TSSM
Creating VCE Success

2018 Trial Examination

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STUDENT NUMBER | | | | | | | | | Letter

PHYSICS

Units 3&4 – Written examination

Reading time: 15 minutes
Writing time: 2 hours and 30 minutes

QUESTION & ANSWER BOOK

Section	*Number of questions*	*Number of questions to be answered*	*Number of marks*
A	20	20	20
B	21	21	110
			Total 130

- Students are permitted to bring into the examination room: pens, pencils, highlighters, erasers, sharpeners and rulers
- Students are NOT permitted to bring into the examination room: blank sheets of paper and/or white out liquid/tape.
- Scientific calculator is permitted in this examination.

Materials supplied

- Question and answer book (including formula and data sheet) of 43 pages.

Instructions

- Print your name in the space provided on the top of this page.
- All written responses must be in English.

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

SECTION A

Instructions
Answer **all** questions on the answer sheer provided for multiple-choice questions.
Choose the response that is **correct** or **best answers** the question.
A correct answer scores 1; an incorrect answer score 0.
Marks will not be deducted for incorrect answers.
Unless otherwise stated, you should take the value of **g** to be 9.8 m s^{-2}.
No marks will be given if more than one answer is completed for any question.
Unless otherwise indicated, diagrams are not to scale.

Question 1
Consider the solenoid shown below in Figure 1.
Which of the following best describes the direction of the magnetic field at point P?

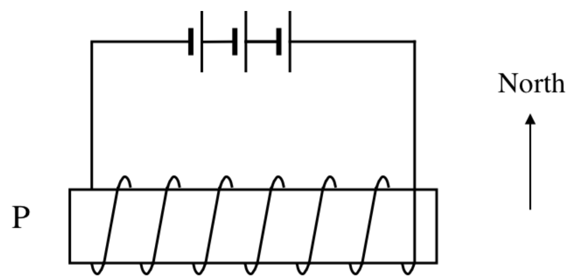


Figure 1

A. North
B. South
C. East
D. West

SECTION A - continued

The following information applies to Questions 2 & 3.

A test charge of 3.2×10^{-19} C is placed within a uniform magnetic field of 1.2×10^{4} N m^{-1}. The pair of plates generating the field have a potential difference of 150 V.

Question 2
Which of the following best estimates the size of the force on the test charge?

A. 1.2×10^{4} N
B. 4.8×10^{-17} N
C. 150 N
D. 3.84×10^{-15} N

Question 3
What is the best estimate for the distance between the plates?

A. 1.25 cm
B. 1.25 m
C. 4.68 cm
D. 4.68 m

The following information applies to Questions 4 & 5.

A step-up transformer converts 15 V AC RMS to 225 V AC RMS.
There are 30 turns on the primary side of the transformer.
The power delivered by the transformer is 450 W.

Question 4
How many turns are on the secondary side?

A. 15
B. 2
C. 450
D. 30

Question 5
Which of the following is the best estimate for the peak current on the secondary side of the transformer?

A. 2.0 A
B. 2.8 A
C. 1.4 A
D. 5.6 A

SECTION A - continued
TURN OVER

Question 6

Figure 2 shows the *emf* output for a Lenz's Law experiment.

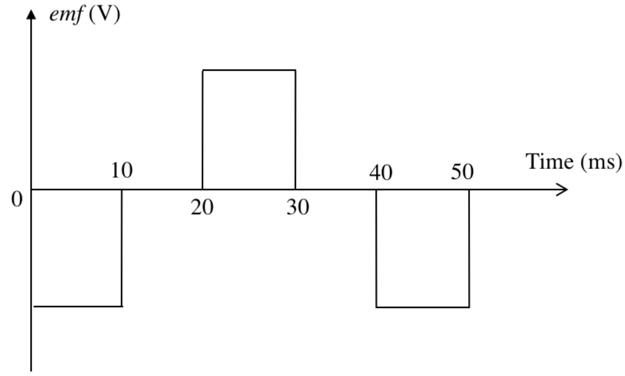
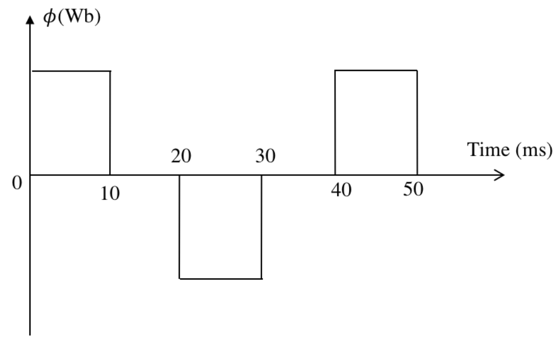


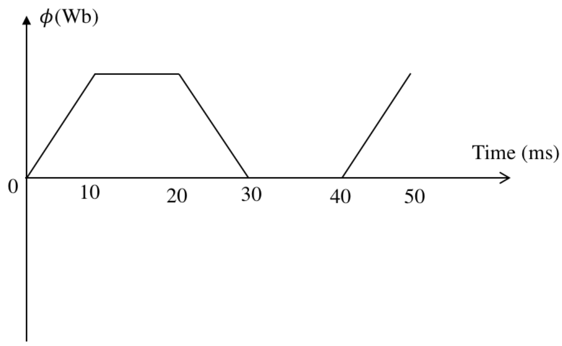
Figure 2

Which of the following best shows the flux vs. time graph that would lead to the *emf* graph in Figure 2?

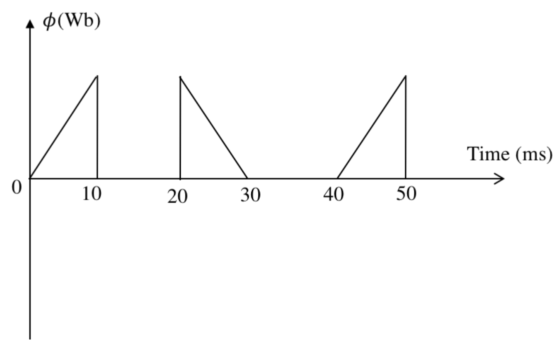
A.



