JAMES RUSE AGRICULTURAL HIGH SCHOOL

2022

TRIAL HIGHER SCHOOL CERTIFICATE EXAMINATION

Physics

General Instructions

- Reading time – 5 minutes
- Working time – 3 hours
- Write using black pen
- Draw diagrams using pencil
- Calculators approved by NESA may be used
- A data sheet, formulae sheet and Periodic Table are provided

Total marks: 100

Section I – 20 marks (pages 2–13)
- Attempt Questions 1–20
- Allow about 35 minutes for this section

Section II – 80 marks (pages 19–42)
- Attempt Questions 21–36
- Allow about 2 hours and 25 minutes for this section

Please Turn over

Section I

20 marks
Attempt Questions 1–20
Allow about 35 minutes for this section
Use the multiple-choice answer sheet for Questions 1–20.

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1 Which of the following statements about nuclear radiation is true?

A. Alpha particles are deflected most by a magnetic field, then beta, then gamma.

B. Alpha particles are deflected most by an electric field, then beta, then gamma.

C. Alpha particles have the highest penetrating power, then beta, then gamma.

D. Alpha particles have the highest ionising ability, then beta, then gamma.

2 The electromagnetic radiation emitted by a blackbody peaks at a wavelength of 345 nm.

What is the temperature of the blackbody?

A. 8.40×10^{-6} K

B. 8.40×10^{-3} K

C. 8.40×10^{3} K

D. 8.40×10^{6} K

3 According to Maxwell's classical theory on electromagnetism, which of the following statements is incorrect?

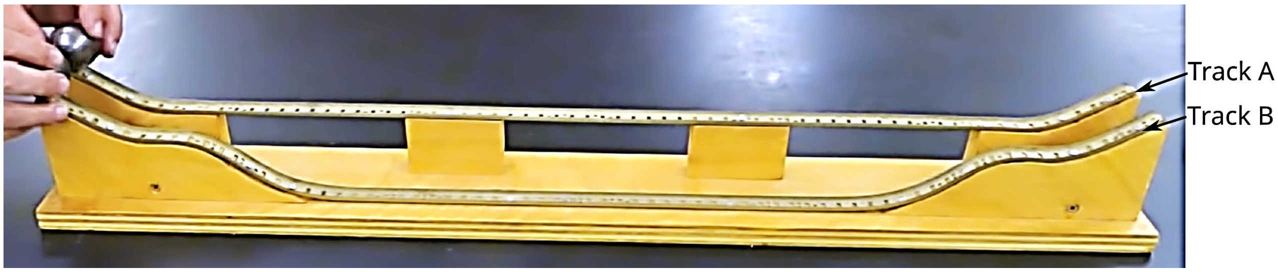
A. An oscillating electric field induces an oscillating magnetic field.

B. An oscillating magnetic field induces an oscillating electric field.

C. Electric and magnetic fields oscillate out of phase with each other.

D. Electromagnetic waves consist of electric and magnetic fields oscillating at right angles to each other.

4 Two balls are released simultaneously from the same vertical position on two tracks which have the same start and end height. Track A is mostly straight, while Track B first curves down and then back upwards by the same amount, as shown below. Rolling resistance can be assumed to be negligible.



Which ball reaches the end of the track first?

A. The balls on Track A and Track B reach the end at the same time.

B. The ball on Track A arrives first.

C. The ball on Track B arrives first.

D. It is not possible to determine the answer without knowing the detailed shape of each track.

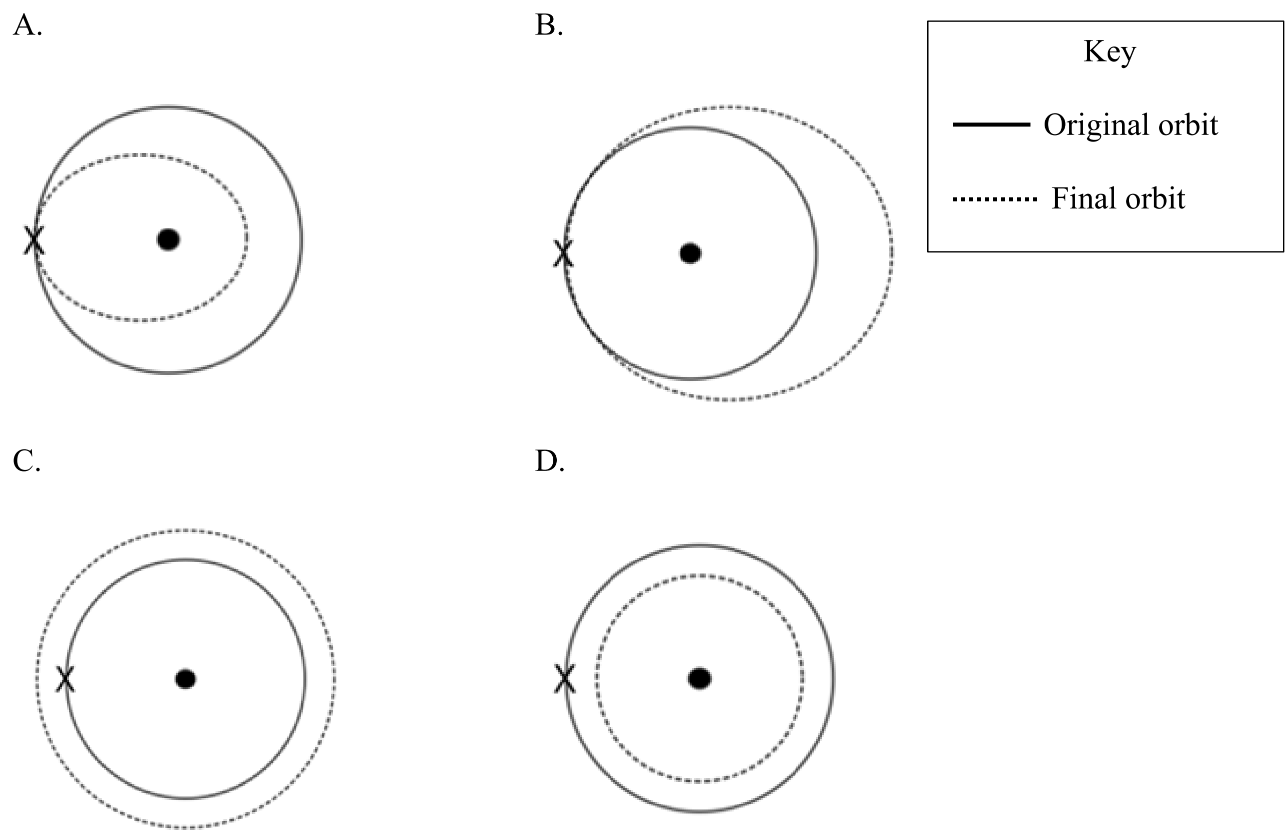
5 When monochromatic light, above a threshold frequency, is incident on a metallic surface, electrons are emitted from the surface.

Which changes will result in electrons of greater kinetic energy being emitted from the surface?

	Frequency of incident light	*Intensity of incident light*	*Work function of metal*
A.	decrease	increase	decrease
B.	increase	increase	decrease
C.	decrease	decrease	increase
D.	increase	decrease	increase

6 A satellite in a circular orbit at position X (shown as a solid line) fires its thrusters briefly, once. This has the effect of reducing its orbital speed.

Which of the following shows a possible final orbit for the satellite?



7 What is the wavelength of an electron travelling at 0.01 c?

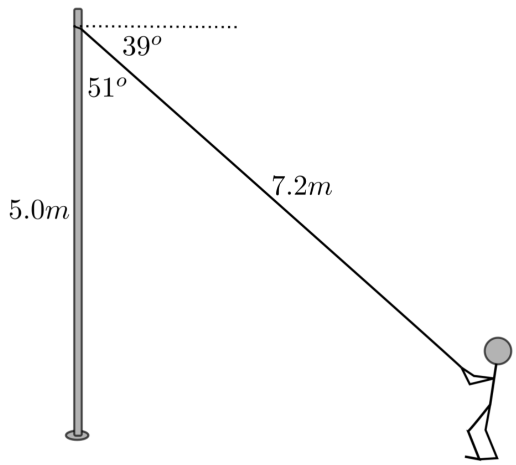
A. 7.3×10^{-2} m

B. 2.4×10^{-10} m

C. 1.3×10^{-13} m

D. 1.4×10^{-21} m

8 A person pulls on a rope attached to the top of a flagpole with a tension force of 350 N.



What is the magnitude of the torque the person exerts on the flagpole, which is attached to the ground at its base?

A. $\tau = 7.2 \times 350 \sin 39°$ Nm

B. $\tau = 5.0 \times 350 \sin 39°$ Nm

C. $\tau = 7.2 \times 350 \sin 51°$ Nm

D. $\tau = 5.0 \times 350 \sin 51°$ Nm

9 Consider the following two statements:

Statement A:

In the Schrodinger model of the atom, the wavefunction can be used to compute the probability of finding the electron at a particular position.

Statement B:

Modelling electrons as standing matter waves according to de Broglie's hypothesis is consistent with the postulates of Bohr's model.

Which of the above statements is correct?

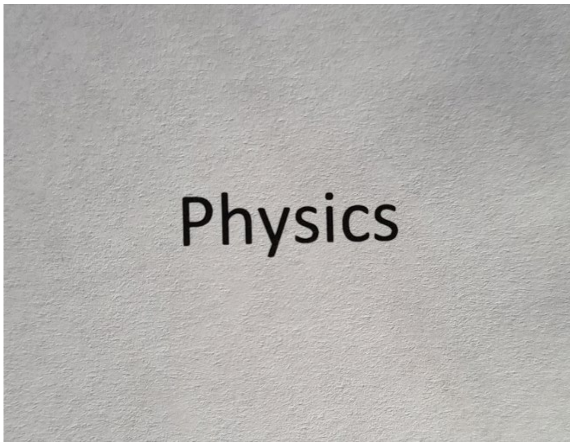
A. Statement A only.

B. Statement B only.

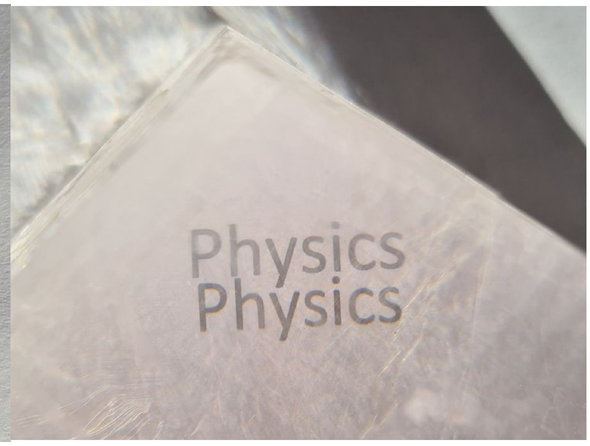
C. Both statement A and statement B.

D. Neither statement A nor statement B.

10 Calcite is a crystal which produces two images of an object when viewed from above. This phenomenon (double refraction) occurs because calcite has a different refractive index for different polarisations of light.



No calcite



With calcite

Double refraction in calcite played an important role in the debate between Newton and Huygens over the nature of light. Newton explained it by hypothesizing that light particles had “sides” and the two types of light particles were separated by the crystal. Huygens, who assumed light was a wave like sound, was unable to explain this phenomenon with his model.

Newton could also explain colour in his model by proposing that different colours corresonded to different sized partices, whereas Huygen’s original model had no explanation for colour.

How did the wave model of light change from Huygens’ original model so that it could successfully explain the phenomena of polarisation and colour?

	Type of wave in new model	*Origin of colour in new model*
A.	Longitudinal	Wavelength
B.	Transverse	Wavelength
C.	Longitudinal	Amplitude
D.	Transverse	Amplitude

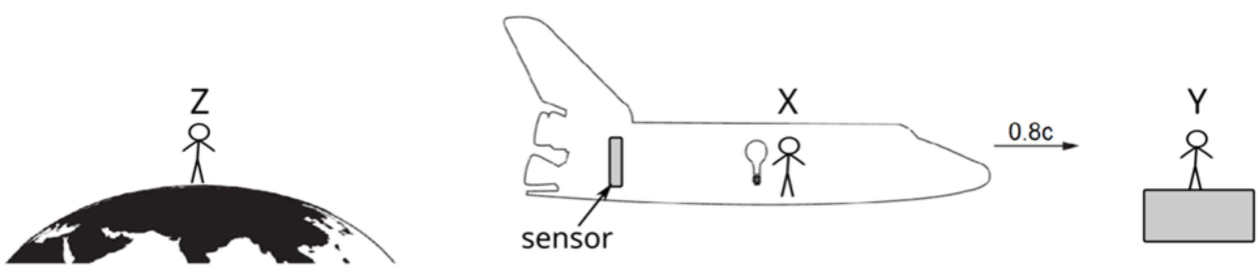
11 A student set up Crookes tubes to investigate the nature of cathode rays.

Which of the following matches the contents of the tube with the conclusion made in Crookes' time about the nature of cathode rays?

	Contents of Crookes tube	*Conclusion*
A.	Paddle wheel	Cathode rays have a high velocity.
B.	Maltese Cross	Cathode rays reflect according to law of reflection.
C.	Paddle wheel	Cathode rays have momentum.
D.	Maltese Cross	Cathode rays can diffract.

12 A person (X) on a spacecraft is flying at a speed of 0.8c directly away from Earth towards a space port. An observer (Y) located on the spaceport is at rest with respect to an observer (Z) on Earth.

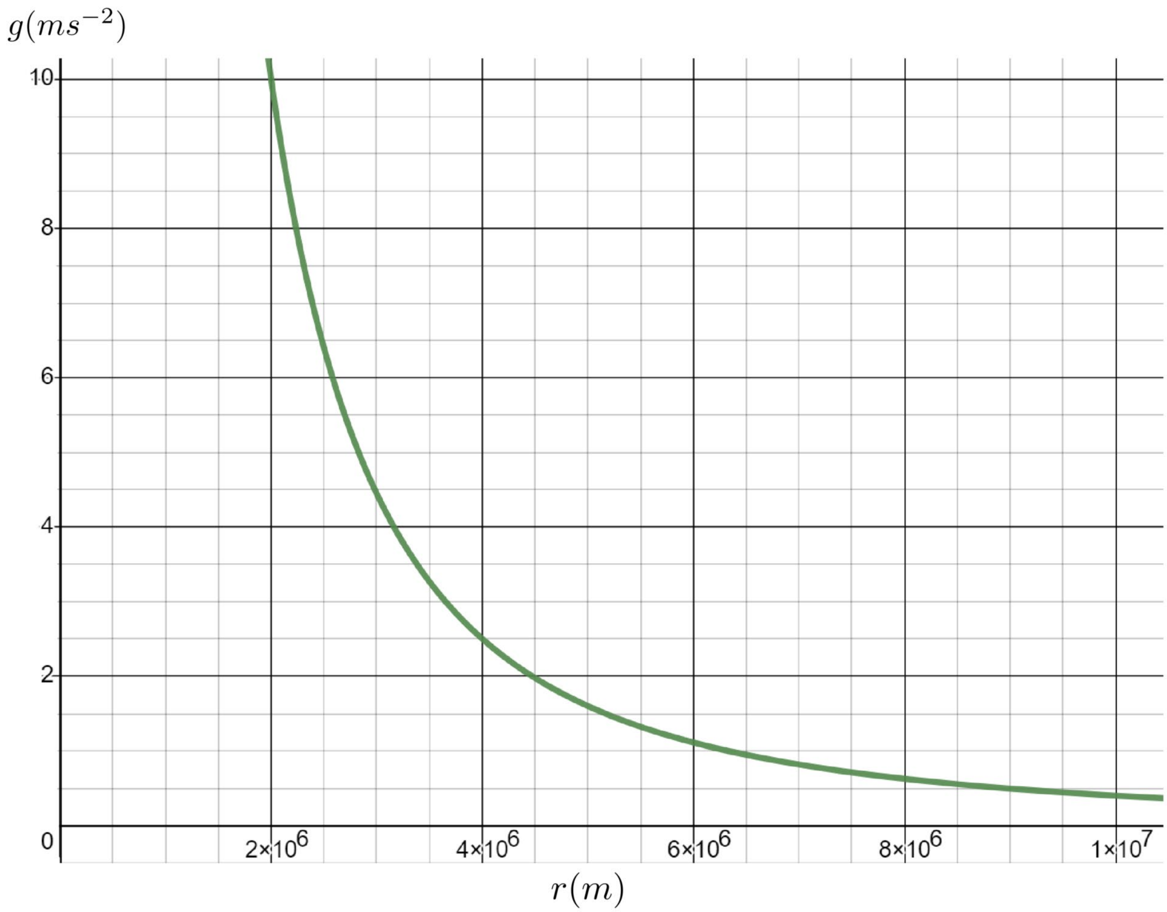
Person X switches on a light. The flash is then detected by a sensor on the spacecraft as shown.



