerates are identical to the results when the train is at rest.

B. The results when the train accelerates differ from the results when the train is in uniform motion in a straight line.

C. The results when the train is at rest differ from the results when the train is in uniform motion in a straight line.

D. The results when the train accelerates are identical to the results when the train is in uniform motion in a straight line.

Question 11

On average, the sun emits 3.8×10^{26} J of energy each second in the form of electromagnetic radiation, which originates from the nuclear fusion reactions taking place in the sun's core.

The corresponding loss in the sun's mass each second would be closest to

A. 2.1×10^{9} kg

B. 4.2×10^{9} kg

C. 8.4×10^{9} kg

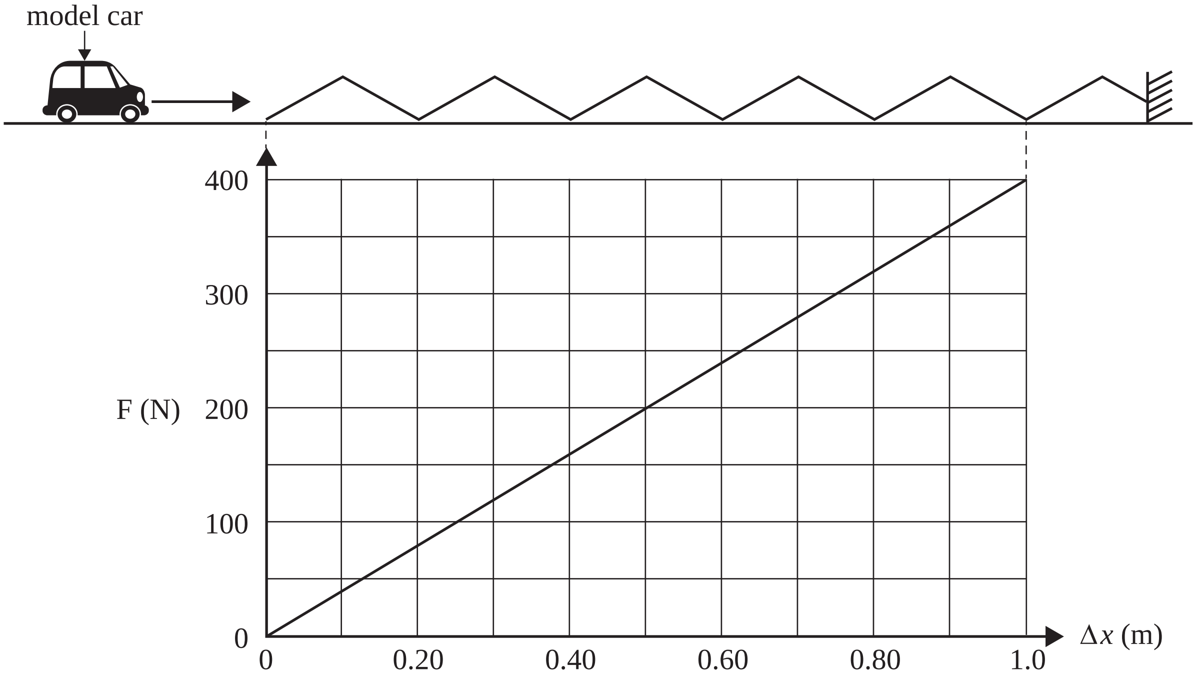
D. 2.1×10^{12} kg

Use the following information to answer Questions 12 and 13.

A model car is on a track and moving to the right. It collides with and compresses a spring that is considered ideal, as shown in the diagram below.

The car compresses the spring to 0.50 m when the car comes to rest. The force–distance graph for the spring is also shown below.

Assume that friction is negligible.



Question 12

Based on the graph above, what is the best estimate of the spring constant, *k*?

A. 100 N m^{-1}

B. 200 N m^{-1}

C. 400 N m^{-1}

D. 800 N m^{-1}

Question 13

What is the initial kinetic energy of the car?

A. 25 J

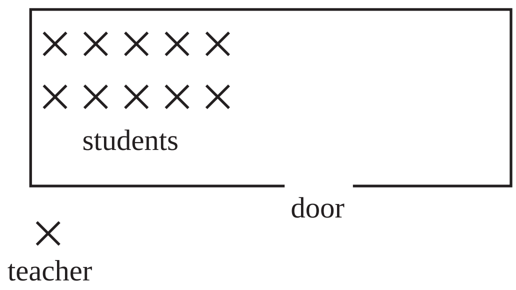
B. 50 J

C. 100 J

D. 200 J

Question 14

A teacher stands in the corridor at a short distance from the open door of her classroom, as shown in the diagram below. She can hear her students, but cannot see them.



Which one of the following best explains why the teacher can hear her students?

A. The speed of sound is much greater than the speed of light.

B. The speed of sound is comparable with the speed of light.

C. Sound diffracts because the wavelength of sound is much smaller than the width of the door.

D. Sound diffracts because the wavelength of sound is comparable with the width of the door.

Question 15

Lee listens while a police car with a loud siren comes towards her, travels past her and then continues on away from her.