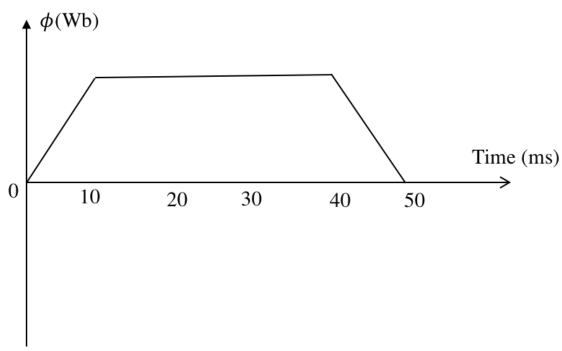
B.



C.



D.



SECTION A - continued

Question 7
Which of the following would be categorised as an experiment being conducted in an inertial reference frame?

A. A pendulum experiment being conducted on a bench in a spacecraft accelerating out of a low earth orbit.
B. A pendulum experiment being conducted on a bench in a spacecraft travelling at 0.5*c* towards Earth.
C. A pendulum experiment being conducted on a rotating bench on Earth.
D. A pendulum experiment being conducted on a bench in a carriage of a train as it brakes upon arriving at a platform.

Question 8
Determine the energy that would be released through the "loss" of 5.6×10^{-27} kg of mass in a fusion reaction.

A. 5.0×10^{-10} J
B. 1.7×10^{-18} J
C. 5.6×10^{-27} J
D. 9.0×10^{16} J

SECTION A - continued
TURN OVER

The following information applies to Questions 9 & 10.

A student sets up a speaker and measures the sound intensity at two positions, X and Y. X and Y are equidistant from the source, but Y is offset by 60°, as showing in Figure 3. The student broadcasts two test frequencies, 150 Hz and 3000 Hz.

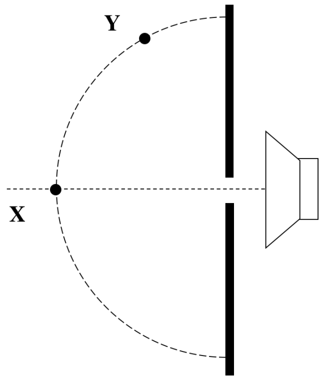


Figure 3

Question 9
Which of the following describes the physical phenomena that gives rise to variation in intensity between X & Y?

A. Diffraction
B. Refraction
C. Reflection
D. Resonance

Question 10
Referring to the table below, which of the following options best describes the variation in intensity at X & Y? Note: I_X = sound intensity at X and I_Y = sound intensity at Y.

Option	150 Hz	3000 Hz
A	$I_X = I_Y$	$I_X < I_Y$
B	$I_X = I_Y$	$I_X > I_Y$
C	$I_X < I_Y$	$I_X < I_Y$
D	$I_X > I_Y$	$I_X > I_Y$

SECTION A - continued

Question 11
A blindfolded pedestrian stands stationary and listens to a car as it passes by with its horn sounding continuously.
The pedestrian notices that the car horn initially appears to have a constant, but higher than normal, pitch. The sound gradually increases in intensity. It then changes to a constant, but lower than normal, pitch that gradually decreases in sound intensity.

Which of the following best describes the likely motion of the source?

A. The car approaches at a constant velocity and passes the pedestrian, continuing at a constant velocity.
B. The car approaches and decelerates until it comes to rest adjacent to the pedestrian.
C. The car approaches, continuing to accelerate and then comes to rest adjacent to the pedestrian
D. The car is moving in a circle around the pedestrian.

Question 12
In an experiment conducted by physics students, a beam of electrons is directed towards a slit of variable width and undergoes diffraction, forming a pattern of nodes and antinodes on a screen positioned beyond the slit.

Which of the following best encapsulates Heisenberg's Uncertainty Principle as applied to this experiment.

A. As the slit is narrowed, the decease in uncertainty in position is accompanied by a increase in the uncertainty in the lateral momentum of the beam, which explains the diffraction.
B. As the slit is narrowed, the increase in uncertainty in position is accompanied by a decrease in the uncertainty in the lateral momentum of the beam, which explains the diffraction.
C. As the slit is narrowed, the decrease in uncertainty in position is accompanied by a decrease in the uncertainty in the lateral momentum of the beam, which explains the diffraction.
D. As the slit is narrowed, the increase in uncertainty in position is accompanied by a increase in the uncertainty in the lateral momentum of the beam, which explains the diffraction.

SECTION A - continued
TURN OVER

Question 13
Consider the following sample of results, which are derived from an experiment that aims to determine the Earth's gravitational field strength.

Student A	9.85	9.83	9.81	9.9	9.7
Student B	8.60	8.60	8.61	8.60	8.61

Which of the following best describes the characteristics of the collected data?
A. Student B's results are more accurate and Student B's results are also more precise.
B. Student B's results are more accurate, but Student A's results are more precise.
C. Student A's results are more accurate, but Student B's results are more precise.
D. Student A's results are more accurate and Student A's results are also more precise.

The following information applies to Questions 14 to 16.

Students are investigating the range of a projectile as it is launched at various angles. The mass of the projectile is 4.0 kg and the launch velocity is 10 m s^{-1}.

Question 14
Based on the description of the experiment, which of the following would be the most appropriate independent variable?
A. Launch velocity.
B. Mass.
C. Launch angle.
D. Range.

Question 15
Based on the description of the experiment, which of the following would be the most appropriate dependent variable?
A. Launch velocity.
B. Mass.
C. Launch angle.
D. Range.