Which of the following is correct when comparing the time taken for the pulse to reach the sensor according to observers X, Y and Z?

	Time measured by Z	*Time measured by Y*
A.	Less than X	Less than X
B.	More than X	Less than X
C.	More than X	More than X
D.	Less than X	More than X

13 The graph below shows gravitational field strength as a function of distance from the centre of Mars.



Using information on the graph, determine which of the following is closest to the mass of Mars.

A. 6×10^{16} kg

B. 3×10^{17} kg

C. 6×10^{23} kg

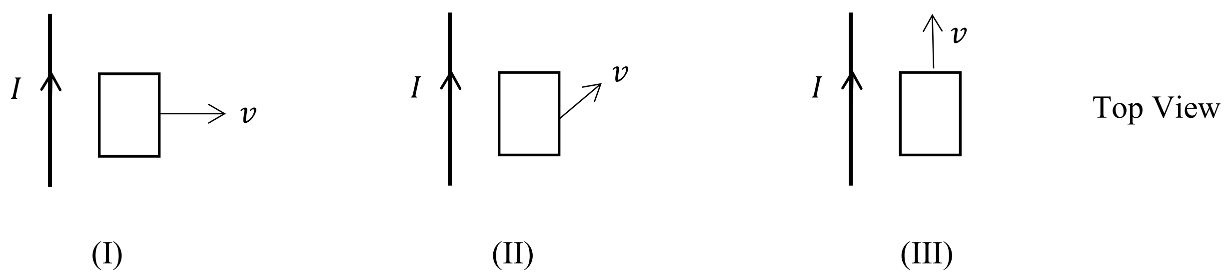
D. 3×10^{24} kg

14 An ideal transformer is used to convert 240 V AC to 12 V AC. A small electric motor draws a current of 2.0 A from the secondary coil of the transformer.

Which row of the table shows the correct number of turns and current in the primary coil if the secondary coil has 50 turns?

	Number of turns	*Current (A)*
A.	500	0.1
B.	1000	0.1
C.	500	0.2
D.	1000	0.2

15 A very long straight wire carries a DC current I. A rectangular metallic wire loop moves with velocity v in the same plane of the wire, as shown in the diagram below.



In which cases will the coil experience an induced current?

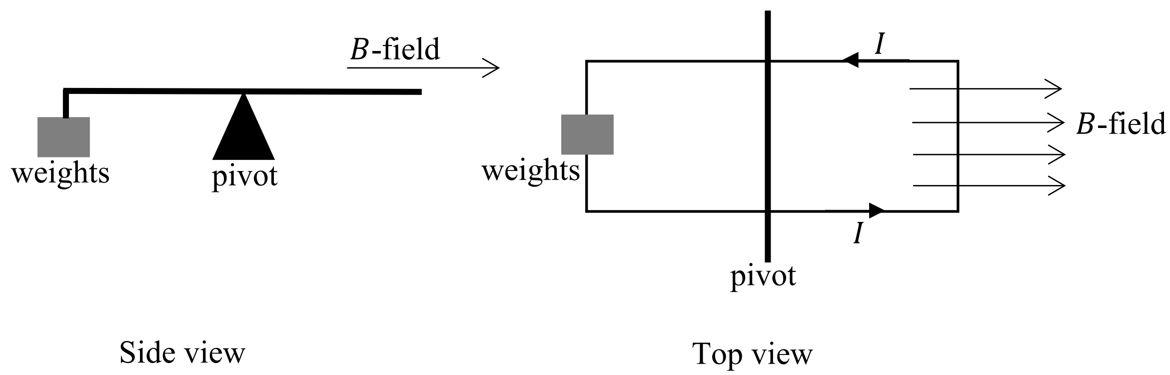
A. I and II

B. I and III

C. II and III

D. I, II and III

16 A simple model of a current balance is assembled as shown in the diagram below:



When current I, flows through the setup, the wire frame is balanced.

If the strength of the magnetic field B is halved, which of the following changes to the setup could ensure that the wire frame remains balanced?

A. doubling the mass of the weights

B. reversing the direction of the current

C. shifting the pivot in the direction of the weights

D. reducing the magnitude of the current I, by half

17 A 1000 kg satellite is to be moved from a circular Low-Earth orbit with a radius of 6800 km to a geostationary orbit at a radius of 42 000 km.

What is the minimum energy that must be supplied to insert the satellite into the new orbit?

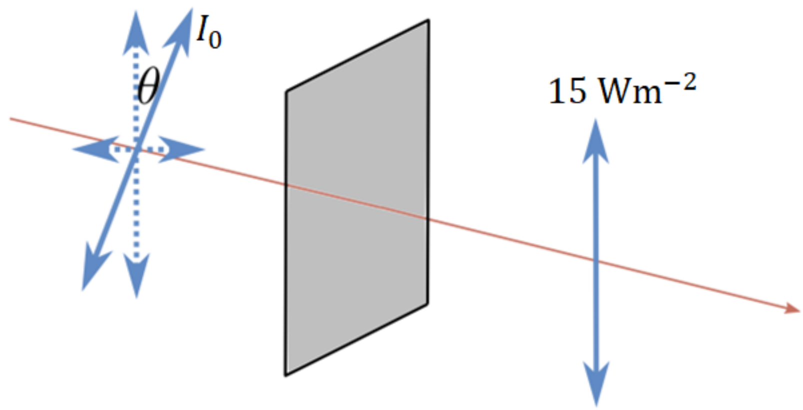
A. 2.5×10^{10} J

B. 4.9×10^{10} J

C. 2.5×10^{13} J

D. 4.9×10^{13} J

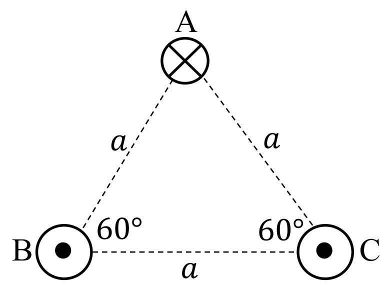
18 Light with an intensity I_0, which is polarised in a direction θ to the vertical, passes through a polarising filter with a vertical polarising axis.



Which row of the table shows a possible combination of I_0 and θ that could produce transmitted light with an intensity of $15\ \mathrm{Wm^{-2}}$?

	I_0 ($\mathrm{Wm^{-2}}$)	θ
A.	20	60^o
B.	20	30^o
C.	30	60^o
D.	30	30^o

19 The arrangement shown consists of 3 parallel current-carrying wires, A, B and C, placed perpendicular to the plane of the paper and equidistant apart.



The conductors are a meters apart and carry equal currents, I.

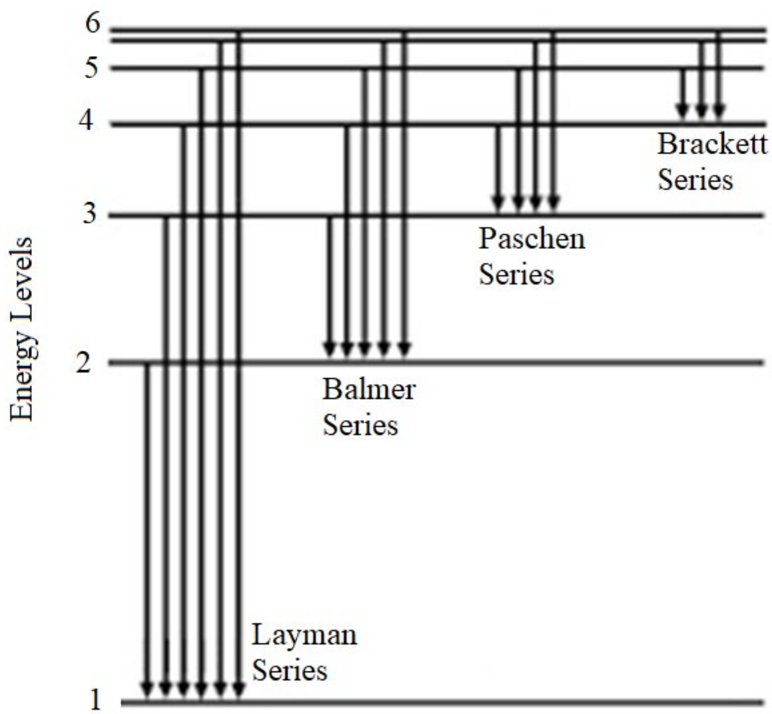
Which row of the table shows the correct magnitude and direction of the net force per unit length acting on wire A?

	magnitude	*direction*
A.	$\frac{\mu_0}{2\pi a} I^2$	upwards
B.	$\frac{\mu_0}{2\pi a} \sqrt{3}\, I^2$	upwards
C.	$\frac{\mu_0}{2\pi a} I^2$	downwards
D.	$\frac{\mu_0}{2\pi a} \sqrt{3}\, I^2$	downwards

20 The first four lines of the Balmer series for the hydrogen emission spectrum lie in the visible spectrum (400 – 700 nm). These involve transitions from higher states into the $n = 2$ state.

The Lyman series involves transitions from higher states into the $n = 1$ state, the Paschen series involves transitions from higher states into the $n = 3$ state and the Brackett series involves transitions from higher states into the $n = 4$ state.

Some of these transitions are shown below:



What is the wavelength of the shortest infra-red line in the hydrogen spectrum?

A. 91 nm

B. 820 nm

C. 1094 nm

D. 4051 nm

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Student Number

TRIAL HSC EXAMINATION 2022

Mark / 100

Physics

Multiple Choice Answer Sheet

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 ◯

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2022

Physics

Section II Answer Booklet

80 marks

Attempt Questions 21 – 36

Allow about 2 hours and 25 minutes for this part

Instructions

- Write your Student Number at the top of pages 15 and 39
- Answer the questions in the spaces provided. These spaces provide guidance for the expected length of response.
- Show all relevant working in questions involving calculations
- Extra writing space is provided at the back of this booklet. If you use this space, clearly indicate which questions you are answering.

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Question 21 (2 marks)

Einstein's two postulates of special relativity are: **2**

- the speed of light in a vacuum is an absolute constant
- all inertial frames of reference are equivalent

Outline the experimental evidence supporting ONE of the postulates.

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Question 22 (3 marks)

According to an observer on Earth, a star is located a distance of 10 light years away.
An astronaut travels from Earth to the star at a constant speed of 0.8c.

(a) Determine the time taken for the trip in the reference frame of an observer on Earth. **1**

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(b) Determine the time taken for the trip in the reference frame of the astronaut. **2**

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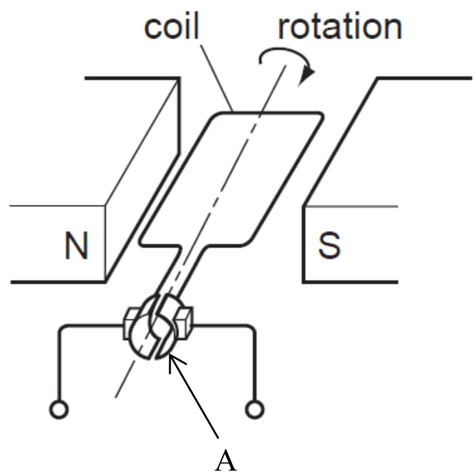
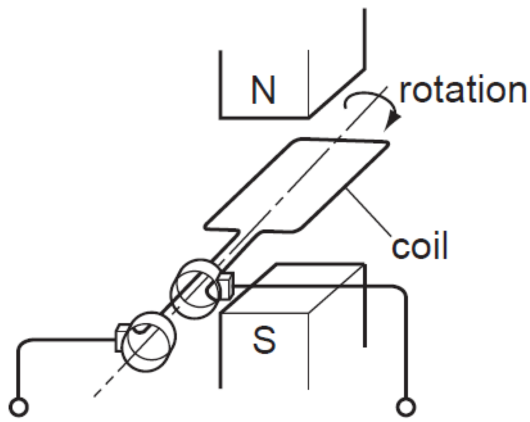
Question 23 (4 Marks)

Two devices that convert energy to other forms of energy are the DC generator and the AC generator.

DC generator



AC generator



(a) Describe the energy transformations that occur in the AC generator. **1**

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(b) By identifying the component labelled A, describe how the DC generator is able to perform its function. **3**

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Question 24 (3 marks)

Explain how a star's spectrum can be used to indicate whether the star is rotating. **3**

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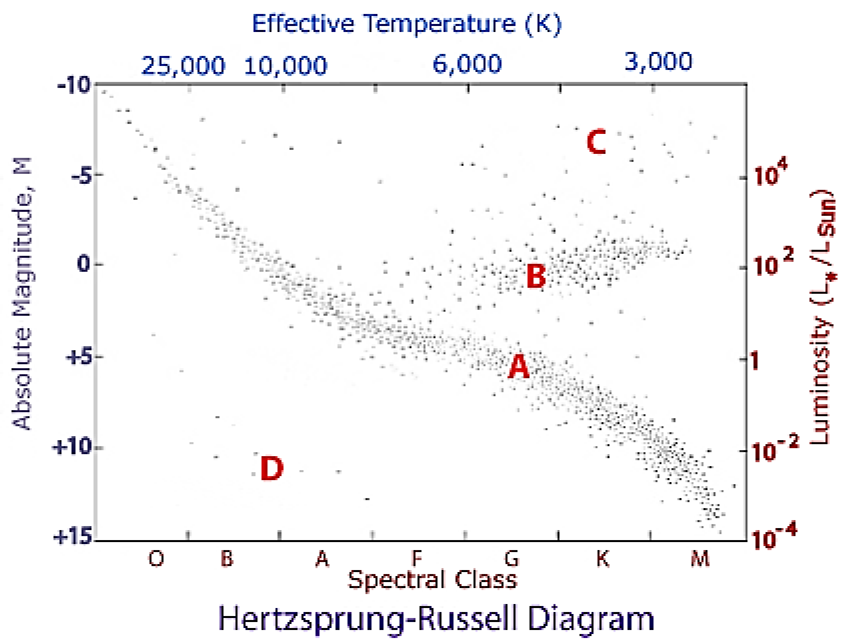
Question 25 (5 marks)

Consider the following Hertzsprung-Russell diagram with stars A, B, C and D.