Compared with the sound she would hear from the siren if the police car were stationary, the sound has

A. a higher frequency as the car comes towards her and a lower frequency when the car moves away.

B. a lower frequency as the car comes towards her and a higher frequency when the car moves away.

C. a lower intensity as the car comes towards her and a greater intensity when the car moves away.

D. the same frequency at all times.

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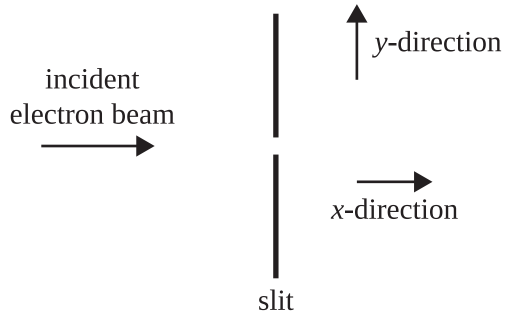
Question 16

A diffraction pattern is produced by a stream of electrons passing through a narrow slit, as shown in the diagram below.



This electron diffraction pattern can be used to illustrate Heisenberg's uncertainty principle.

This is because knowing the uncertainty in the

A. electron's speed is large leads to the uncertainty in its kinetic energy being small.

B. slit width is small leads to a large uncertainty in the electron's momentum in the *y*-direction.

C. electron's momentum in the *y*-direction is small leads to a large uncertainty in the slit's width.

D. electron's angle of approach to the slit leads to a large uncertainty in the electron's momentum in the *y*-direction.

Question 17

Quantised energy levels within atoms can best be explained by

A. electrons behaving as individual particles with varying energies.

B. atoms having specific energy requirements that can only be satisfied by electrons.

C. electrons behaving as waves, with each energy level representing a diffraction pattern.

D. electrons behaving as waves, with only standing waves at particular wavelengths allowed.

Question 18

Two students, Rob and Jan, measure the current in the same circuit on separate occasions.

Rob obtains the following readings: 9.50 mA, 9.21 mA, 9.10 mA and 9.60 mA (average 9.35).

Jan obtains the following readings: 9.20 mA, 9.25 mA, 9.31 mA and 9.36 mA (average 9.28).

The true value of the current is known to be 9.35 mA.

Which one of the following best describes these two sets of measurements?

A. Rob's results are more accurate than Jan's results.

B. Both sets of results are equally accurate.

C. Rob's results are more precise than Jan's results.

D. Both sets of results are equally precise.

Question 19

Which one of the following best describes a hypothesis?

A. a possible explanation that needs to be rigorously tested by experimental evidence

B. an explanation that has been supported by rigorous experimental evidence

C. a statement that is widely accepted by scientists

D. an explanation that is mathematically correct

Question 20

Which one of the following statements about systematic and random errors is correct?

A. Random errors can be reduced by repeated readings.

B. Both random and systematic errors can be reduced by repeated readings.

C. Systematic errors can be reduced by repeated readings.

D. Neither systematic nor random errors can be reduced by repeated readings.

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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 (1 mark)

Three charges are arranged in a line, as shown in Figure 1.

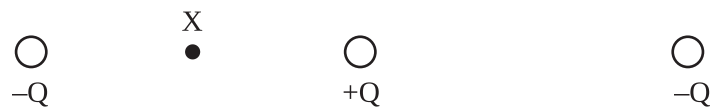

Figure 1

Draw an arrow at point X to show the direction of the resultant electric field at X. If the resultant electric field is zero, write the letter ‘N’ at X.

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Question 2 (5 marks)

According to one model of the atom, the electron in the ground state of a hydrogen atom moves around the stationary proton in a circular orbit with a radius of 53 pm (53×10^{-12} m).

a. Show that the magnitude of the force acting between the proton and the electron at this separation is equal to 8.2×10^{-8} N. Take $k = 9.0 \times 10^{9}$ N m^{2} C^{-2} and the magnitude of the electron and proton charges as 1.6×10^{-19} C. Show all the steps of your working. 2 marks

b. Using 8.2×10^{-8} N as the value of the magnitude of the force given in **part a.**, calculate the speed of the electron in its circular path. Take the mass of the electron to be 9.1×10^{-31} kg. Show your working. 3 marks

m s^{-1}

Question 3 (5 marks)

Figure 2 shows a schematic diagram of a simple DC motor.

It consists of two magnets, a single 9.0 V DC power supply, a split-ring commutator and a rectangular coil of wire consisting of 10 loops.

The total resistance of the coil of wire is 6.0 Ω.

The length of the side JK is 12 cm and the length of the side KL is 6.0 cm.

The strength of the uniform magnetic field is 0.50 T.