Question 16
Based on the description of the experiment, how could random error be reduced in this experiment?
A. Increase launch velocity.
B. Check the calibration of protractor used to measure angles.
C. Check the calibration of eletronic mass scales.
D. Repeated trials.

SECTION A - continued

Question 17
An unknown light source has the following characteristics:

- High intensity.
- Single wavelength.
- Coherent.
- Low divergence.

Which of the following is the best match for the source described?

A. Incadescent globe.
B. Helium gas vapour lamp.
C. Light emitting diode.
D. Laser.

Question 18
Which of the following best describes the nature of the gravitational field of the Earth?
A. Uniform and static.
B. Non-uniform and static.
C. Uniform and dynamic.
D. Non-uniform and dynamic.

Question 19
Which of the following is the best estimate for the kinetic energy of a proton moving such that it has a Lorentz factor of $\gamma = 1.8$?
[Take the rest mass of the proton is 1.67×10^{-27} kg.]
A. 9.0×10^{-19} J
B. 4.0×10^{-19} J
C. 1.2×10^{-10} J
D. 2.7×10^{-10} J

SECTION A - continued
TURN OVER

Question 20

The force vs. time graph for a stick making contact with a ball of mass 350 g is shown below in Figure 4.

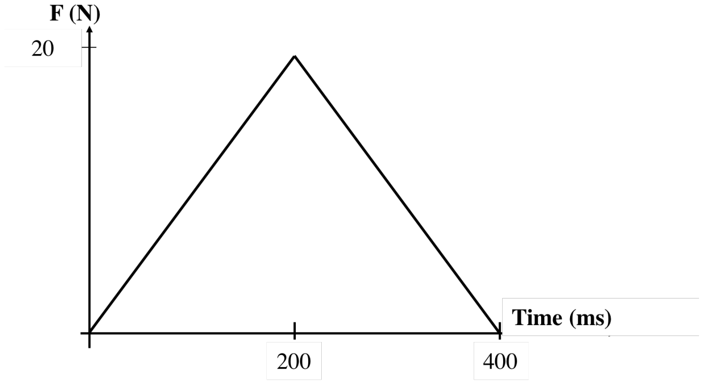


Figure 4

Which of the following is the best estimate for the change in velocity of the ball?

A. $4.0\ \text{m s}^{-1}$
B. $11.4\ \text{m s}^{-1}$
C. $8.0\ \text{m s}^{-1}$
D. $22.9\ \text{m s}^{-1}$

END OF SECTION A

SECTION B

Instructions

Answer **all** questions in this section in the spaces provided. Write using black or blue pen.
Where an answer box has a unit printed in it, give your answer in that unit.
Unless otherwise stated, you should take the value of **g** to be 9.8 m s^{-2}.
Where answer boxes are provided write your final answer in the box.
In questions worth more than 1 mark appropriate working should be shown.
Unless otherwise indicated, diagrams are not to scale.

Question 1 (2 marks)

The force acting on two charges of $+3$ μC and -2 μC respectively is 2.4 N.
Determine the distance between the two forces.

m

2 marks

SECTION B – continued
TURN OVER

Question 2 (8 marks)
A proton beam is initially directed in a straight line in an easterly direction and encounters a magnetic field of magnitude 2.2 T directed upwards. The protons moves in a circular arc of radius 2.7 cm.

Data:
- Mass of proton: 1.67×10^{-27} kg (ignore relativistic effects)
- Charge on proton: 1.6×10^{-19} C

a. Show that the velocity of the proton is 5.7×10^{6} m s^{-1}.

2 marks

b. Determine the magnitude of the voltage required to accelerate the protons to a linear velocity of 5.7×10^{6} m s^{-1}.

V

2 marks

SECTION B – Question 2 - continued

c. Determine the de Broglie wavelength of a proton as it travels in a straight line.

m

2 marks

The magnetic field is now removed and the protons are directed through a gap of 1.7 μm.

d. Use an equation to explain whether any significant diffraction would likely be observed.

2 marks

SECTION B – continued
TURN OVER

Question 3 (6 marks)
A satellite maintains a stable equatorial orbit around the Earth such that the gravitational field strength is constant at $8.21\ \text{N kg}^{-1}$.

a. Show that the satellite orbits at an altitude of 600 km.

2 marks

b. Determine the period of the satellite's orbit in minutes.

mins

2 marks

SECTION B – Question 3 - continued

c. Determine the orbital speed of the satellite.

m s^{-1}

2 marks

Question 4 (4 marks)
The gravitational field strength profile for the Earth is shown below in Figure 5.
[Note: R is the distance from the centre of the Earth to the object.]
An incoming object, mass 260 kg, moving directly towards the Earth is observed at 8.0×10^6 m with a velocity of 1.50×10^3 m s^{-1}. Its velocity increases as it falls to a distance of 7.0×10^6 m.
Determine the velocity of the object at 7.0×10^6 m.