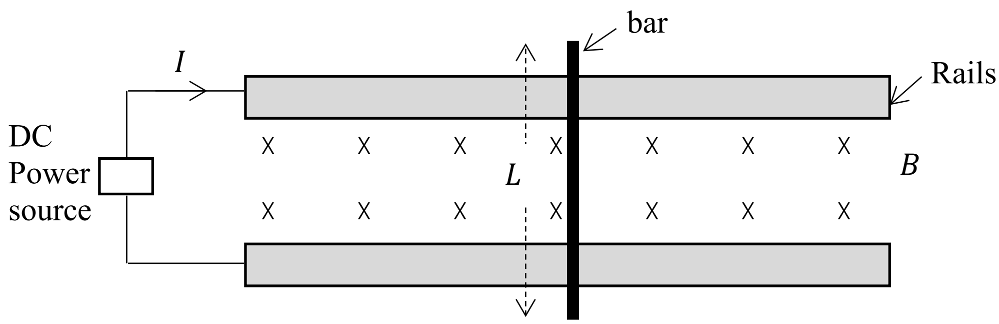
(a) Complete the following table: **4**

Star	*Evolutionary stage of star*	*Fusion process(es) occurring inside star (if any)*
A		
B		
C		
D		

(b) Annotate the diagram to show the expected evolutionary sequence for our Sun. **1**

Question 26 (3 marks)

A conducting bar with mass m, length L, is at rest on two horizontal conducting rails. **3**
A uniform magnetic field B perpendicular to the rails fills the region between it.



When the rails are connected to a DC power source which maintains the current at a constant I, the bar experiences a force F due to the motor effect.

Ignore the friction between the rails and the bar.

Show that the speed attained by the bar is $v = \sqrt{\frac{2B\,L\,I\,d}{m}}$, where d is the horizontal distance travelled by the bar.

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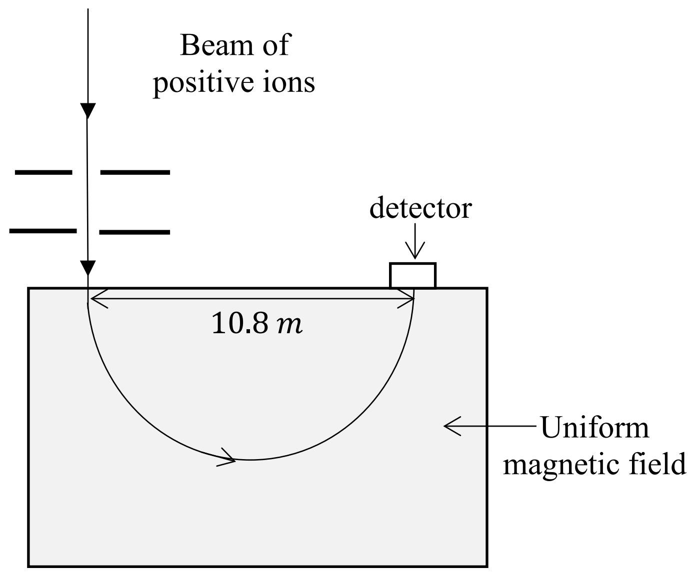
Question 27 (5 Marks)

A beam of singly charged positive ions in vacuum enters a region of uniform magnetic field strength B, where it undergoes anticlockwise deflection in a semicircular arc as shown in the diagram below.



The ions travelling with speed $1.20 \times 10^5\ m\ s^{-1}$, are detected by a fixed detector when the diameter of the arc is $10.8\ m$.

(a) If the ions have a mass of $20\ u$, calculate the strength of the magnetic field. **2**

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Question 27 continues on page 25

Question 27 (continued)

(b) Ions with heavier mass and same charge are also present in the beam. **1**
Sketch qualitatively the path of these ions in the same region of magnetic field.

(c) Explain the adjustment that needs to be made to the magnetic field to enable the heavier ions with the same speed to reach the detector. **2**

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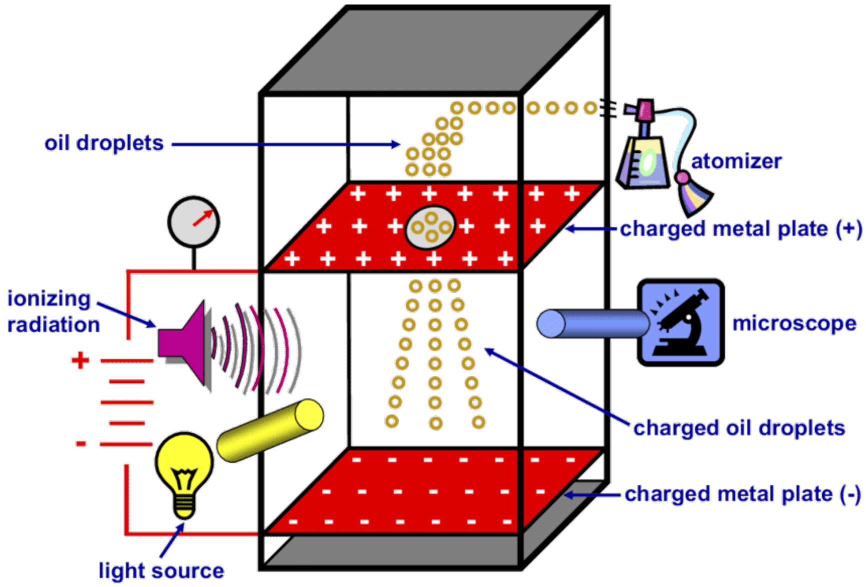
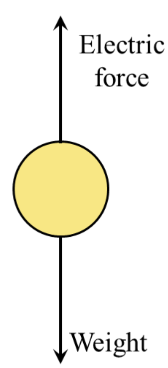
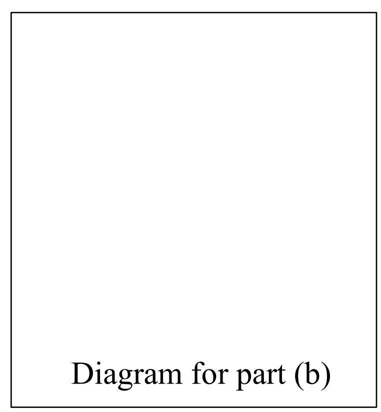
Question 28 (4 marks)

An experiment was carried out to model the Millikan oil-drop experiment.



An oil drop was selected for viewing through the microscope and the size of the applied voltage altered until the oil drop was stationary. The forces on the drop at this point can be represented in the following free-body diagram:





Question 28 continues on page 27

Question 28 (continued)

(a) The top plate was $5085\ \text{V}$ higher than the bottom plate, with a separation of $16\ \text{mm}$. The mass of the oil drop was 8.8×10^{-11} g. **3**

Calculate the number of excess electrons on this oil drop.

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(b) The mass of the drop was estimated with the voltage source off, which resulted in the oil drops falling downwards at constant speed. **1**

Draw a free body diagram for an oil drop next to the free body diagram shown earlier, using the same scale.

End of Question 28

Please turn over

Question 29 (4 marks)

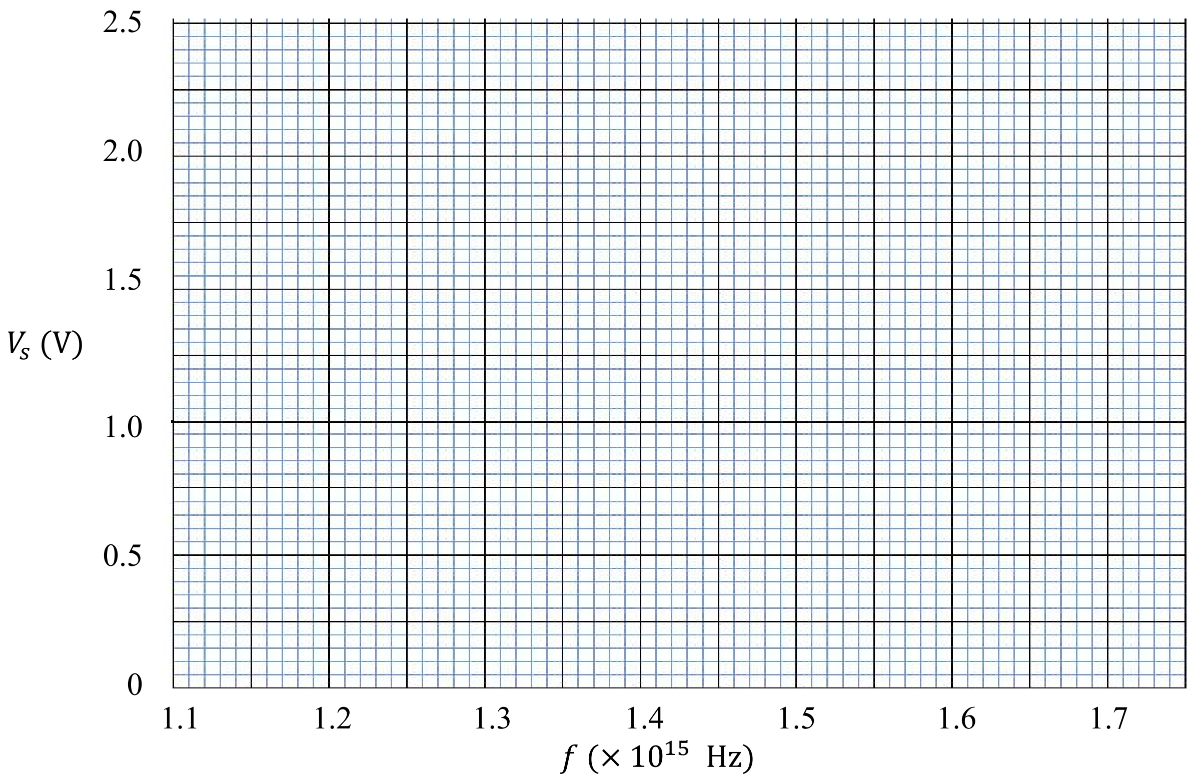
A student performed a photoelectric experiment in which he exposed an unidentified metal to various frequencies of incident electromagnetic radiation, f, and measured the stopping voltage, V_s, of the emitted photoelectrons. The results are shown in the table below. **4**

f ($\times 10^{15}$ Hz)	1.3	1.4	1.5	1.6	1.7
V_s (V)	0.6	1.1	1.5	1.9	2.4

By analysing the data graphically, and using the work functions of some metals given in the table below, identify the unknown metal used by the student.

Support your answer with relevant calculations.

Metal	Sodium	Cobalt	Lead	Zinc	Iron	Silver	Platinum
Work function (eV)	2.28	3.90	4.14	4.31	4.50	4.79	6.35



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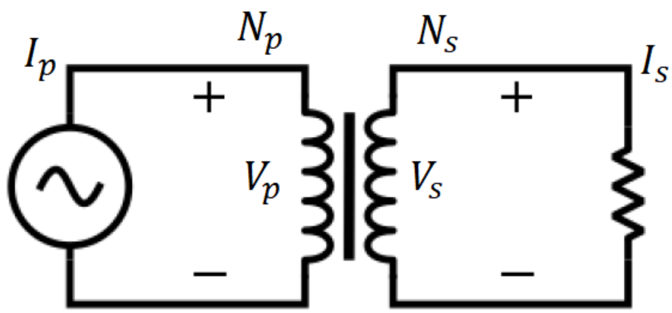
Question 30 (4 marks)

The ideal transformer is a device capable of changing the voltage and current characteristics of an AC power supply without dissipating any energy according to the following model.

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

$$V_p I_p = V_s I_s$$



(a) Identify two limitations of the ideal transformer model when applied to real transformers. **2**

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(b) Outline qualitatively two strategies used to improve transformer efficiency. **2**

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Question 31 (8 marks)

A coracle is a very small, light boat that can be used for fishing. It floats high so that it barely disturbs the water.

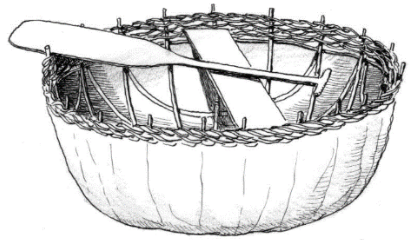

Figure A (left): An example of a coracle.

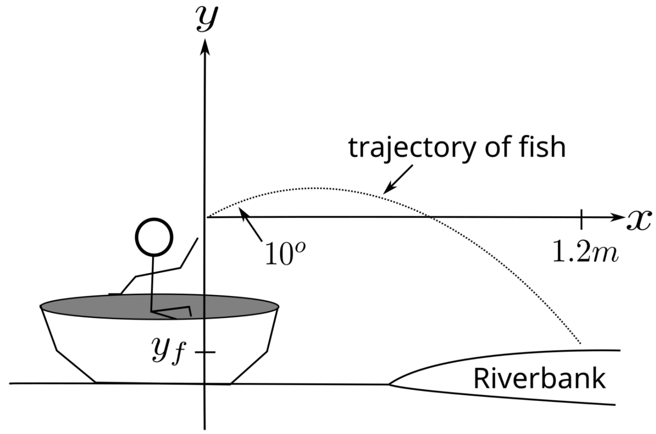

Figure B (right): Trajectory of the fish.

A child of mass 30.0 kg sits in a coracle of mass 10.0 kg on the water at rest. The child throws a fish of mass 5.0 kg onto the riverbank. The fish leaves their hand with at a speed of 5.0 ms^{-1} at an angle of 10° above the horizontal.

(a) Determine the initial vertical component of the velocity of the fish. **2**

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Question 31 continues on page 31

Question 31 (continued)

(b) The fish lands a horizontal distance of 1.2 m from the child's hand. **3**

Determine the vertical displacement, y_f, of the fish from the point it left the child's hand to where it lands.

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(c) How fast are the boat and child moving horizontally after the throw? **3**

Identify any assumption/s you make in this calculation.

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End of Question 31

Please turn over

Question 32 (5 marks)

In your course you used a diffraction grating to observe spectra from discharge tubes.

(a) Identify the purpose of the diffraction grating in this investigation. **1**

The image below is a photograph of the visible spectra from a hydrogen discharge tube after it passes through a diffraction grating which has 300 lines per mm.

Central maxima **cyan 1** **red 1** **cyan 2** **red 2**

The central maxima (containing all colours of light from the discharge tube) is visible on the far left in the photo. The first and second order cyan spectral lines (both with $\lambda = 486$ nm), marked "cyan 1" and "cyan 2" are labelled above the spectrum. The first and second order red spectral lines (both with $\lambda = 656$ nm) are marked "red 1" and "red 2".

The angular separation between the cyan 1 line and the central maxima is $\theta_c = 8.4^o$.

(b) Find the angular separation θ_r between the red 1 line and the central maxima. **2**

Question 32 continues on page 33

Question 32 (continued)

(c) Explain quantitatively why the distance between the cyan 2 and red 2 lines on the photograph is double the distance between the cyan 1 and red 1 lines. **2**

You may assume $\sin\theta \approx \tan\theta \approx \theta$.

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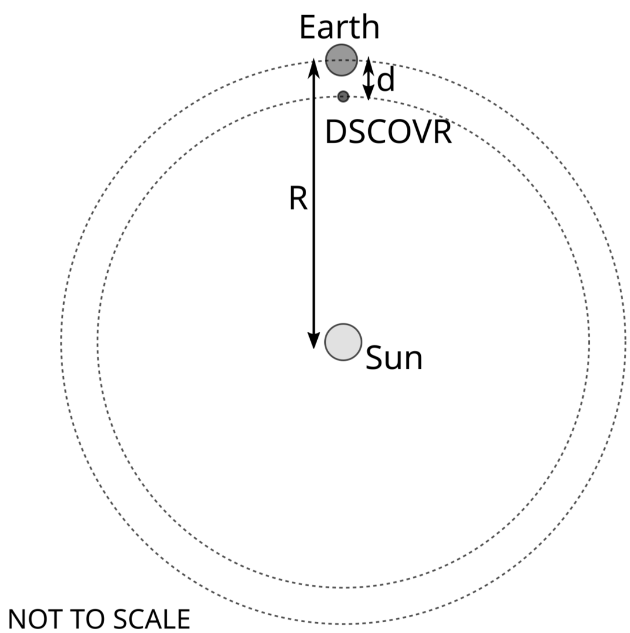
End of Question 32

Please turn over

Question 33 (5 marks)

The Deep Space Climate Observatory (DSCOVR), is a space probe that is located at a position where it orbits the Sun with the same period as the Earth, maintaining a fixed distance from the Earth and the Sun.