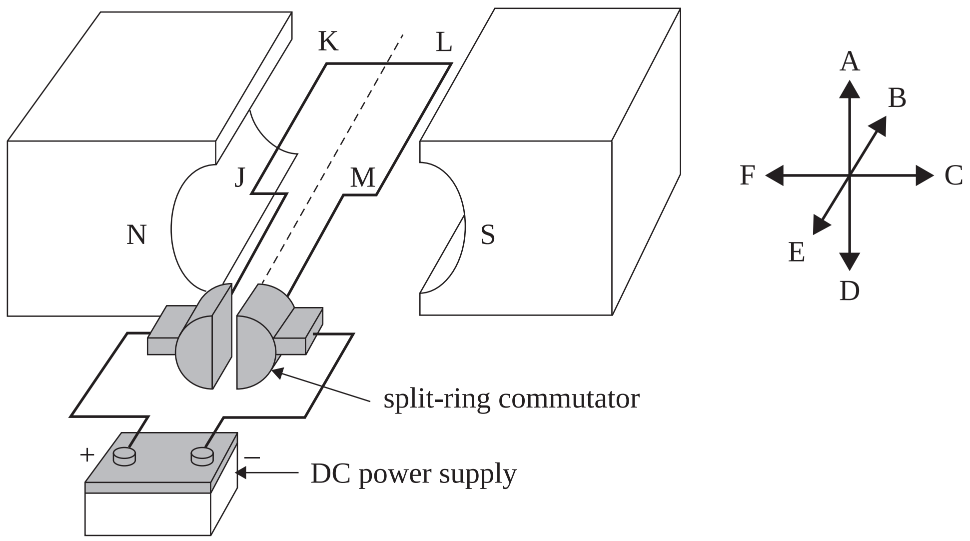

Figure 2

a. Determine the size and the direction (A–F) of the force acting on the side JK. 3 marks

N	Direction

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b. What is the size of the force acting on the side KL in the orientation shown in Figure 2? Explain your answer. 2 marks

N

Question 4 (9 marks)

Charon, a moon of Pluto, has a circular orbit.

Data

mass of Pluto	1.3×10^{22} kg
radius of Pluto	1.2×10^{6} m
mass of Charon	1.6×10^{21} kg
radius of orbit of Charon	1.8×10^{7} m
universal gravitational constant (G)	6.67×10^{-11} N m^{2} kg^{-2}

Assume that Pluto is a uniform sphere.

a. Calculate the gravitational field strength at the surface of Pluto. Show your working and include an appropriate unit. 3 marks

b. Calculate the period of orbit of Charon. Show your working. 3 marks

s

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c. Scientists wish to place a spacecraft, of mass 1000 kg, in an orbit of the same radius as Charon. Three students, Rick, Melissa and Nam, are discussing the situation and have different opinions.

Rick says as the spacecraft is lighter, it will have to move at a greater speed than Charon to achieve the same orbit.

Melissa says the spacecraft would need to move at the same speed as Charon.

Nam says the spacecraft would need only to move at a lower speed as it is lighter than Charon.

Evaluate these three opinions. Detailed calculations are **not** necessary. 3 marks

Question 5 (8 marks)

The alternator in Figure 3 has a rectangular coil with sides of 0.30 m × 0.40 m and 10 turns. The coil rotates four times a second in a uniform magnetic field. The magnetic flux through the coil in the position shown is 0.20 Wb.

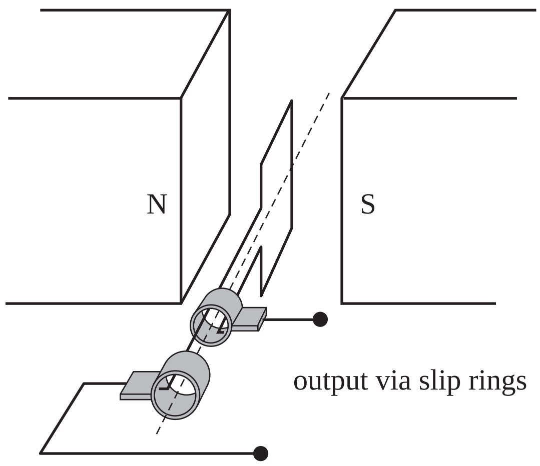

Figure 3

a. Calculate the magnitude of the magnetic field. Include an appropriate unit. 3 marks

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b. Calculate the magnitude of the average EMF (ε) generated in a quarter of a turn. Show all the steps of your working. 3 marks

V

c. Figure 4 shows the output EMF (ε) versus time graph of the alternator for two complete cycles.

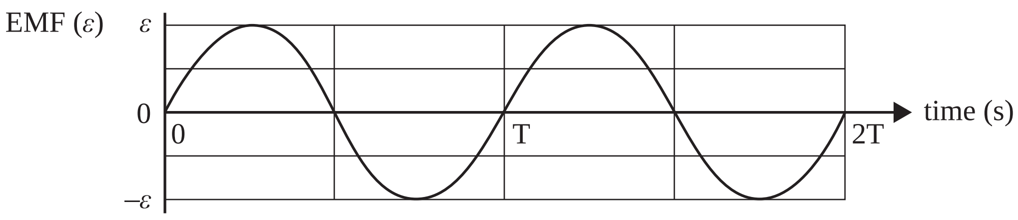
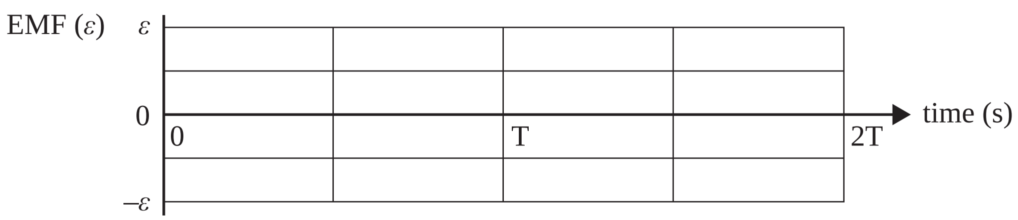


Figure 4

The two slip rings in Figure 3 are now replaced with a split-ring commutator.

On the axes provided below, sketch the EMF (ε) versus time graph of this new arrangement for two complete cycles. 2 marks



Question 6 (4 marks)

Figure 5 shows a generator at an electrical power station that generates 100 MW_{RMS} of power at 10 kV_{RMS} AC.