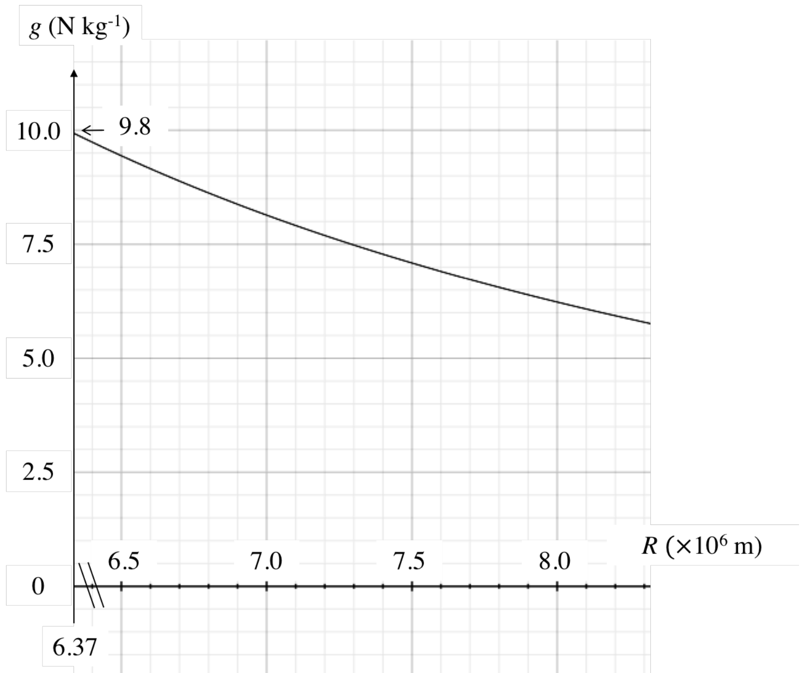


Figure 5

SECTION B – Question 4 - continued
TURN OVER

$m\ s^{-1}$

4 marks

SECTION B – continued

Question 5 (4 marks)
A 1.5 kg mass is attached to a central pole by a thin cable. The mass moves in a horizontal circle as shown in Figure 6. The radius of the circle is 0.6 m and the mass moves with a period of 0.40 sec.

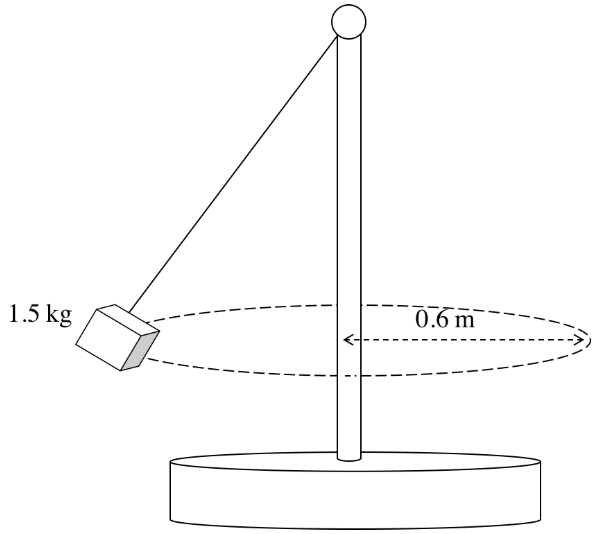


Figure 6

a. Determine the net force acting on the mass.

N	2 marks

SECTION B – Question 5 - continued
TURN OVER

b. Determine the tension force acting on the mass.

N

2 marks

Question 6 (5 marks)
A standing wave is generated on a 0.45 m guitar string as shown in Figure 7.
It is known that transverse waves on the guitar string travel at 1.50×10^{2} m s^{-1}.

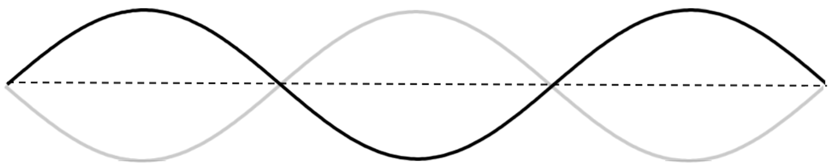


Figure 7

a. Determine the frequency of the standing wave.

Hz

2 marks

SECTION B – Question 6 - continued

b. Using appropriate physics terminology, explain how the standing wave is formed on the string.

3 marks

SECTION B – continued
TURN OVER

Question 7 (3 marks)
Figure 8 shows a simplified schematic diagram of a DC motor. The coil rotates anti-clockwise as a force of 0.45 N acts on side AB in the position shown. The current in the coil is 0.6 A, the field strength is 0.6 T and there are 10 turns in the coil.

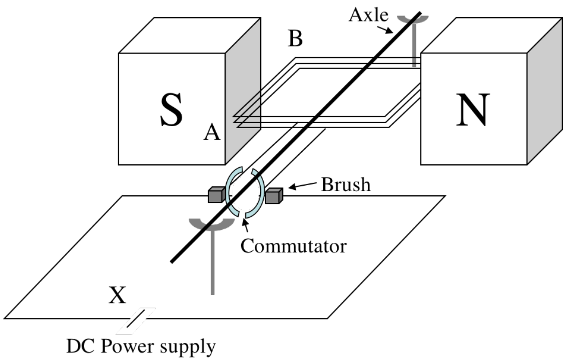


Figure 8

a. Determine the length of side AB in centimetres.

cm

2 marks

b. State the polarity of terminal X of the DC power supply (positive or negative).

1 mark

SECTION B – continued

Question 8 (6 marks)

A student is experimenting with a toy cart of mass 0.15 kg, which is designed to be launched by a spring along a track and directed towards a vertical loop, as shown in Figure 9.

The spring has a constant of $k = 50 \text{ N m}^{-1}$ and the student initially compress it by 0.20 m before releasing the cart.

Ignore friction effects along the track.

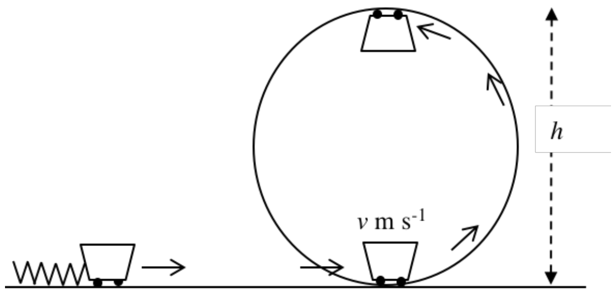


Figure 9

a. Show that the velocity of the cart at the base of the loop is 3.7m s^{-1}.