<u>Data</u>:

Mass of the DSCOVR:
$m = 570$ kg

Mass of the Sun:
$M_S = 2.0 \times 10^{30}$ kg

Period of the Earth's orbit:
$T_E = 3.16 \times 10^7$ s.

(a) Calculate the radius of the Earth's orbit, R. **2**

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Question 33 continues on page 35

Question 33 (continued)

(b) Identify the force/s acting on DSCOVR. **3**

Write down an equation which could be solved using the information provided to determine the distance d.

You do not need to solve this equation.

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End of Question 33

Please turn over

Question 34 (11 marks)

Cobalt-60 is an isotope that is used to treat some type of cancers. One of the products of the decay is a β-particle.

(a) Show that the rest mass of the β-particle is equivalent to 0.511 MeV. **1**

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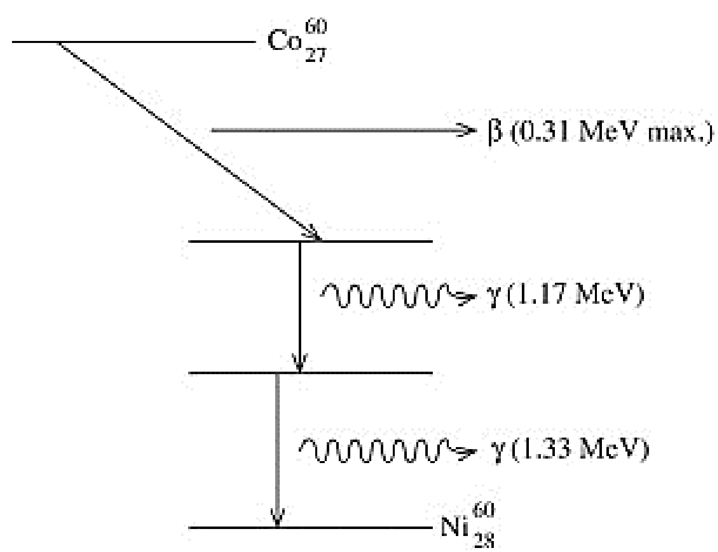
Cobalt-60 undergoes radioactive decay according to the following equation:

$$ {}^{60}_{27}Co \rightarrow {}^{60}_{28}Ni \; + \; {}^{0}_{-1}e + 2\,{}^{0}_{0}\gamma $$

This can be represented diagrammatically, as shown below:



producing stable nickel-60, a β-particle with a maximum 0.31 MeV kinetic energy, two γ photons and an antineutrino (not shown). The γ photons are responsible for killing rapidly dividing cells, specifically the tumour cells.

Question 34 continues on page 37

Question 34 (continued)

(b) The mass of a cobalt-60 nucleus is $59.919015\ \text{u}$. Calculate the mass of the nickel-60 nucleus. **3**

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(c) Small pellets, about the size of a grain of rice, are injected into the tumour and left for a set period of time before being removed. **2**

The cobalt-60 pellets typically have an activity of $18.5\ \text{GBq}$ per pellet when fresh, where $1\text{Bq} = 1$ decay per second.

Each pellet can be used for many treatments, but they need to be replaced once the activity has decreased to $7.0\ \text{GBq}$ per pellet. The half-life for cobalt-60 is 5.27 years.

Assuming the activity is proportional to the amount of Cobalt-60 present, how frequently would the cobalt-60 pellets need to be replaced to maintain sufficient activity?

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Question 34 continues on page 38

Question 34 (continued)

(d) In one treatment regime, a fresh pellet is inserted into the tumour and removed after 10 minutes.

(i) Calculate the change in temperature of a 60 kg patient caused by the ejected particles. **3**

Assume:

- the specific heat capacity of the patient is 3.5×10^3 J kg^{-1} K^{-1}
- the activity remains constant during the 10 minutes.
- $1\ \text{GBq} = 10^9\ \text{Bq}$
- $Q = m\, c\, \Delta T$

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(ii) Identify TWO other significant physical assumptions that you made in your calculation above. **2**

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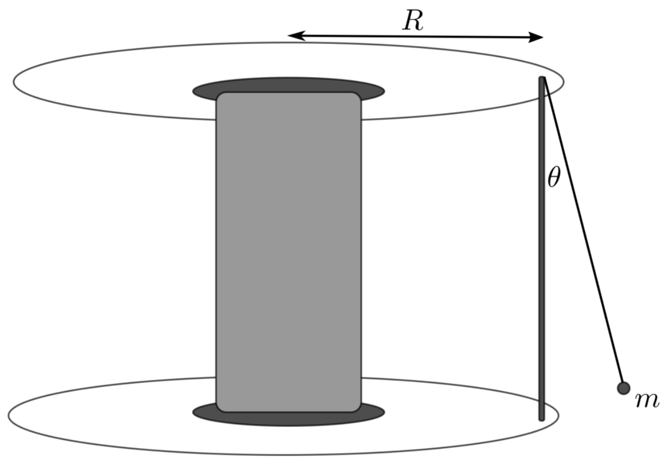
End of Question 34

Please turn over

Student Number:

Question 35 (5 marks)

A carousel (below, left) is a children's ride that rotates at a constant angular velocity. A mass m is attached by a string to one of the vertical bars at a distance R from the center of the carousel (below, right). The mass hangs at an angle θ when the ride is rotating with a constant angular velocity of ω.



a) Draw a free body diagram showing the forces acting on the mass, to scale. Indicate the net force with a dotted arrow. **2**

b) Explain, qualitatively and quantitatively, how the angle θ would change if the string was attached to a pole at a distance $\frac{1}{2}R$ from the center of the carousel while it is still rotating at the same constant angular velocity ω. You may assume the angle θ is small. **3**

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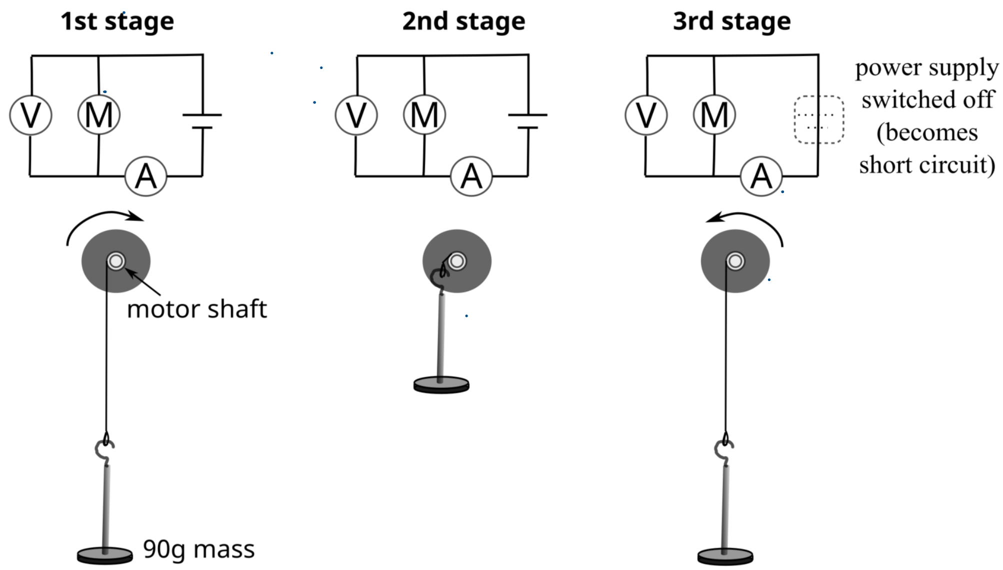
Question 36 (9 Marks)

A 90 g mass is attached via a light string to the shaft of a DC motor.
An investigation is performed consisting of three stages:

Stage 1: The power supply is switched on and the mass moves up.
Stage 2: The string is fully wound up and the shaft is stationary.
Stage 3: The power supply is switched off and the mass moves down.



The vertical velocity of the mass during each stage is measured using video analysis and is shown below.

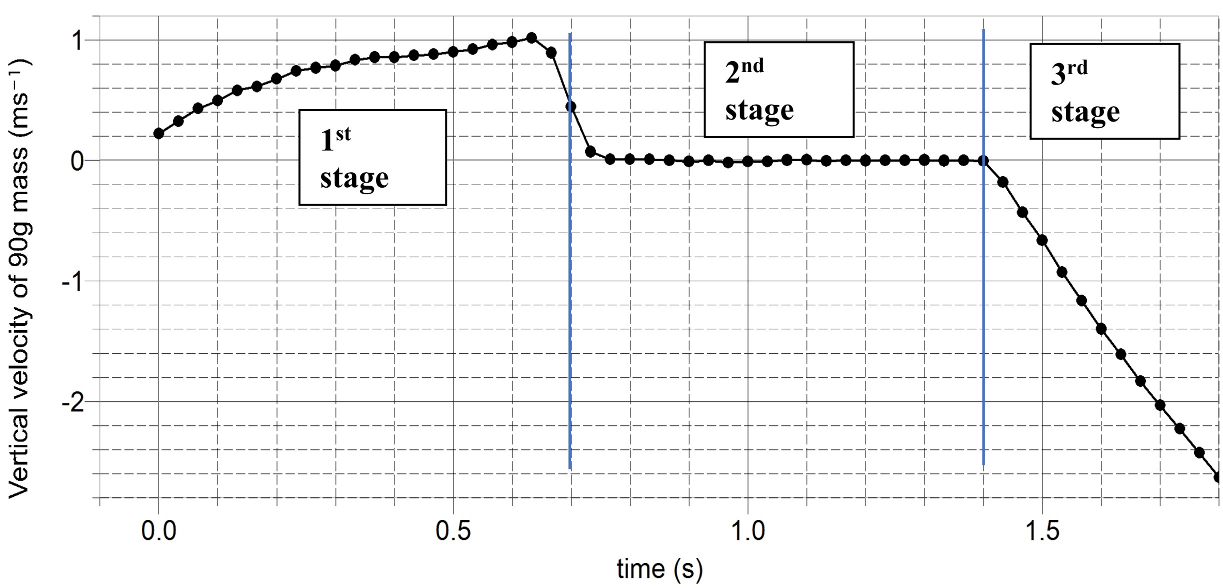


Figure 1: Vertical velocity of 90 g mass versus time

Question 36 continues on page 41

The current through the motor and the potential difference (voltage) across the motor were also measured during each stage and are shown below.

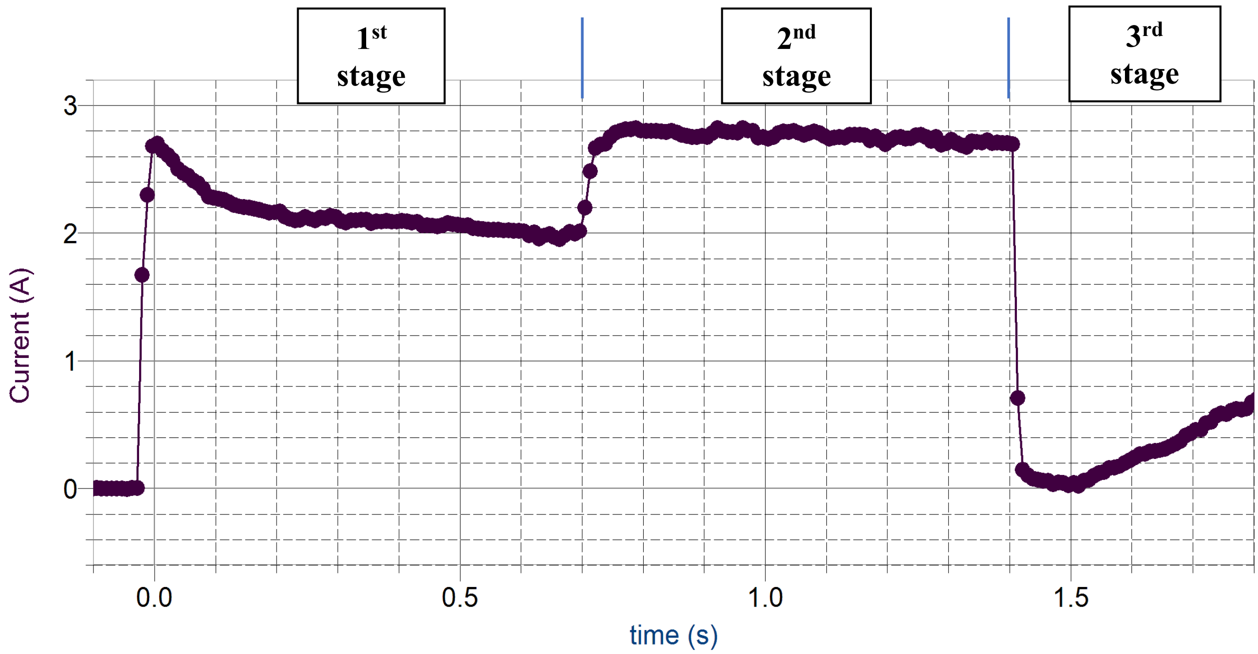


Figure 2: Current versus time

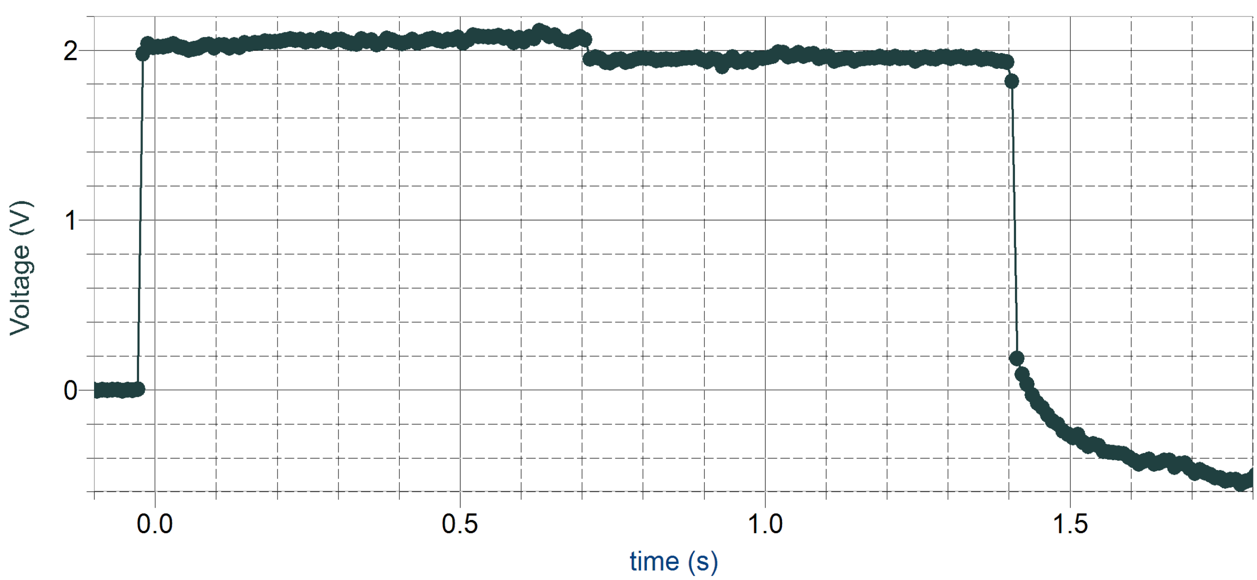


Figure 3: Potential difference versus time

Question 36 continues on page 42

Question 36 (continued)

Analyse the physics involved, and as well as how the law of conservation of energy applies to the system consisting of the 90 g mass and the motor during each of the three stages of the investigation. **9**

Your analysis should include both qualitative and quantitative information.

END OF PAPER

Section II extra writing space

If you use this space, clearly indicate which question you are answering.