Transformer T_1 steps the voltage up to 500 kV_{RMS} AC for transmission through transmission wires that have a total resistance, R_T, of 3.0 Ω. Transformer T_2 steps the voltage down to 50 kV_{RMS} AC at the substation. Assume that both transformers are ideal.

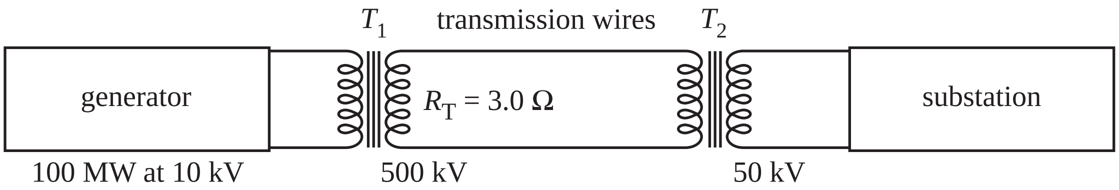


Figure 5

a. The current in the transmission lines is 200 A.

Calculate the total electrical power loss in the transmission wires. 2 marks

kW

b. Transformer T_1 stepped the voltage up to 250 kV_{RMS} AC instead of 500 kV_{RMS} AC.

By what factor would the power loss in the transmission lines increase? 2 marks

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Question 7 (4 marks)

A bicycle and its rider have a total mass of 100 kg and travel around a circular banked track at a radius of 20 m and at a constant speed of 10 m s^{-1}, as shown in Figure 6. The track is banked so that there is no sideways friction force applied by the track on the wheels.

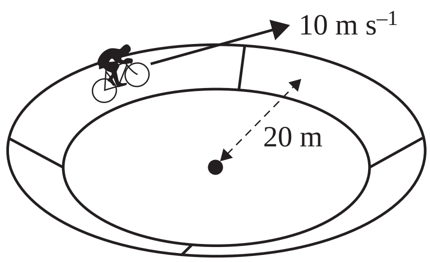
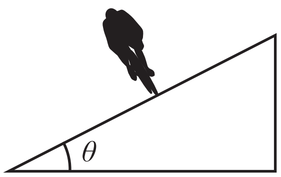


Figure 6

a. On the diagram below, draw all of the forces on the rider and the bicycle, considered as a single object, as arrows. Draw the net resultant force as a dashed arrow labelled F_{net}. 2 marks



b. Calculate the correct angle of bank for there to be no sideways friction force applied by the track on the wheels. Show your working. 2 marks

°

Question 8 (4 marks)

A roller-coaster is arranged so that the normal reaction force on a rider in a car at the top of the circular arc at point P, shown in Figure 7, is briefly zero. The section of track at point P has a radius of 6.4 m.

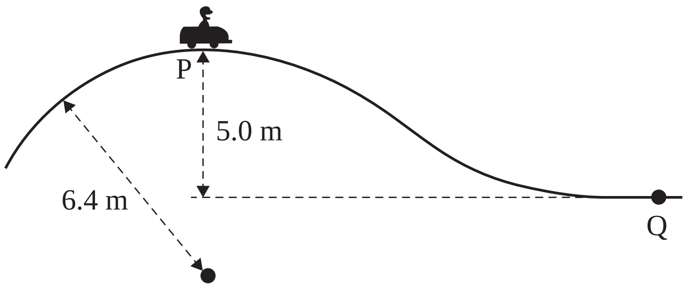


Figure 7

a. Calculate the speed that the car needs to have to achieve a zero normal reaction force on the rider at point P. 2 marks

m s^{-1}

b. The car is faulty and only achieves a speed of 4.0 m s^{-1} at the top of the arc at point P.

Calculate how fast this car would be moving when it reaches the bottom at point Q, 5.0 m below point P. Assume that there is no friction and no driving force on the car. 2 marks

m s^{-1}

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Question 9 (14 marks)

Students use a catapult to investigate projectile motion. In their first experiment, a ball of mass 0.10 kg is fired from the catapult at an angle of 30° to the horizontal. Ignore air resistance. In this first experiment, the ball leaves the catapult at ground level with a speed of 20 m s^{-1}.

However, instead of reaching the ground, the ball strikes a wall 26 m from the launching point, as shown in Figure 8a. Figure 8b shows an enlarged view of the catapult.

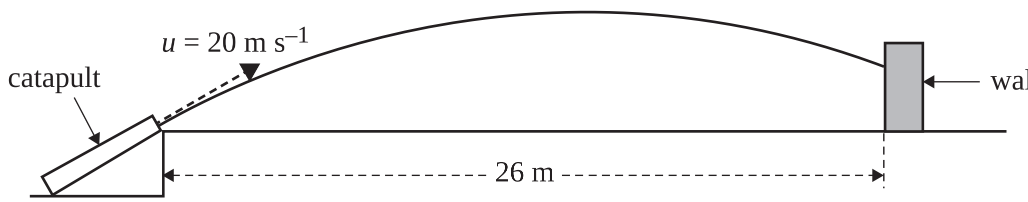

Figure 8a

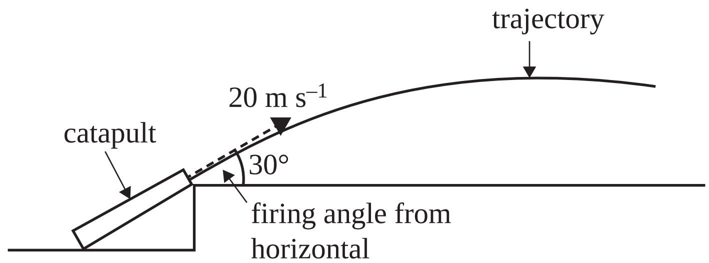

Figure 8b

a. Calculate the height of the ball above the ground when it strikes the wall. Show your working. 3 marks

m

b. The students next investigate the relationship between various initial variables and range, R (on level ground), as shown in Figure 9. In this second experiment, they use a 0.10 kg ball and keep the catapult at a fixed angle of 30° during the experiment. The ball lands at the same height as it is fired.