2 marks

SECTION B – Question 8 - continued
TURN OVER

b. Determine the maximum height of the loop possible for the cart to stay in contact for the full vertical circle.

m

4 marks

Question 9 (5 marks)

A simple generator is constructed as shown in Figure 10. The magnetic field strength provided by the permanent magnets is 0.3 T and the maximum flux through the circular coil is 2.4 mWb.

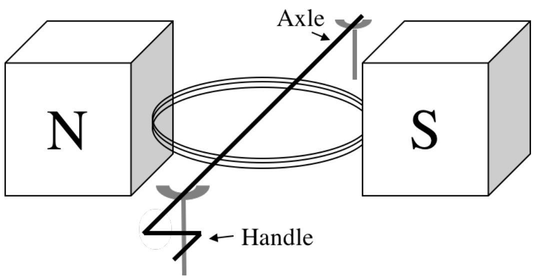


Figure 10

a. Determine the radius of the circular loop.

m

2 marks

SECTION B – Question 9 - continued

The coil is now rotated to generate voltage. Over a quarter turn, an average *emf* of 0.3 V is generated. There are 25 turns in the coil.

b. Determine the frequency of rotation.

Hz

3 marks

Question 10 (5 marks)
A transmission system is shown in Figure 11. A generator is operating at 50 MW and 15 kV. It is stepped up by a transformer of turns ratio 1:5, then linked to a load via transmission lines with resistance 4.0 Ω. The supply voltage is then stepped down by a different transformer at the load site. The voltage at the load is measured to be 3617 V.

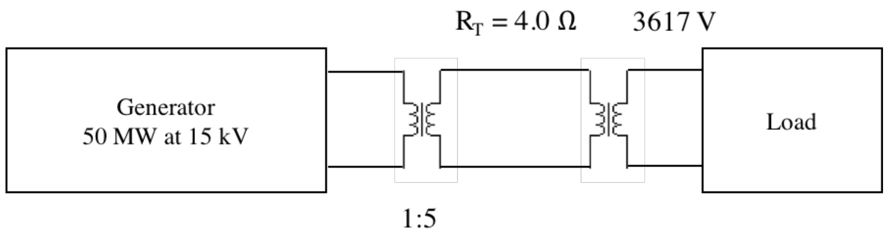


Figure 10

a. Determine the turns ratio required by the step-down transformer.

SECTION B – Question 10 - continued
TURN OVER

3 marks

b. Determine the percentage power loss in the system.

%

2 marks

Question 11 (4 marks)
A student is attempting to throw a ball over a barrier and onto a platform that is 20 m high. The barrier is 25 m high and the ball must land a distance of 6 m horizontally beyond the starting position, as shown in Figure 11. Assume that the ball reaches a maximum height of 25 m.

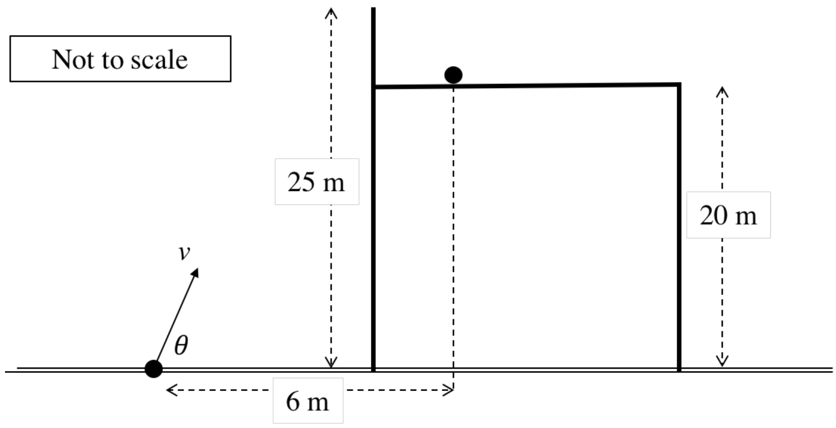


Figure 11

SECTION B – Question 11 - continued

a. Find the launch velocity and angle required for a successful attempt.

m s^{-1}
degrees

4 marks

SECTION B – continued
TURN OVER

Question 12 (6 marks)
A physicist is investigating the decay of high velocity particles in a laboratory.
At rest, the particles have a half-life of 6 μs.
The physicists now accelerate the particles so that they have a Lorentz factor of $\gamma = 16$.
The length of the measuring device is 26 m, as measured by the physicist.

a. Determine the velocity of particles in terms of *c*.

c

2 marks

b. Determine the half-life of the moving particles as observed by the physicist.

s

2 marks

c. Determine the length of the measuring device in the reference frame of the moving particles.

m

2 marks

SECTION B – continued

Question 13 (4 marks)
Two carts engage in a collision on an air track.
Before the collision, Cart A has a mass of 3.0 kg and is moving at 6.0 m s^{-1}. Cart B has a mass of 2.0 kg and is moving at 2.0 m s^{-1} in the same direction.
After the collision, Cart A continues at 2.8 m s^{-1}, whilst Cart B moves away at 6.8 m s^{-1}.
Figure 12 illustrates the scenario.

Show, with the aid of calculations, whether the collision is isolated **and/or** elastic.

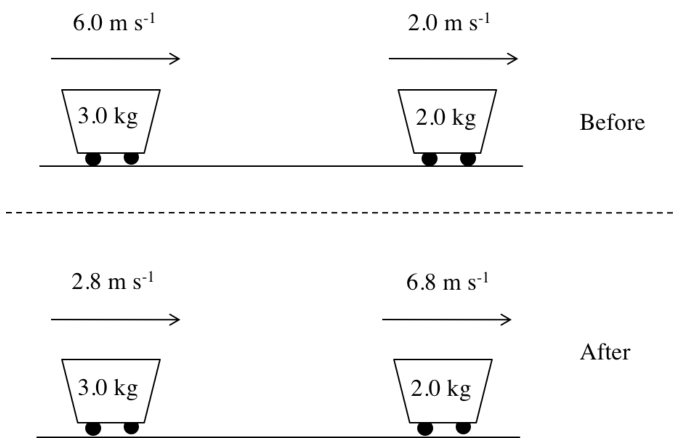


Figure 12

Isolated:

YES	NO

Elastic:

YES	NO

4 marks

Question 14 (5 marks)
A 15.0 kg mass is released from the top of a 20.0 m tower, connected to an elastic cord with a constant $k = 25\ \text{N m}^{-1}$. At its lowest point, the mass reaches a height of 3.0 m above the ground.