JAMES RUSE AGRICULTURAL HIGH SCHOOL

2022

TRIAL HIGHER SCHOOL CERTIFICATE EXAMINATION

Physics

General Instructions	• Reading time – 5 minutes • Working time – 3 hours • Write using black pen • Draw diagrams using pencil • Calculators approved by NESA may be used • A data sheet, formulae sheet and Periodic Table are provided
Total marks: 100	**Section I – 20 marks** (pages 2–13) • Attempt Questions 1–20 • Allow about 35 minutes for this section **Section II – 80 marks** (pages 19–42) • Attempt Questions 21–36 • Allow about 2 hours and 25 minutes for this section

Please Turn over

Section I

20 marks
Attempt Questions 1–20
Allow about 35 minutes for this section
Use the multiple-choice answer sheet for Questions 1–20.

---

1 Which of the following statements about nuclear radiation is true?

A. Alpha particles are deflected most by a magnetic field, then beta, then gamma.

B. Alpha particles are deflected most by an electric field, then beta, then gamma.

C. Alpha particles have the highest penetrating power, then beta, then gamma.

D. Alpha particles have the highest ionising ability, then beta, then gamma.

2 The electromagnetic radiation emitted by a blackbody peaks at a wavelength of 345 nm.

What is the temperature of the blackbody?

A. 8.40×10^{-6} K

B. 8.40×10^{-3} K

C. 8.40×10^{3} K

D. 8.40×10^{6} K

3 According to Maxwell's classical theory on electromagnetism, which of the following statements is incorrect?

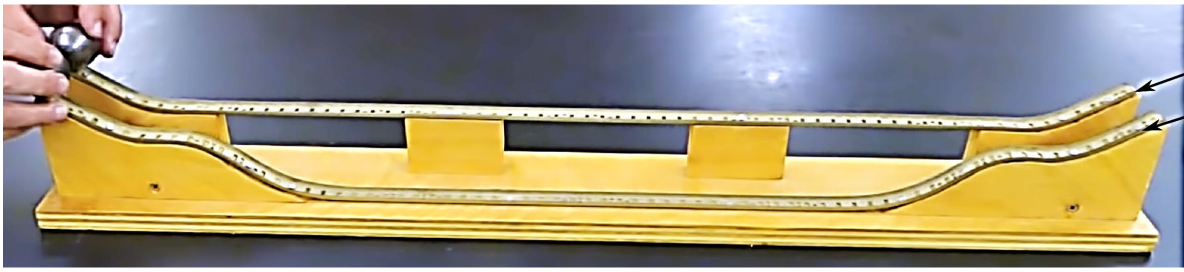
A. An oscillating electric field induces an oscillating magnetic field.

B. An oscillating magnetic field induces an oscillating electric field.

C. Electric and magnetic fields oscillate out of phase with each other.

D. Electromagnetic waves consist of electric and magnetic fields oscillating at right angles to each other.

4 Two balls are released simultaneously from the same vertical position on two tracks which have the same start and end height. Track A is mostly straight, while Track B first curves down and then back upwards by the same amount, as shown below. Rolling resistance can be assumed to be negligible.



Which ball reaches the end of the track first?

A. The balls on Track A and Track B reach the end at the same time.

B. The ball on Track A arrives first.

C. The ball on Track B arrives first.

D. It is not possible to determine the answer without knowing the detailed shape of each track.

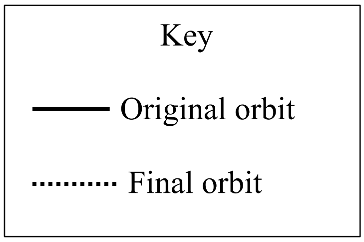
5 When monochromatic light, above a threshold frequency, is incident on a metallic surface, electrons are emitted from the surface.

Which changes will result in electrons of greater kinetic energy being emitted from the surface?

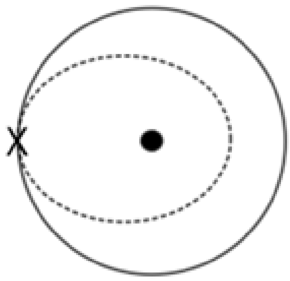
	Frequency of incident light	*Intensity of incident light*	*Work function of metal*
A.	decrease	increase	decrease
B.	increase	increase	decrease
C.	decrease	decrease	increase
D.	increase	decrease	increase

6 A satellite in a circular orbit at position X (shown as a solid line) fires its thrusters briefly, once. This has the effect of reducing its orbital speed.

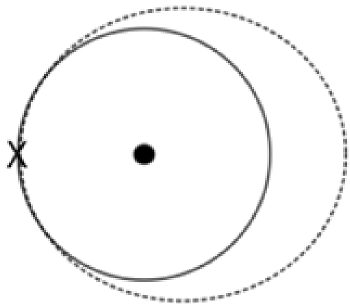
Which of the following shows a possible final orbit for the satellite?



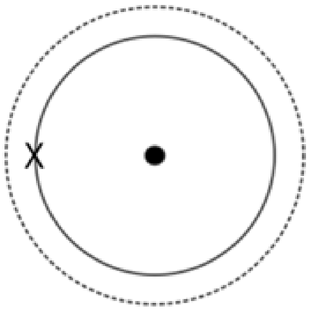
A.



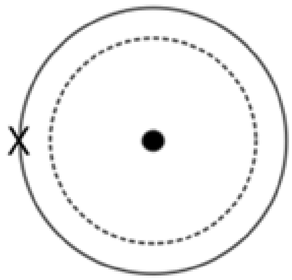
B.



C.



D.



7 What is the wavelength of an electron travelling at 0.01 c?

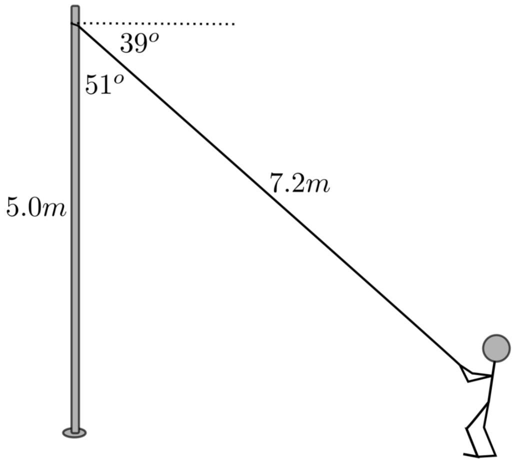
A. 7.3×10^{-2} m

B. 2.4×10^{-10} m

C. 1.3×10^{-13} m

D. 1.4×10^{-21} m

8 A person pulls on a rope attached to the top of a flagpole with a tension force of 350 N.



What is the magnitude of the torque the person exerts on the flagpole, which is attached to the ground at its base?

A. $\tau = 7.2 \times 350 \sin 39°$ Nm

B. $\tau = 5.0 \times 350 \sin 39°$ Nm

C. $\tau = 7.2 \times 350 \sin 51°$ Nm

D. $\tau = 5.0 \times 350 \sin 51°$ Nm

9 Consider the following two statements:

Statement A:

In the Schrodinger model of the atom, the wavefunction can be used to compute the probability of finding the electron at a particular position.

Statement B:

Modelling electrons as standing matter waves according to de Broglie's hypothesis is consistent with the postulates of Bohr's model.

Which of the above statements is correct?

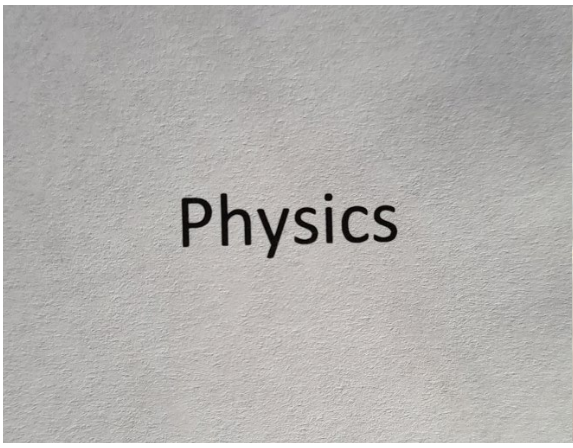
A. Statement A only.

B. Statement B only.

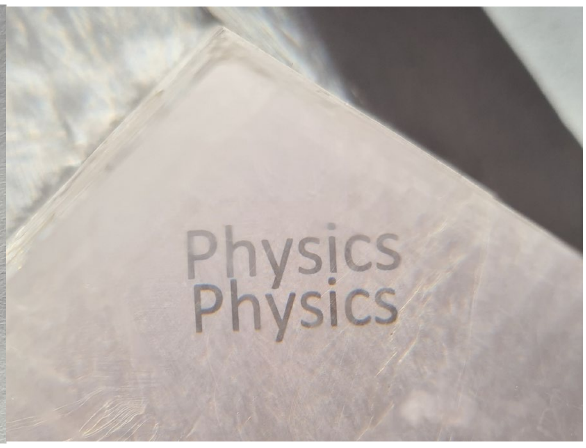
C. Both statement A and statement B.

D. Neither statement A nor statement B.

10 Calcite is a crystal which produces two images of an object when viewed from above. This phenomenon (double refraction) occurs because calcite has a different refractive index for different polarisations of light.



No calcite



With calcite

Double refraction in calcite played an important role in the debate between Newton and Huygens over the nature of light. Newton explained it by hypothesizing that light particles had "sides" and the two types of light particles were separated by the crystal. Huygens, who assumed light was a wave like sound, was unable to explain this phenomenon with his model.

Newton could also explain colour in his model by proposing that different colours corresonded to different sized partices, whereas Huygen's original model had no explanation for colour.

How did the wave model of light change from Huygens' original model so that it could successfully explain the phenomena of polarisation and colour?

	Type of wave in new model	*Origin of colour in new model*
A.	Longitudinal	Wavelength
B.	Transverse	Wavelength
C.	Longitudinal	Amplitude
D.	Transverse	Amplitude

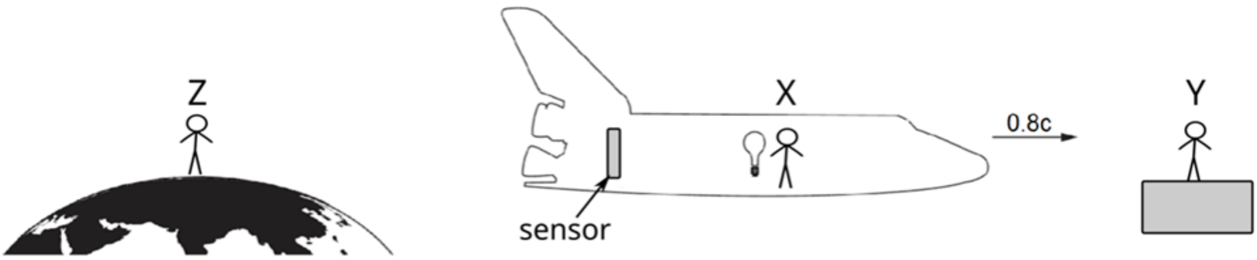
11 A student set up Crookes tubes to investigate the nature of cathode rays.

Which of the following matches the contents of the tube with the conclusion made in Crookes' time about the nature of cathode rays?

	Contents of Crookes tube	*Conclusion*
A.	Paddle wheel	Cathode rays have a high velocity.
B.	Maltese Cross	Cathode rays reflect according to law of reflection.
C.	Paddle wheel	Cathode rays have momentum.
D.	Maltese Cross	Cathode rays can diffract.

12 A person (X) on a spacecraft is flying at a speed of 0.8c directly away from Earth towards a space port. An observer (Y) located on the spaceport is at rest with respect to an observer (Z) on Earth.

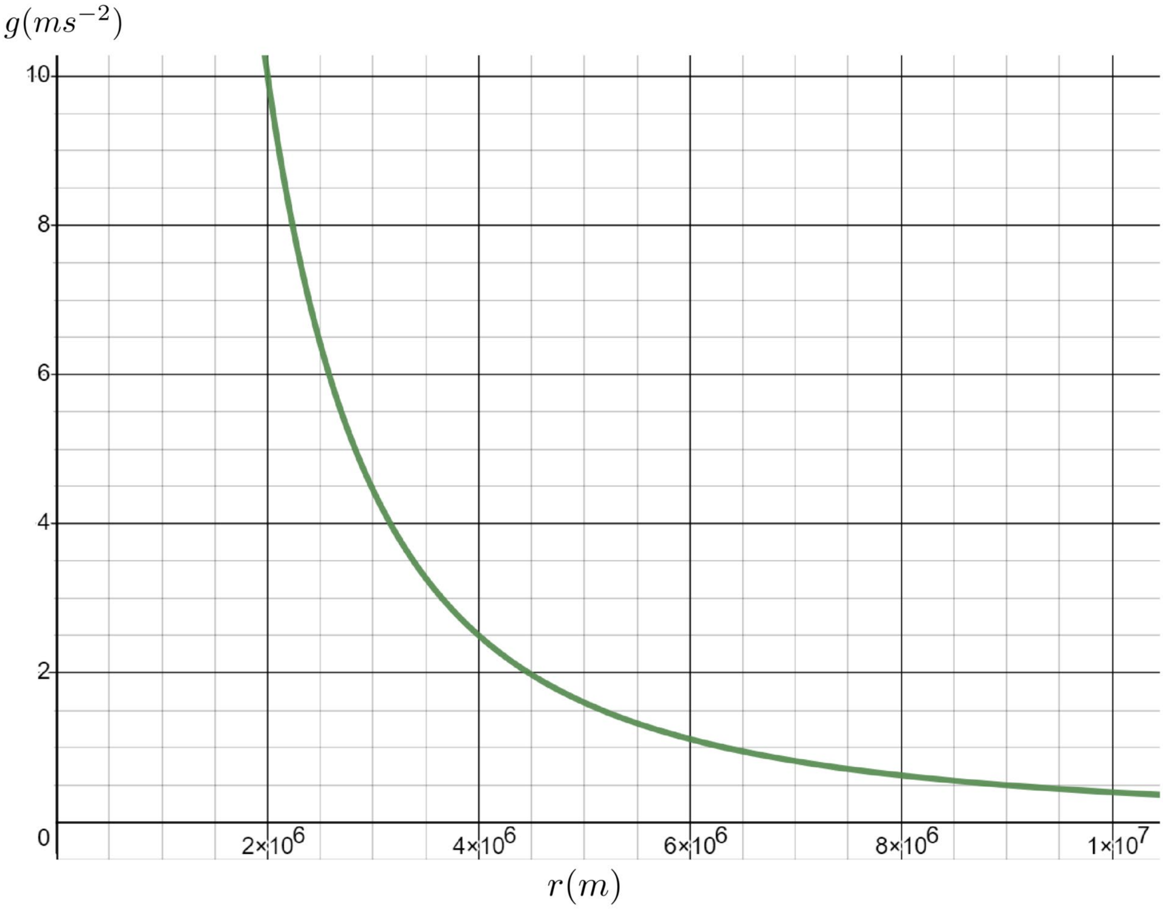
Person X switches on a light. The flash is then detected by a sensor on the spacecraft as shown.



Which of the following is correct when comparing the time taken for the pulse to reach the sensor according to observers X, Y and Z?

	Time measured by Z	*Time measured by Y*
A.	Less than X	Less than X
B.	More than X	Less than X
C.	More than X	More than X
D.	Less than X	More than X

13 The graph below shows gravitational field strength as a function of distance from the centre of Mars.



Using information on the graph, determine which of the following is closest to the mass of Mars.

A. 6×10^{16} kg

B. 3×10^{17} kg

C. 6×10^{23} kg

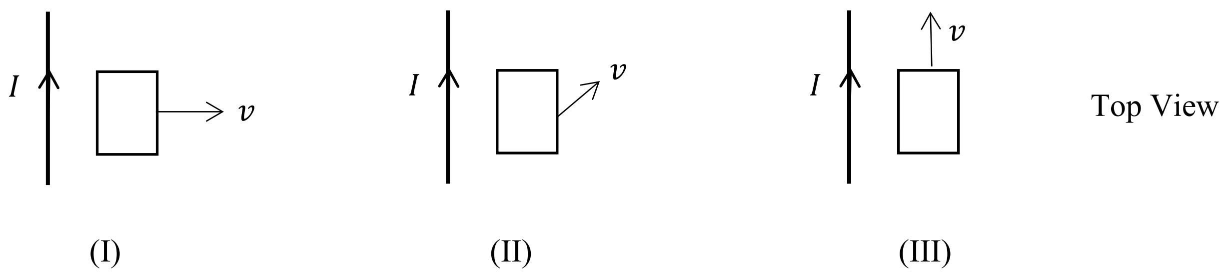
D. 3×10^{24} kg

14 An ideal transformer is used to convert 240 V AC to 12 V AC. A small electric motor draws a current of 2.0 A from the secondary coil of the transformer.