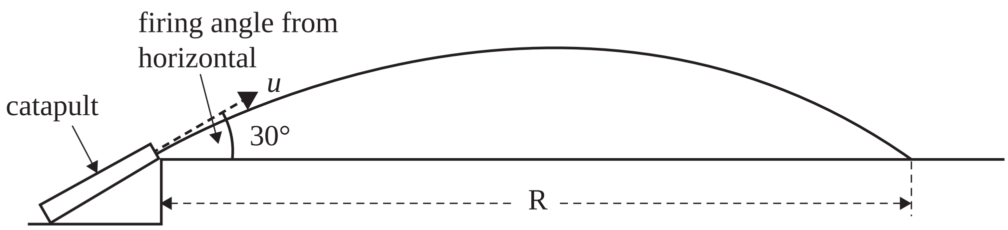

Figure 9

The variables in this experiment can be classified as controlled, dependent or independent.

Complete the table below by providing one variable from the experiment for each classification. 3 marks

Classification	Variable
controlled	
dependent	
independent	

c. The students gather the following data from a series of experiments similar to the one described in **part b.**

u = initial speed (m s^{-1})	R = range (m)
1.0	0.10
2.0	0.35
3.0	0.78
4.0	1.40
5.0	2.15

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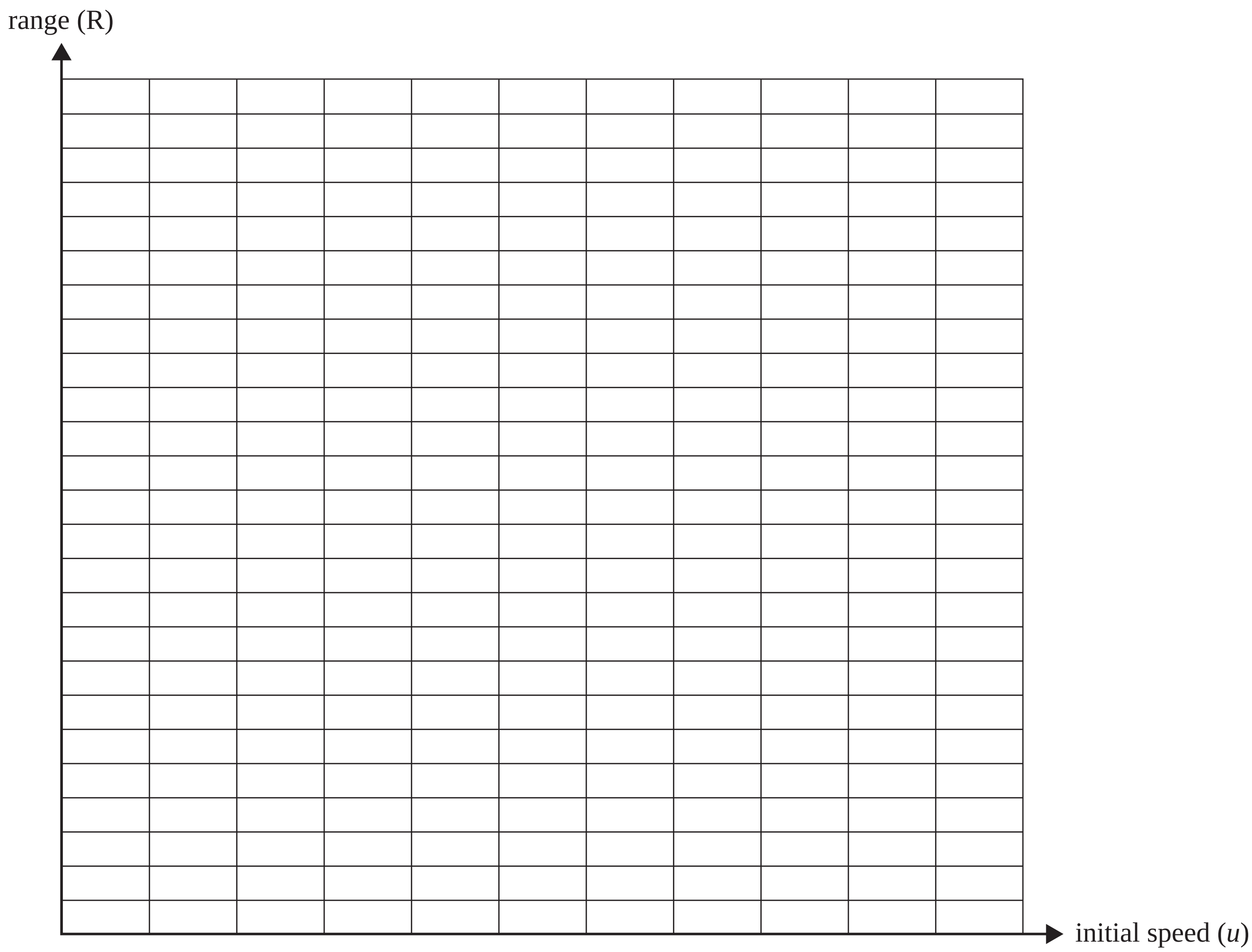
The students use a tape measure that is marked with intervals of 10 cm to measure the range that the ball travels at different initial speeds.