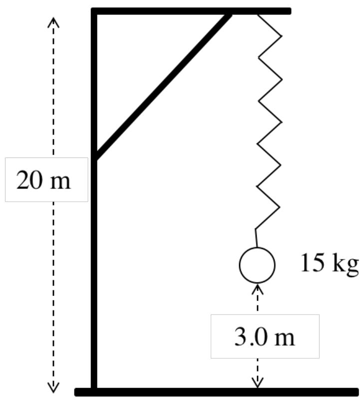


Figure 13

a. Determine the natural length of the cord.

	m

3 marks

SECTION B – Question 14 - continued

b. Determine the height of the mass once it has come to rest.

m

2 marks

Question 15 (2 marks)
A laser is directed from within an unknown liquid solution into air as shown in Figure 14.

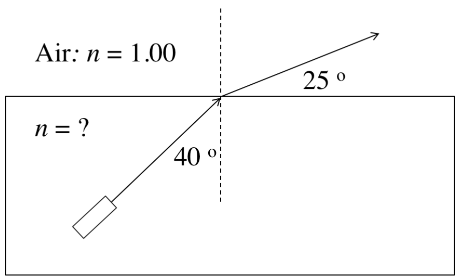


Figure 14

Determine the refractive index of the liquid.

2 marks

SECTION B – continued
TURN OVER

Question 16 (2 marks)
A simplified optical fibre is shown in Figure 15. The fibre is a step-index fibre, consisting of a glass core and cladding.

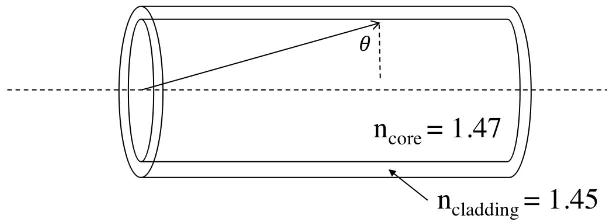


Figure 15

Determine the critical angle for the fibre, correct to the nearest degree.

degrees

2 marks

Question 17 (7 marks)
A pair of speakers is positioned 3.0 m apart and broadcast a constant frequency, as shown in Figure 16. A student moves from the centre to Point Z. Point Z is the **second** loud point from the centre.

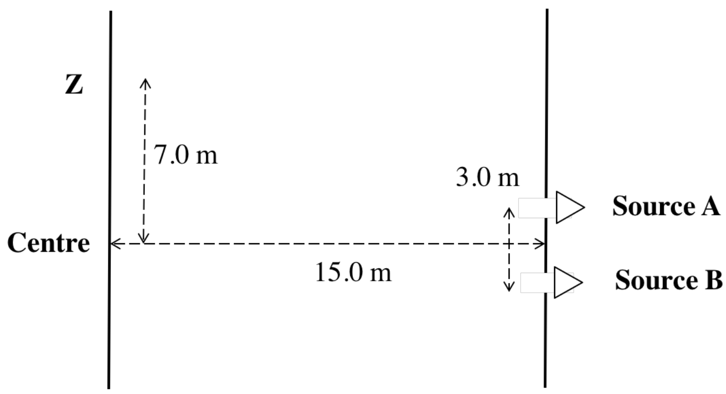


Figure 16

SECTION B – Question 17 - continued

a. Determine the wavelength of the signal.

m

3 marks

The frequency of the signal is decreased and the pattern changes.

b. Determine the direction (**towards** or **away** from the centre) that the student would need to move to reach the second loud point again.

1 mark

c. Explain how a quiet point could be formed by the interaction of the two speakers.

3 marks

SECTION B – continued
TURN OVER

Question 18 (10 marks)
Peta is conducting an experiment with the photoelectric effect.
Using a light source of wavelength 231 nm, she collects data and constructs a voltage vs. photocurrent as shown in Figure 17.

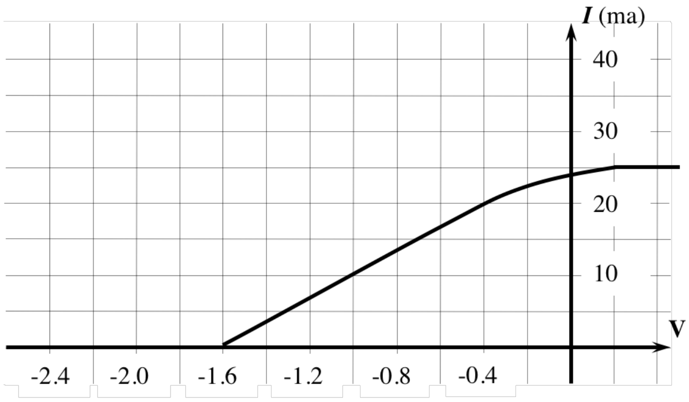


Figure 17

a. State the area of the electromagnetic spectrum that the source lies.

1 mark

b. Determine the frequency of the light source.

Hz

1 mark

SECTION B – Question 18 - continued

c. Determine the work function for the metal.

eV

2 marks

d. Explain what is meant by the **threshold frequency** for this experiment.

2 marks

e. Identify and explain two pieces of evidence from the photoelectric effect that support the particle model for light.