Which row of the table shows the correct number of turns and current in the primary coil if the secondary coil has 50 turns?

	Number of turns	*Current (A)*
A.	500	0.1
B.	1000	0.1
C.	500	0.2
D.	1000	0.2

15 A very long straight wire carries a DC current I. A rectangular metallic wire loop moves with velocity v in the same plane of the wire, as shown in the diagram below.



In which cases will the coil experience an induced current?

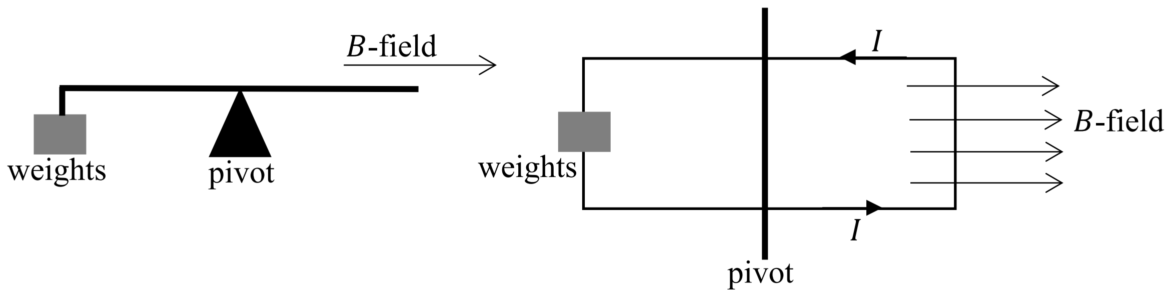
A. I and II

B. I and III

C. II and III

D. I, II and III

16 A simple model of a current balance is assembled as shown in the diagram below:



Side view Top view

When current I, flows through the setup, the wire frame is balanced.

If the strength of the magnetic field B is halved, which of the following changes to the setup could ensure that the wire frame remains balanced?

A. doubling the mass of the weights

B. reversing the direction of the current

C. shifting the pivot in the direction of the weights

D. reducing the magnitude of the current I, by half

17 A 1000 kg satellite is to be moved from a circular Low-Earth orbit with a radius of 6800 km to a geostationary orbit at a radius of 42 000 km.

What is the minimum energy that must be supplied to insert the satellite into the new orbit?

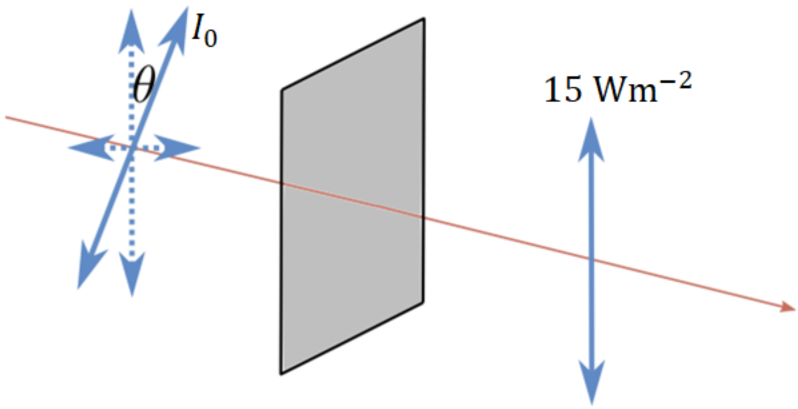
A. 2.5×10^{10} J

B. 4.9×10^{10} J

C. 2.5×10^{13} J

D. 4.9×10^{13} J

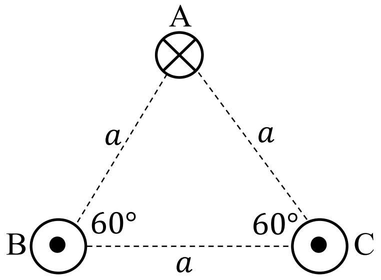
18 Light with an intensity I_0, which is polarised in a direction θ to the vertical, passes through a polarising filter with a vertical polarising axis.



Which row of the table shows a possible combination of I_0 and θ that could produce transmitted light with an intensity of 15 Wm^{-2}?

	I_0 (Wm^{-2})	θ
A.	20	60^o
B.	20	30^o
C.	30	60^o
D.	30	30^o

19 The arrangement shown consists of 3 parallel current-carrying wires, A, B and C, placed perpendicular to the plane of the paper and equidistant apart.



The conductors are a meters apart and carry equal currents, I.

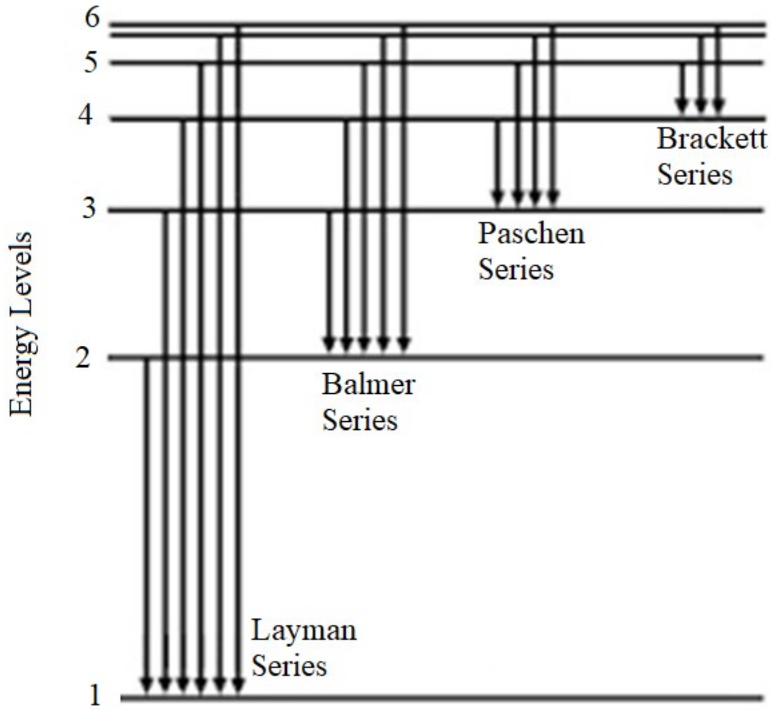
Which row of the table shows the correct magnitude and direction of the net force per unit length acting on wire A?

	magnitude	*direction*
A.	$\frac{\mu_0}{2\pi a} I^2$	upwards
B.	$\frac{\mu_0}{2\pi a} \sqrt{3}\, I^2$	upwards
C.	$\frac{\mu_0}{2\pi a} I^2$	downwards
D.	$\frac{\mu_0}{2\pi a} \sqrt{3}\, I^2$	downwards

20 The first four lines of the Balmer series for the hydrogen emission spectrum lie in the visible spectrum (400 – 700 nm). These involve transitions from higher states into the $n = 2$ state.

The Lyman series involves transitions from higher states into the $n = 1$ state, the Paschen series involves transitions from higher states into the $n = 3$ state and the Brackett series involves transitions from higher states into the $n = 4$ state.

Some of these transitions are shown below:



What is the wavelength of the shortest infra-red line in the hydrogen spectrum?

A. 91 nm

B. 820 nm

C. 1094 nm

D. 4051 nm

Student Number

TRIAL HSC EXAMINATION 2022

Mark / 100

Physics

Multiple Choice Answer Sheet

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

JAMES RUSE AGRICULTURAL HIGH SCHOOL
2022

Physics

Section II Answer Booklet

80 marks

Attempt Questions 21 – 36

Allow about 2 hours and 25 minutes for this part

Instructions

- Write your Student Number at the top of pages 15 and 39
- Answer the questions in the spaces provided. These spaces provide guidance for the expected length of response.
- Show all relevant working in questions involving calculations
- Extra writing space is provided at the back of this booklet. If you use this space, clearly indicate which questions you are answering.

Question 21 (2 marks)

Einstein's two postulates of special relativity are: **2**

- the speed of light in a vacuum is an absolute constant
- all inertial frames of reference are equivalent

Outline the experimental evidence supporting ONE of the postulates.

Criteria	Marks
Names and briefly describes experimental evidence supporting one of the postulates	2
Names a relevant piece of experimental evidence for one of the postulates	1

Evidence supporting the constancy of the speed of light:

Michelson-Morley experiment: Used perpendicular beams of light in an interferometer to demonstrate that the speed of light did not depend on whether the light was moving in the same direction as the earth's motion, or perpendicular to this.

Willem de Sitter: Used evidence from the spectra of binary stars to show that the speed of light did not depend upon the motion of the emitting body.

Evidence supporting the equivalence of inertial frames of reference:

Experiments in mechanics produce the same result in different initial reference frames. For example an object hanging on a string will hang straight down whether the object is at "rest" or moving with a constant velocity.

Experiments in electromagnetism produce the same results regardless of the reference frame in which they are performed. For example, pushing a magnet into a loop of wire connected to a galvanometer produces the same current as if the loop of wire is pushed towards the magnet at the same speed.

Question 22 (3 marks)

According to an observer on Earth, a star is located a distance of 10 light years away.
An astronaut travels from Earth to the star at a constant speed of 0.8c.

(a) Determine the time taken for the trip in the reference frame of an observer on Earth. **1**

Criteria	Marks
Applies v = d/t correctly.	1

The time taken for the trip in earth's reference frame is $t = \frac{d}{v} = \frac{10}{0.8} = 12.5$ years.

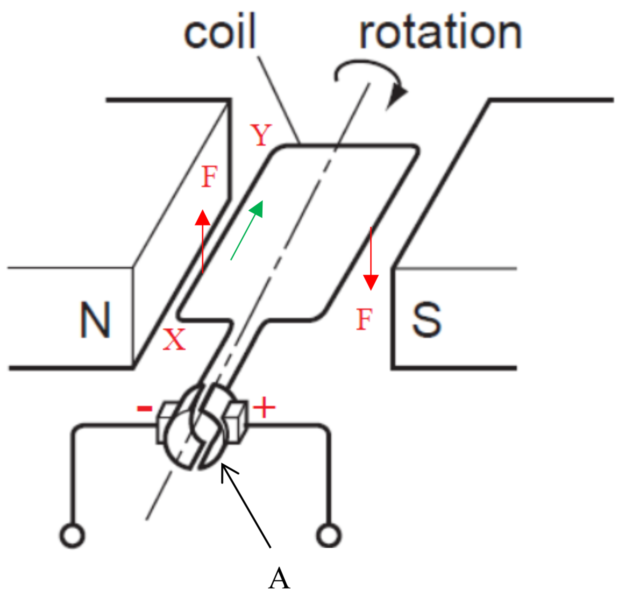
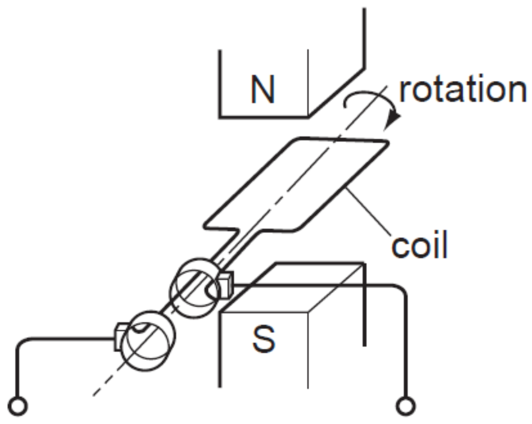
(b) Determine the time taken for the trip in the reference frame of the astronaut. **2**

Criteria	Marks
Correctly calculates the time taken for the trip in the astronaut's reference frame.	2
Substitutes into a correct equation (either the time-dilation or length contraction equation). May have t_0 and t_v (or l_o and l_v) reversed.	1

The time taken for the trip in the astronaut's reference frame is $t_0 = t_v\sqrt{1 - 0.8^2} = 12.5 \times 0.6 = 7.5$ years.

Question 23 (4 Marks)

Two devices that convert energy to other forms of energy are the DC generator and the AC generator.

DC generator	***AC generator***
	

(a) Describe the energy transformations that occur in the AC generator. **1**

Conversion of mechanical energy to electrical energy

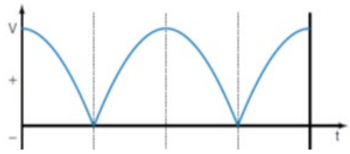
Comment: About 5% of candidature believed it was the other way around.

(b) By identifying the component labelled A, describe how the DC generator is able to perform its function. **3**

Criteria	Mark
Identifies the appropriate part and provides a good description of how the DC generator performs its function (Part A, its function and mentions fluctuating, unidirectional current/voltage (camel humps, external circuit) or shows graphically)	3
Identifies the appropriate part and provides a moderate description of how the DC generator performs its function (omits fluctuating unidirectional current/voltage)	2
Provides some relevant information	1

<u>DC generator</u>: By rotating the coil in an external magnetic field, the coil experiences a change in flux and by Faraday's law an emf is induced in the coil. The coil being part of a complete circuit, a current is induced in the internal circuit (from x to y), in accordance with Lenz's law. Half a turn later, the current should still be flowing from x to y which is in contravention of Lenz's law. With the force down here, the field from N to S, the induced current has to be from y to x to preserve Lenz's law. Thus part A, the split-ring commutator ensures for every half a turn the current in the internal circuit reverses its direction, while the brushes maintains its polarity all the time, producing unidirectional

current (DC) in the external circuit. This results in production of a DC voltage (steady state, constant, depending on the rotational speed, orientation of the coil and number of turns) as follows:



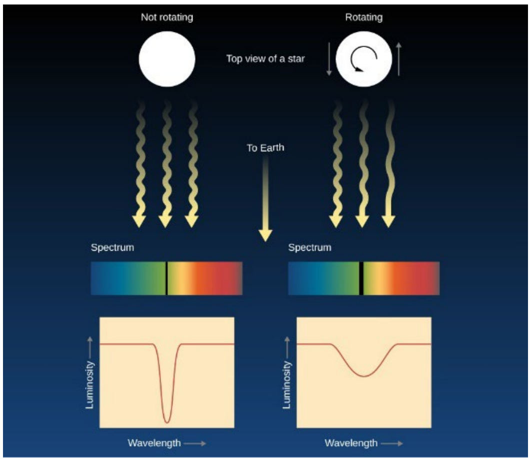
Comments:
This question was poorly done, clearly revealing the misconceptions students held. There appears to be general confusion between the DC motor and the DC generator. Furthermore no distinction was provided between the internal circuit where current reversal occurs and the external circuit where unidirectional current flows. This was an area where majority of students were penalised. Please be aware that for this single coil, the current (voltage) is fluctuating between max and zero, while in real generators with many coils, the current/voltage is constant (horizontal line)

Question 24 (3 marks)

Explain how a star's spectrum can be used to indicate whether the star is rotating. **3**

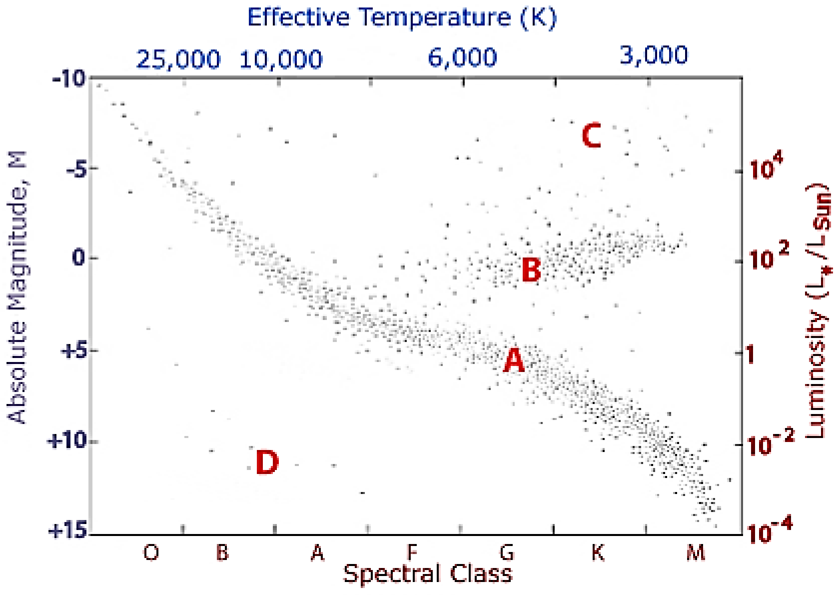
Criteria	Mark
Provides an explanation of how a star's spectrum can be used to infer it is rotating	3
Shows some understanding of how a star's spectrum can be used to infer it is rotating	2
Provides some relevant information	1

If a star is rotating then one side is travelling away (receding) while the other side is approaching. Light emitted from the receding side will be doppler red-shifted, while light from the approaching side will be doppler blue-shifted by almost the same amount. Light from other parts of the star will fall within these two limits. This causes the individual spectral lines to be broadened by an amount depending on the rotational velocity of the star. The faster a star rotates the more broadening of spectral lines will occur.