On the grid provided below:

- graph the data gathered by the students (from the table on page 24)
- include scales and units on each axis
- insert appropriate uncertainty bars for the range (distance) on the graph
- draw a smooth curve of best fit.

8 marks



Question 10 (2 marks)

The length of a spaceship is measured to be exactly one-third of its rest length as it passes by an observing station.

What is the speed of this spaceship, as determined by the observing station, expressed as a multiple of *c*?

c

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Question 11 (7 marks)

Tests of relativistic time dilation have been made by observing the decay of short-lived particles. A muon, travelling from the edge of the atmosphere to the surface of Earth, is an example of such a particle.

To model this in the laboratory, another elementary particle with a shorter half-life is produced in a particle accelerator. It is travelling at $0.99875c$ ($\gamma = 20$). Scientists observe that this particle travels 9.14×10^{-5} m in a straight line from the point where it is made to the point where it decays into other particles. It is not accelerating.

a. Calculate the lifetime of the particle in the scientists' frame of reference. 2 marks

s

b. Calculate the distance that the particle travels in the laboratory, as measured in the particle's frame of reference. 2 marks

m

c. Explain why the scientists would observe more particles at the end of the laboratory measuring range than classical physics would expect. 3 marks

Question 12 (3 marks)

Students are using two trolleys, Trolley A of mass 4.0 kg and Trolley B of mass 2.0 kg, to investigate kinetic energy and momentum in collisions.

Before the collision, Trolley A is moving to the right at 5.0 m s^{-1} and Trolley B is moving to the right at 2.0 m s^{-1}, as shown in Figure 10a. The trolleys collide and lock together, as shown in Figure 10b.

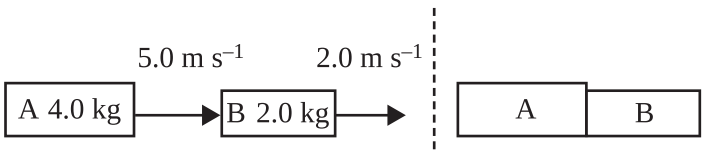

Figure 10a **Figure 10b**

Determine, using calculations, whether the collision is elastic or inelastic. Show your working and justify your answer.

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Question 13 (7 marks)

Pat and Robin hang a mass of 2.00 kg on the end of a spring with spring constant $k = 20.0$ N m^{-1}.

They hold the mass at the unstretched length of the spring and release it, allowing it to fall, as shown in Figure 11.

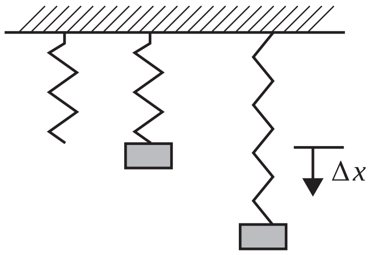

Figure 11

a. Determine how far the spring stretches until the mass comes momentarily to rest at the bottom. Show your working. 3 marks

m

b. Explain how the three energies involved and the total energy of the mass vary as the mass falls from top to bottom. Calculations are **not** required. 4 marks

Question 14 (5 marks)

A light ray from a laser passes from a glucose solution (n = 1.44) into the air (n = 1.00), as shown in Figure 12.

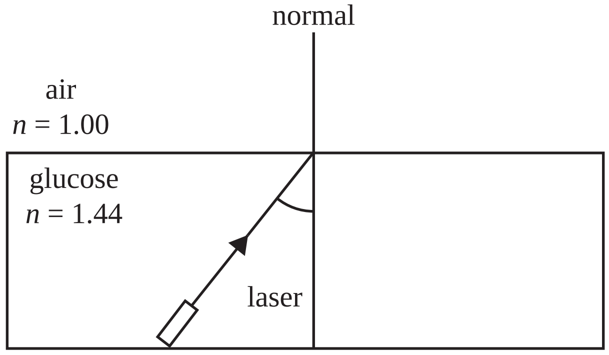

Figure 12

a. Calculate the critical angle (total internal reflection) from the glucose solution to the air. 1 mark

°

b. The light ray strikes the surface at an angle of incidence to the normal of less than the critical angle calculated in **part a.**

On Figure 12, sketch the ray or rays that should be observed. 2 marks

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c. The angle to the normal is increased to a value greater than the critical angle. An observer at point X in Figure 13 says she cannot see the laser.

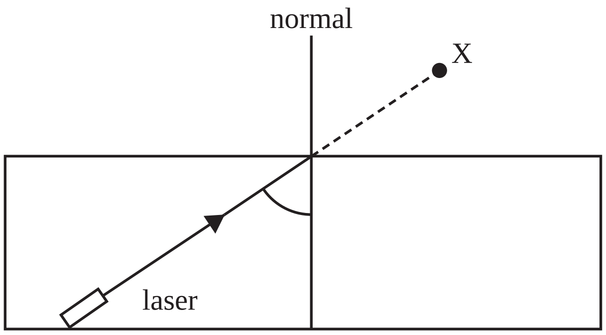

Figure 13

Explain why the observer says she cannot see the laser. 2 marks

Question 15 (7 marks)

A Physics teacher intends to demonstrate wave phenomena to her students. She takes her students to the school oval to listen to a 680 Hz sound.