4 marks

SECTION B – continued
TURN OVER

Question 19 (6 marks)
An energy level diagram for an unknown element is shown below in Figure 18. An electron transitions from $n = 4$ to $n = 2$ as shown by the downwards arrow.

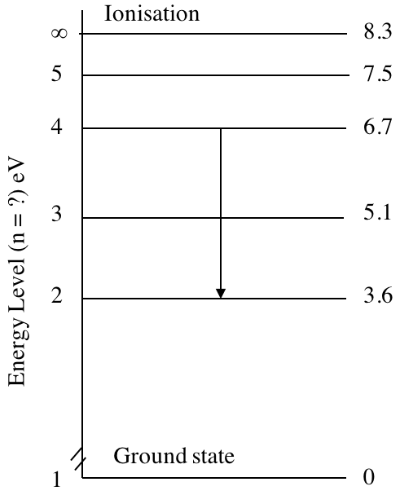


Figure 18

a. Determine the wavelength of the photon that is emitted as the electron transitions.

nm

2 marks

SECTION B – Question 19 - continued

b. Explain the difference between an **absorption** and an **emission** spectrum.

2 marks

c. Explain how the quantised energy states shown in Figure 18 support a wavelike model for matter.

2 marks

SECTION B – continued
TURN OVER

Question 20 (5 marks)
A familiar diffraction experiment is setup with x-rays and electrons yielding similar patterns as shown in Figure 19. The electrons are known to have a de Broglie wavelength of 5.5 nm.

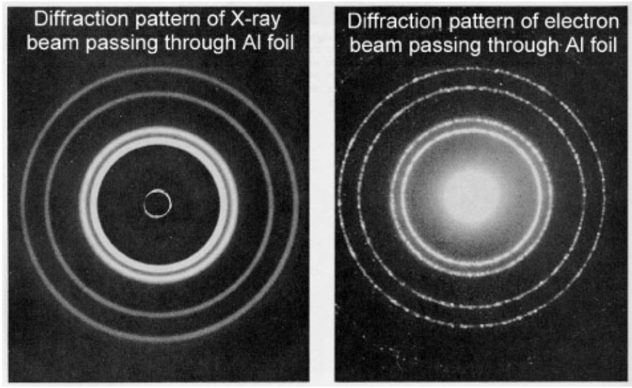


Figure 19

a. Determine the energy of the x-ray source.

eV

2 marks

b. Determine the energy of the electrons.

eV

3 marks

SECTION B – continued

Question 21 (9 marks)
Students are conducting a photoelectric effect experiment. They measure the wavelength of their light sources using equipment that has markings every 50 nm.
They record their data in a table as shown in Figure 20.

Source		**Stopping Voltages (V)**					
Wavelength (nm)	**Frequency ($\times 10^{14}$ Hz)**	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**	**Average**	**Error**
400	7.50	1.50	1.55	1.44	1.64		
450	6.33	1.20	1.20	1.10	1.30	1.20	
500	6.00	1.00	1.00	1.10	1.20	1.00	
550	5.45	0.80	0.85	0.90	0.80	0.80	

Figure 20

a. Determine an appropriate error for the **frequency** 7.50×10^{14} Hz.

Hz

2 marks

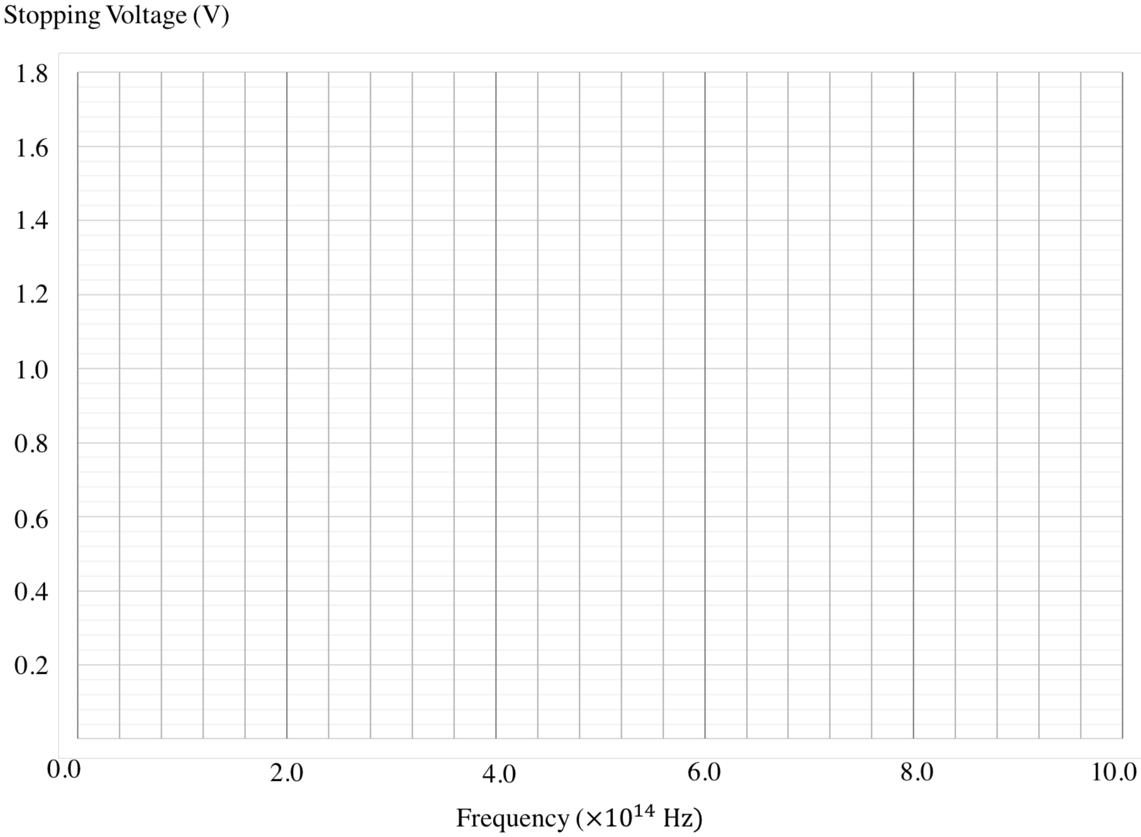
b. Determine the average value and an appropriate error for the **stopping voltage** for the trials at $f = 7.50 \times 10^{14}$ Hz.