Question 25 (5 marks)

Consider the following Hertzsprung-Russell diagram with stars A, B, C and D.



Hertzsprung-Russell Diagram

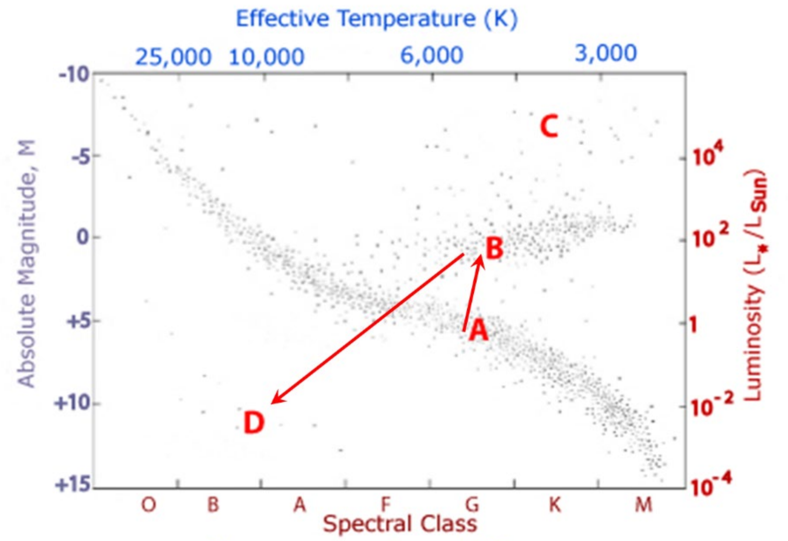
(a) Complete the following table: **4**

Marking criteria	Marks
Correctly filled table with each entry distinct	4
1-2 errors/omissions with each filled entry distinct	3
3-4 errors	2
5-6 errors	1

Label	Evolutionary stage of star	Main process(es) occurring inside star
A	Main Sequence	Hydrogen fusion in core (p-p chain) (*CNO is minor*)
B	Red giant	H fusion in shell (*CNO cycle*) *Helium fusion in core (Triple-alpha)*
C	Red supergiant	Fusion of elements up to iron in a series of shells
D	White dwarf	None

(b) Annotate the diagram to show the expected evolutionary sequence for our Sun. **1**

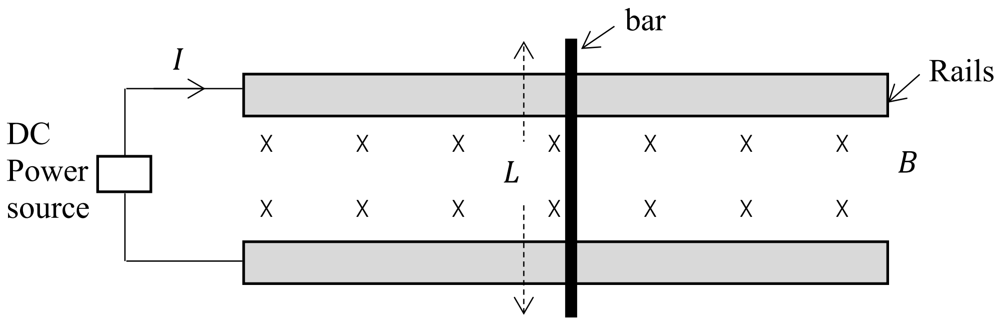
Marking criteria	Marks
Correct sequence (A→ B → D, not going too close to C)	1



Hertzsprung-Russell Diagram

Question 26 (3 marks)

A conducting bar with mass m, length L, is at rest on two horizontal conducting rails. **3**
A uniform magnetic field B perpendicular to the rails fills the region between it.



When the rails are connected to a DC power source which maintains the current at a constant I, the bar experiences a force F due to the motor effect.

Ignore the friction between the rails and the bar.

Show that the speed attained by the bar is $v = \sqrt{\frac{2B\,L\,I\,d}{m}}$, where d is the horizontal distance travelled by the bar.

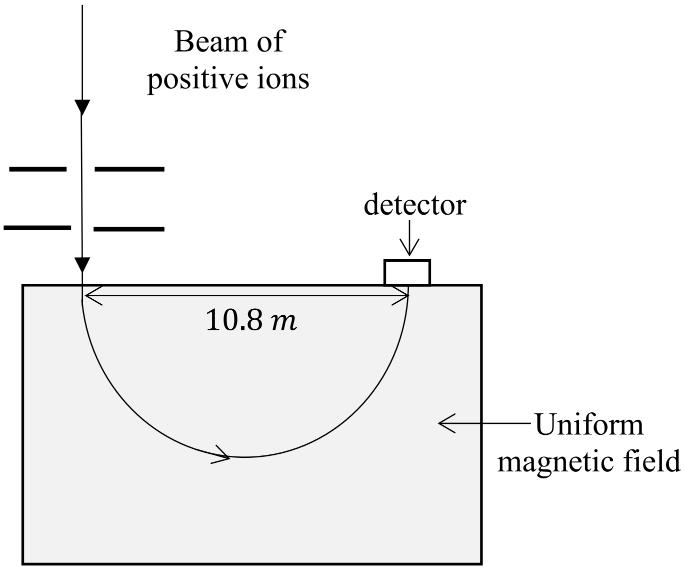
Criteria	Mark
Correctly derives the relationship (Uses $F = BIL, W = \Delta K = F.d, including\ u = 0\ or\ K_i = 0$)	3
Shows some correct steps or reasoning (uses 2 of the above)	2
Provides some relevant information (uses one of the above)	1

By the motor effect, the bar experiences a force given by $F = BIL$.
But the work done on the bar is given by $W = \Delta K$.
i.e. $F.d = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$
With $u = 0$, $v = \sqrt{\frac{2Fd}{m}} = \sqrt{\frac{2BILd}{m}}$ by sub F

Comments:
This was a show question and many students omitted vital steps in their derivation. Please note that work done is not equal to the kinetic energy but to the change in kinetic energy i.e. $W = \Delta K$.

Question 27 (5 Marks)

A beam of singly charged positive ions in vacuum enters a region of uniform magnetic field strength B, where it undergoes anticlockwise deflection in a semicircular arc as shown in the diagram below.



The ions travelling with speed $1.20 \times 10^5\ m\ s^{-1}$, are detected by a fixed detector when the diameter of the arc is $10.8\ m$.

(a) If the ions have a mass of $20\ u$, calculate the strength of the magnetic field. **2**

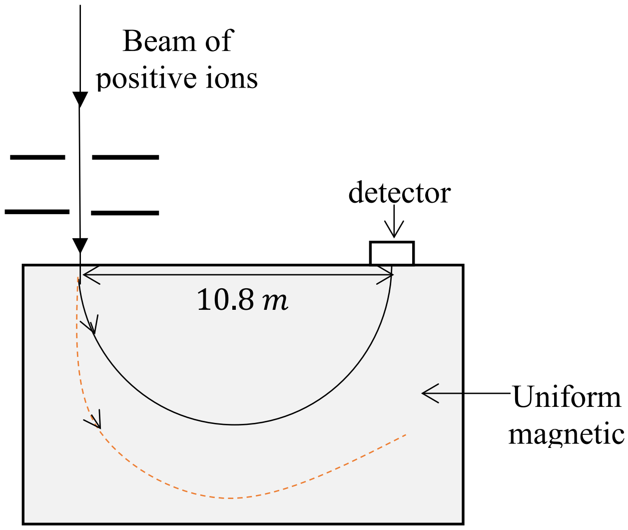
Criteria	Marks
Correctly calculates the strength of the magnetic field (including Tesla as the unit for B, Wb not accepted)	2
Provides some relevant information	1

$$\frac{mv^2}{r} = qvB$$

$$B = \frac{mv}{qr} = \frac{20 \times 1.661 \times 10^{-27} \times 1.20 \times 10^5}{1.602 \times 10^{-19} \times 5.4} = 4.6\ mT$$

Comments:
Generally well done except for a few students who interpretated "singly charged" as being 1 coulomb of charge. It is prudent to reflect on the reasonableness of your answer and this will prompt you to double check your calculation, and correct if necessary.

(b) Ions with heavier mass and same charge are also present in the beam. Sketch qualitatively the path of these ions in the same region of magnetic field. **1**



(c) Explain the adjustment that needs to be made to the magnetic field to enable the heavier ions with the same speed to reach the detector. **2**

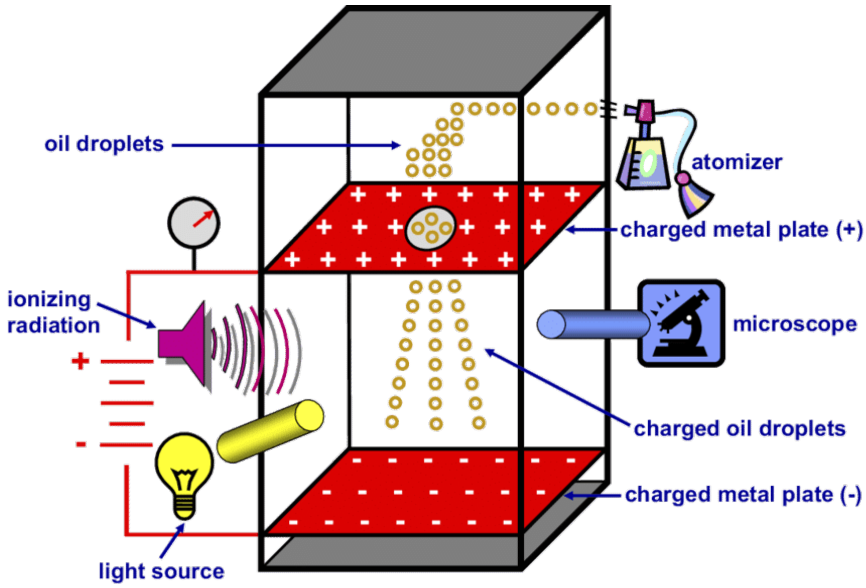
Criteria	Marks
Provides the correct adjustment and a relevant explanation. (makes reference to $B = \frac{mv}{qr}$ or to the centripetal force (qvB), and should provide direction)	2
Provides the correct adjustment with a superficial explanation	1

For the larger ions to be detected (i.e. $r = 5.4\ m$), the centripetal force would need to be increased. This is achieved by increasing the strength of the magnetic field, from $\frac{mv^2}{r} = qvB$, while retaining its direction.

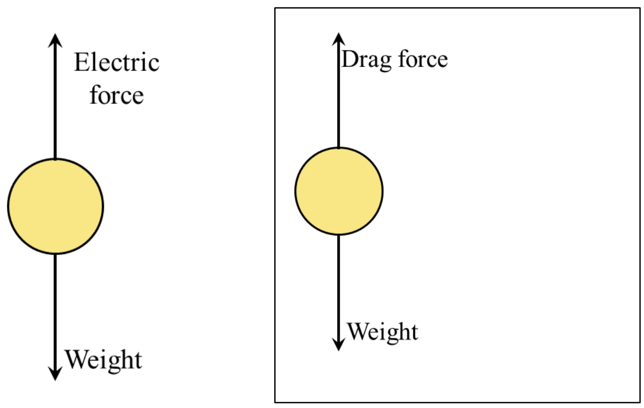
Comments:
An easy question to explain using an equation which many students could easily do. The equation helps to verify the relationship when some variables are kept constant.

Question 28 (4 marks)

An experiment was carried out to model the Millikan oil-drop experiment.



An oil drop was selected for viewing through the microscope and the size of the applied voltage altered until the oil drop was stationary. The forces on the drop at this point can be represented in the following free-body diagram:



(a) The top plate was 5085 V higher than the bottom plate, with a separation of 16 mm. The mass of the oil drop was 8.8×10^{-11} g. **3**

Calculate the number of excess electrons on this oil drop.

Marking criteria	Marks
Calculates number of excess electrons	3
As above with 1 error	2
As above with 2 errors	1

$F_{net} = 0 = \text{weight} – \text{electric} = mg – qE$
$qE = mg = 8.8 \times 10^{-14} \times 9.8 = 8.624 \times 10^{-13}$ N
$E = V/d = 5085/0.016 = 3.18 \times 10^{5}$ V m^{-1} or N C^{-1}
$q = 8.624 \times 10^{-13} / 3.178 \times 10^{5} = 2.714 \times 10^{-18}$ C
Charge on electron = -1.602×10^{-19}
Number of electrons = $2.679 \times 10^{-18} / 1.602 \times 10^{-19} = 16.96$ (approximately 17 excess as the electrostatic force on the charged particle is towards the positive plate)

Comment: most students were able to make some progress on solving this. A number seemed to be thrown by the word excess. An oil drop has a large number of electrons, due to the fact that it is made from carbon, hydrogen and oxygen atoms (which contain electrons). These are balanced by the nuclear charge, and do not help the drop to experience a net force in an electric field. However, the excess electrons (those above and beyond the ones which were originally there) can contribute to a net force in an electric field.

(b) The mass of the drop was estimated with the voltage source off, which resulted in the oil drops falling downwards at constant speed. **1**

Draw a free body diagram for an oil drop next to the free body diagram shown earlier, using the same scale.

Marking criteria	Marks
Free body diagram drawn to scale for terminal velocity	1

Comment: use a ruler.