The speed of sound in air is 340 m s^{-1}.

a. Calculate the wavelength of the sound. 1 mark

m

The teacher now sets up two loudspeakers placed 4 m apart with the sound in phase. Seven students are placed in a row 24 m from the loudspeakers, as shown in Figure 14. Each student is 1.5 m away from the next student.

Student 4 is in the middle and is exactly the same distance from each loudspeaker.

When a single loudspeaker is sounding, all the students hear very close to the same intensity.

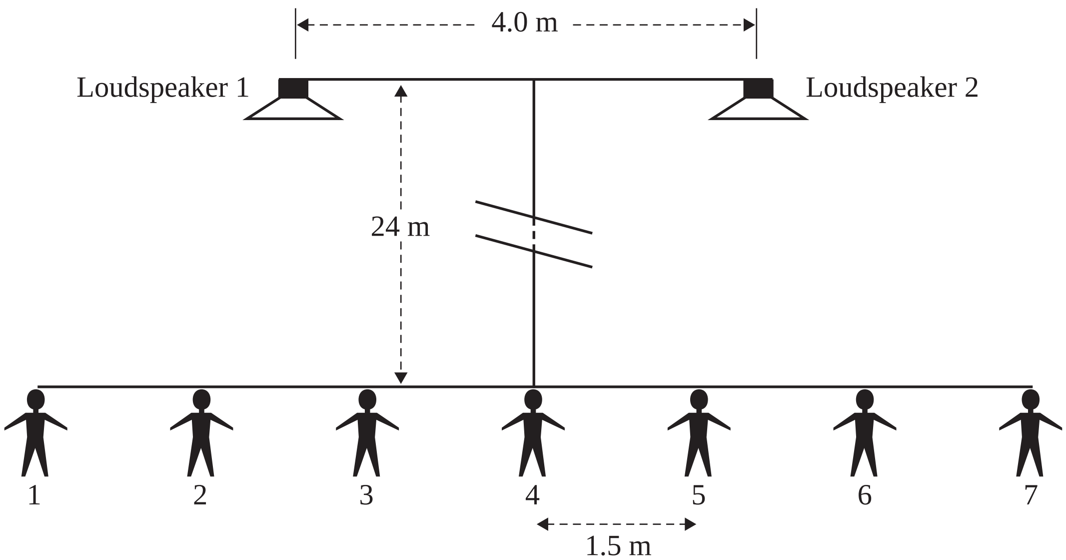

Figure 14

The teacher now connects both loudspeakers.

One student, Elli, predicts that now they will hear a similar sound of double the intensity.

Another student, Sam, disagrees. He says the intensity of the sound will depend on each student's relative distance from each speaker.

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b. Evaluate Elli's and Sam's responses. 3 marks

c. Will students 2 and 5 in Figure 14 hear similar or different sound intensities? If you predict that one of these students will hear a higher sound intensity, state which student and justify your prediction. Show your working. 3 marks

Question 16 (7 marks)

Standing waves are formed on a string of length 4.0 m that is fixed at both ends. The speed of the waves is 240 m s^{-1}.

a. Calculate the wavelength of the lowest frequency resonance. 2 marks

m

b. Calculate the frequency of the second-lowest frequency resonance. 2 marks

Hz

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c. Explain the physics of how standing waves are formed on the string. Include a diagram in your response. 3 marks

Question 17 (9 marks)

In an experiment, blue light of frequency 6.25×10^{14} Hz is shone onto the sodium cathode of a photocell. The apparatus is shown in Figure 15.

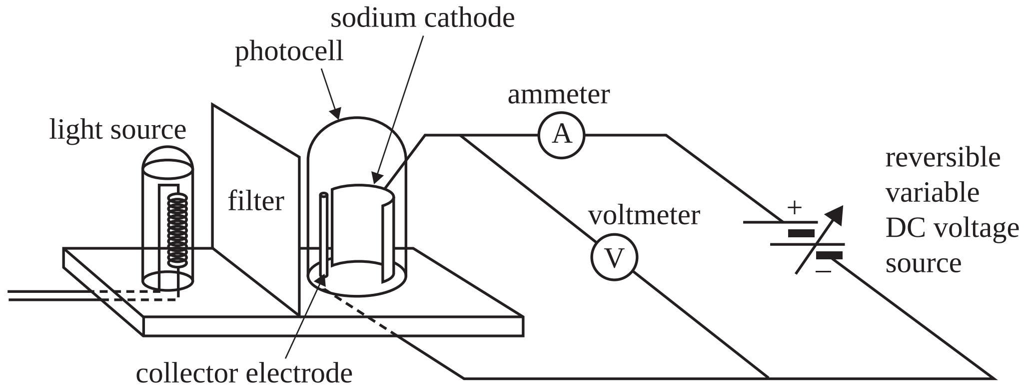

Figure 15

The graph of photoelectric current versus potential difference across the photocell is shown in Figure 16.