V

2 marks

SECTION B – Question 21 - continued
TURN OVER

c. Plot the frequency vs average stopping voltage on the graph provided. Show the horizontal and vertical error bars for the data point for $f = 7.50 \times 10^{14}$ Hz.



3 marks

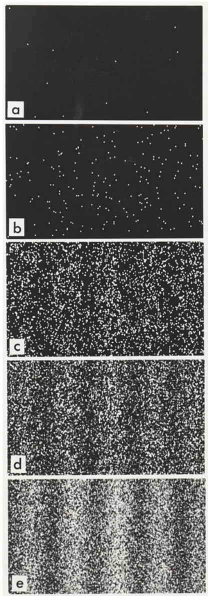
d. Use your graph to determine an estimate for Planck's constant.

eVs

2 marks

SECTION B – continued

Question 22 (2 marks)
The image below shows that an interference pattern can build up over time when electrons or photons are sent through a double-slit interference experiment **one at a time**.



Source: Belsazar - With permission of Dr. Tonomura

Explain how this supports the idea of wave-particle duality.

2 marks

END OF QUESTION AND ANSWER BOOK

Multiple Choice Answer Sheet

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

Prefixes

n = nano = 10^{-9}	m = milli = 10^{-3}	M = mega = 10^{6}
μ = micro = 10^{-6}	k = kilo = 10^{3}	G = giga = 10^{9}

General constants

Universal 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
Mass of the electron	$m_e = 9.1 \times 10^{-31}$ kg
Charge on the electron	$q = -1.6 \times 10^{-19}$ C
Speed of light	$c = 3.0 \times 10^{8}$ m s^{-1}
Planck's constant	$h = 6.63 \times 10^{-34}$ J s $h = 4.14 \times 10^{-15}$ eV s
Tonne	t = tonne = 10^{3} kg
Gravitational field strength at surface of Earth	9.8 N kg^{-1}
Coulomb constant	$k = 8.99 \times 10^{9}$ N m^2 C^{-2}

Area of Study 1 – How do things move without contact?

Electric field	$E = k\frac{Q}{r^2}$
Electric force	$F = \frac{kq_1q_2}{r^2}$
Uniform electric field	$E = \frac{V}{d}$
Potential energy changes in a uniform field	$W = qV$
Force on a charged particle due to uniform electric field	$F = qE$
Force on moving charged particle in magnetic field	$F = qvB$
Radius of path followed by charged particle in magnetic field	$qvB = \frac{mv^2}{r}$
Gravitational field and force	$g = \frac{GM}{r^2}, F = \frac{GMm}{r^2}$
Potential energy changes in uniform gravitational field	$E_g = mg\Delta h$
Satellite motion	$a = \frac{v^2}{r} = \frac{4\pi^2 r}{T^2}$
Force on a current carrying conductor	$F = nIlB$

Area of Study 2 – How are fields used to move electrical energy?

Magnetic flux	$\phi = B_{\perp}A$
Electromagnetic induction	$\varepsilon = -N\frac{\Delta\phi}{\Delta t}$
Transformer action	$\frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{I_2}{I_1}$
AC voltage, RMS	$V_{RMS} = \frac{V_{PEAK}}{\sqrt{2}}, I_{RMS} = \frac{I_{PEAK}}{\sqrt{2}}$
Voltage, Power	$V = IR,\ P = VI = I^2R$

Area of Study 3 – How fast can things go?

Velocity, acceleration	$v = \frac{\Delta x}{\Delta t}, a = \frac{\Delta v}{\Delta t}$
Equations for constant acceleration	$v = u + at$ $x = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$ $x = \frac{1}{2}(v + u)t$
Newton's second law	$\Sigma F = ma$
Circular motion	$a = \frac{v^2}{r} = \frac{4\pi^2 r}{T^2}$
Hooke's law	$F = -kx$
Elastic potential energy	$E_s = \frac{1}{2}kx^2$
Kinetic energy	$E_k = \frac{1}{2}mv^2$
Gravitational potential energy near Earth's surface	$E_g = mgh$
Time dilation	$t = t_o\gamma$
Length contraction	$L = \frac{L_o}{\gamma}$
Lorentz factor	$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$
Momentum and impulse	$\Delta p = m\Delta v = F_{av}\Delta t$
Mass-Energy	$E_{tot} = E_k + E_0 = \gamma m_o c^2$, where $E_0 = m_o c^2$ $E_k = (\gamma - 1)m_o c^2$

Unit 4: Area of Study 1 – How can waves explain the behaviour of light?

Wave equation	$v = f\lambda$
Path difference	Nodes: $n\lambda$, Antinodes: $\left(n - \frac{1}{2}\right)\lambda$
Interference pattern spacing	$\Delta x = \frac{\lambda L}{d}$
Snell's Law	$n_1 \sin i = n_2 \sin r$

Unit 4: Area of Study 2 – How are light and matter similar?

Photoelectric effect	$E_{k\,max} = hf - \phi$
de Broglie wavelength	$\lambda = \frac{h}{p}$
Momentum of photons	$p = \frac{h}{\lambda} = \frac{E}{c}$
Energy of photons	$E = hf = \frac{hc}{\lambda}$