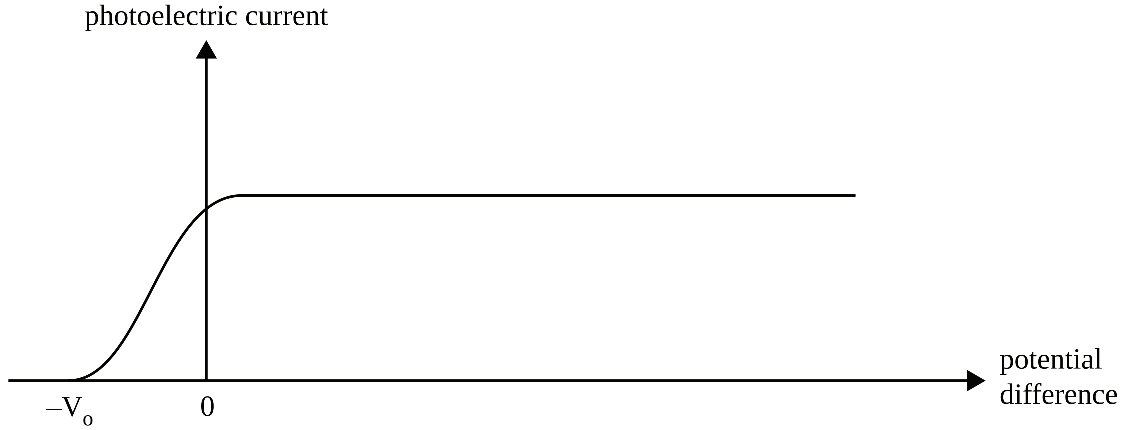

Figure 16

The threshold frequency for sodium is 5.50×10^{14} Hz.

a. What is the cut-off potential, V_o, when blue light of frequency 6.25×10^{14} Hz is shone onto the sodium cathode of the photocell referred to in Figures 15 and 16? 2 marks

V

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b. On the graph of photoelectric current versus potential difference shown in Figure 16, sketch the curve expected if the light is changed to **ultraviolet** with a **higher intensity** than the original blue light. 2 marks

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

Outline **two** aspects of these results that provide the strong evidence that is not explained by the wave model of light, and explain why. 5 marks

Question 18 (5 marks)

The energy-level diagram for sodium is shown in Figure 17. Part of the emission spectrum of sodium vapour includes a photon of energy 1.65 eV.

Assume that $c = 3.0 \times 10^8$ m s^{-1}.

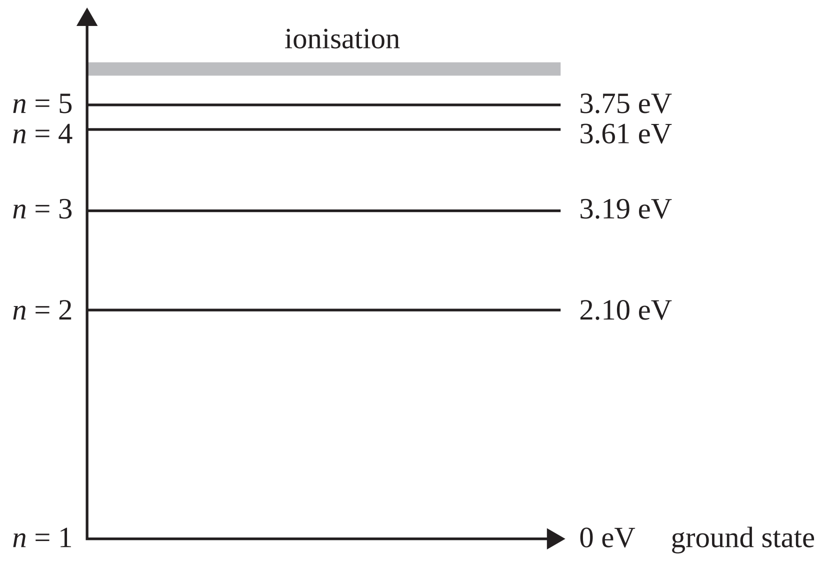

Figure 17

a. Draw an arrow on the energy-level diagram in Figure 17 to demonstrate the atomic energy level transition resulting in the emission of a 1.65 eV photon. 1 mark

b. What is the shortest possible wavelength of a photon that can be emitted when the atom decays from the $n = 5$ level to the ground state? 2 marks

nm

c. A student reported observing a spectral line corresponding to 2.5 eV.

In terms of the quantised states of the atom, explain why this would be impossible. 2 marks

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Question 19 (4 marks)

Roger and Mary are discussing diffraction.

Mary says electrons produce a diffraction pattern.

Roger says this is impossible as diffraction is a wave phenomenon and electrons are particles; diffraction can only be observed with waves, as with electromagnetic waves, such as light and X-rays.

Evaluate Mary's and Roger's statements in light of the current understanding of light and matter. Describe **two** experiments that show the difference between Mary's and Roger's views.

END OF QUESTION AND ANSWER BOOK

VICTORIAN CURRICULUM
AND ASSESSMENT AUTHORITY

Victorian Certificate of Education
2017

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	$E_{K\ max} = hf - W$
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	$g = 9.8$ m s^{-2}
mass of the electron	$m_e = 9.1 \times 10^{-31}$ kg
magnitude of the charge of the electron	$e = 1.6 \times 10^{-19}$ 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	$c = 3.0 \times 10^{8}$ m s^{-1}
gravitational constant	$G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}
mass of Earth	$M_E = 5.98 \times 10^{24}$ 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}

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