Question 29 (4 marks)

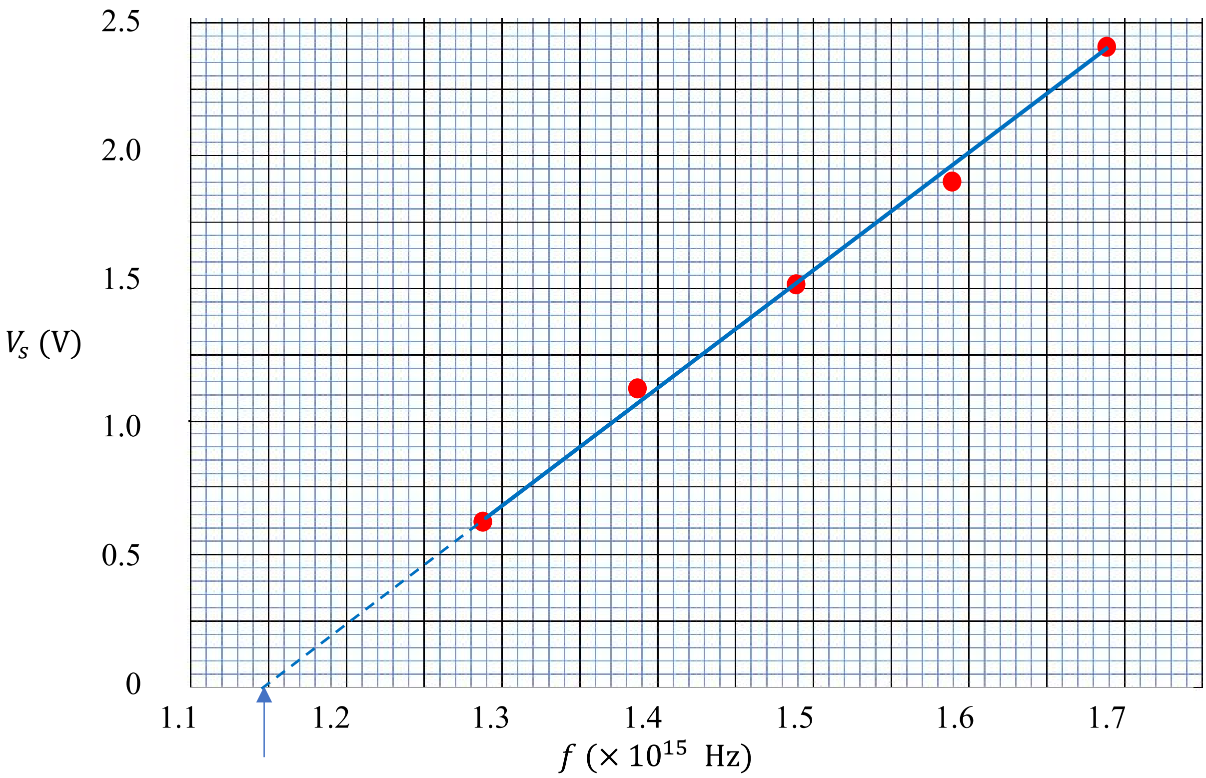
A student performed a photoelectric experiment in which he exposed an unidentified metal to various frequencies of incident electromagnetic radiation, f, and measured the stopping voltage, V_s, of the emitted photoelectrons. The results are shown in the table below. **4**

f ($\times 10^{15}$ Hz)	1.3	1.4	1.5	1.6	1.7
V_s (V)	0.6	1.1	1.5	1.9	2.4

By analysing the data graphically, and using the work functions of some metals given in the table below, identify the unknown metal used by the student.

Support your answer with relevant calculations.

Metal	Sodium	Cobalt	Lead	Zinc	Iron	Silver	Platinum
Work function (eV)	2.28	3.90	4.14	4.31	4.50	4.79	6.35



Criteria	Marks
Determines the correct work function using the line of best fit (1 for plotting, 1 for extrapolating, 1 for relevant equation, 1 for correct work function)	4
Any three of the above	3
Correctly plots some points or Correctly draws a line of best fit, (With incorrect working for the work function)	2
Provides some relevant information on the graph, Or provides some relevant calculation/information	1

$$\begin{aligned}\phi &= hf_0 \\ &= 6.626 \times 10^{-34} \times 1.17 \times 10^{15} \\ &= 7.75 \times 10^{-19}\ J \\ &= 4.83\ eV\end{aligned}$$

Hence the unknown metal is Silver

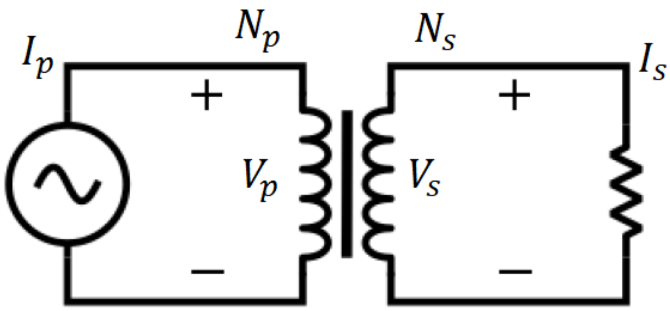
Comments:
Generally well done, with the majority of the cohort gaining maximum marks. Please consider the number of marks and the space provided when deciding on a line of action to follow. Many students, although correct, used the equation connecting the stopping voltage to the frequency ($V_s = \frac{h}{e} f - \frac{\emptyset}{e}$*) and substituted a point in the equation to obtain the work function. This really took up a lot of space and definitely a lot of time!*

Question 30 (4 marks)

The ideal transformer is a device capable of changing the voltage and current characteristics of an AC power supply without dissipating any energy according to the following model.

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

$$V_p I_p = V_s I_s$$



(a) Identify two limitations of the ideal transformer model when applied to real transformers. **2**

Criteria	mark
identifies any two limitations of the ideal transformer model	2
Any one of the above	1

Any Two of the following limitations:

- Incomplete flux linkage resulting in less flux from the primary being transferred to the secondary
- Production of eddy currents in the core results in power losses in the core
- Magnetic hysteresis in core resulting in loss of flux
- Resistive heating effects in the conducting wires

(b) Outline qualitatively two strategies used to improve transformer efficiency. **2**

Criteria	mark
outlines any two strategies to increase efficiency	2
Any one of the above	1

Any two of the following strategies:

- ✓ Increase flux linkage by tightly wrapping coils around core and in multiple orientations
- ✓ Use of soft iron core made of ferrite material to reduce magnetic hysteresis
- ✓ Laminate the core to reduce eddy current formation, thereby reducing power losses
- ✓ Use of thicker resistance wires in core to reduce resistive heating effects

Comments:
Although generally well done, students believed that energy and power are synonymous. Furthermore loss of flux and loss of power seemed to be synonymous as well. Also, the pictorial model shown above is a single transformer and not two transformers! Each loop shown, depicts the primary and secondary coils.

Question 31 (8 marks)

A coracle is a very small, light boat that can be used for fishing. It floats high so that it barely disturbs the water.

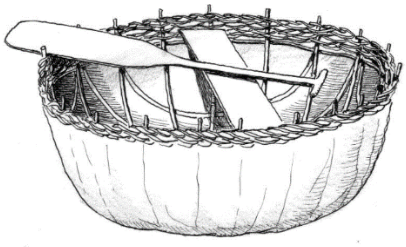


Figure A (left): An example of a coracle.

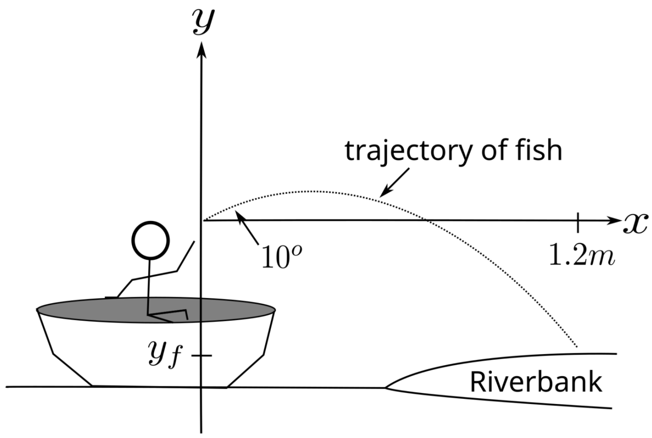


Figure B (right): Trajectory of the fish.

A child of mass 30.0 kg sits in a coracle of mass 10.0 kg on the water at rest. The child throws a fish of mass 5.0 kg onto the riverbank. The fish leaves their hand with at a speed of 5.0 ms^{-1} at an angle of 10° above the horizontal.

(a) Determine the initial vertical component of the velocity of the fish. **2**

Criteria	Marks
Calculates the correct value for the initial vertical velocity, **including units**	2
Provides some relevant information.	1

$$u_y = u \sin\theta = 5ms^{-1} \times \sin 10 = 0.87ms^{-1}$$

(b) The fish lands a horizontal distance of 1.2 m from the child's hand. **3**

Determine the vertical displacement, y_f, of the fish from the point it left the child's hand to where it lands.

Criteria	Marks
Calculates the correct vertical displacement, including sign.	3
Applies a correct process to calculate the vertical displacement, but makes a numerical error.	2
Provides some relevant information.	1

Use the range to find the time of flight via $x = u\cos\theta\, t$

Rearranging: $t = \frac{x}{u\cos\theta} = \frac{1.2m}{5.0ms^{-1}\cos 10} = 0.244s$

The change in vertical displacement is given by

$y_f = u_y t + \frac{1}{2}at^2 = 0.87ms^{-1} \times 0.244s + \frac{1}{2}(-9.8ms^{-2}) \times (0.244s)^2 = -7.9 \times 10^{-2}m$

The fish has a vertical displacement of $y_f = -7.9cm$.

(c) How fast are the boat and child moving horizontally after the throw? **3**

Identify any assumption/s you make in this calculation.

Criteria	Marks
• Correctly applies conservation of momentum to calculate the speed of the boat and child after the fish leaves the child's hand, showing all working. • Identifies and justifies any assumptions made Note: simply saying "assume momentum is conserved" is not sufficient – momentum is always conserved if you choose a system containing all interacting objects. By applying conservation of momentum to a system consisting of *just* the boat, boy and fish you must assume all external forces acting on this system are negligible compared to the force between the fish and boy.	3
Applies conservation of momentum, but makes a numerical error AND Correctly identifies an assumption made OR Correctly calculates the speed of the boat.	2
Provides some relevant information.	1

We will apply conservation of momentum to the throw. The assumption that we will make is that there is no external force/s acting on the system consisting of the boat, child and fish during the throw. If the coracle floats high so that it barely disturbs the water then this implies that the force between the boat and coracle is small, so it is a reasonable assumption.

$$m_{BC}u_{BC} + m_F u_F = m_{BC}u_{BC} + m_F u_F$$

As fish and coracle are initially at rest the left-hand side is zero.
As we wish to find the final velocity of the coracle in the horizontal direction, we need to determine the final velocity of the fish in the horizontal direction.
This is $u_x = u \cos\theta = 5.0ms^{-1} \times \cos 10 = 4.9ms^{-1}$ (As this is close to 5m/s, students can use this value, but would then need to list this as an assumption for full marks)

Solving for the final velocity of the boat + child:
$v_{BC} = -\frac{m_F u_F}{m_{BC}} = -\frac{5kg \times 4.9ms^{-1}}{40kg} = -0.62ms^{-1}$
The boat and child are moving at a speed of 0.62m/s away from the bank.

Question 32 (5 marks)

In your course you used a diffraction grating to observe spectra from discharge tubes.

(a) Identify the purpose of the diffraction grating in this investigation. **1**

Criteria	Marks
Identifies the purpose of the diffraction grating as separating the different colours/lines in the spectra (or equivalent)	1

The diffraction grating is used to separate the light from the discharge tube into its constituent colours.

The image below is a photograph of the visible spectra from a hydrogen discharge tube after it passes through a diffraction grating which has 300 lines per mm.

Central maxima **cyan 1** **red 1** **cyan 2** **red 2**

The central maxima (containing all colours of light from the discharge tube) is visible on the far left in the photo. The first and second order cyan spectral lines (both with $\lambda = 486$ nm), marked "cyan 1" and "cyan 2" are labelled above the spectrum. The first and second order red spectral lines (both with $\lambda = 656$ nm) are marked "red 1" and "red 2".

The angular separation between the cyan 1 line and the central maxima is $\theta_c = 8.4^o$.

(b) Find the angular separation θ_r between the red 1 line and the central maxima. **2**

Criteria	Marks
Correctly calculates the angular separation of the red lines in the spectrum.	2
Substitutes the correct value for d or λ into the correct equation OR Makes an error in substitution but otherwise solves the problem using a correct process.	1

Using $d \sin\theta = n\lambda$, with $d = \frac{1\times10^{-3}}{300} = 3.33\times10^{-6}m$, $\lambda = 656\times10^{-9}m$ and $n = 1$, we have $\sin\theta = \frac{656\times10^{-9}m}{3.33\times10^{-6}m} = 0.197$

So $\theta = 11.3^o$

(c) Explain quantitatively why the distance between the cyan 2 and red 2 lines on the photograph is double the distance between the cyan 1 and red 1 lines. **2**

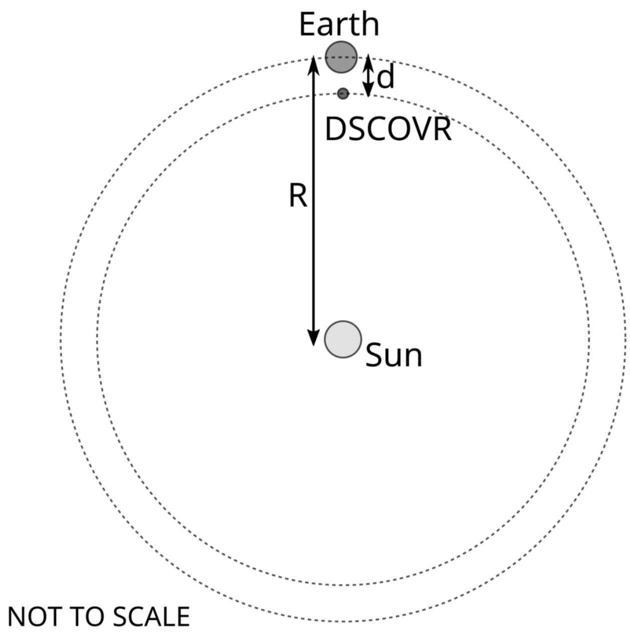
You may assume $\sin\theta \approx \tan\theta \approx \theta$.

Criteria	Marks
Shows quantitatively that separation of the second order lines is double that of the first order lines.	2
Identifies that the separation of the lines is proportional to the difference in the angular separation of the red lines and cyan lines.	1

For small angles, the separation of the red 1 and cyan 1 lines is proportional to $\theta_r - \theta_c$.
For small angles, $\theta_{2r} = \frac{2\lambda_r}{d} = 2\theta_r$ and $\theta_{2c} = \frac{2\lambda_c}{d} = 2\theta_c$
The separation of the red 2 and cyan 2 lines is therefore proportional to $2\theta_r - 2\theta_c = 2(\theta_r - \theta_c)$, and the separation of the red 2 and cyan 2 lines should be double the separation of the red 1 and cyan 1 lines.

Question 33 (5 marks)

The Deep Space Climate Observatory (DSCOVR), is a space probe that is located at a position where it orbits the Sun with the same period as the Earth, maintaining a fixed distance from the Earth and the Sun.



Data: Mass of the DSCOVR: $m = 570$ kg   Mass of the Sun: $M_S = 2.0 \times 10^{30}$ kg   Period of the Earth's orbit: $T_E = 3.16 \times 10^7$ s.

(a) Calculate the radius of the Earth's orbit, R. **2**

Using Kepler's 3rd law relating the period of the earth to its radius, we have

$$\frac{r_E^3}{T_E^2} = \frac{GM}{4\pi^2}$$

Which can be rearranged for the earth's radius as

$$r_E = \left(\frac{GMT_E^2}{4\pi^2}\right)^{1/3} = \left(\frac{6.67 \times 10^{-11} \times 2.0 \times 10^30 \times (3.16 \times 10^7)^2}{4\pi^2}\right)^{1/3} = 1.50 \times 10^{11} m$$

Criteria	Marks
Correctly calculates the radius of the Earth	2
Provides some relevant information	1

(b) Identify the force/s acting on DSCOVR. **3**

Write down an equation which could be solved using the information provided to determine the distance d.

You do not need to solve this equation.

Criteria	Marks
Obtains a correct equation, which includes the information about the period of the orbit.	3
Attempts to apply Newton's 2nd law to DSCOVR, including identifying the centripetal force, and the gravitational forces due to the Sun and Earth.	2
Identifies at least one force acting on DSCOVR	1

There are two forces acting on DSCOVR, one due to the gravitational force of the Earth and one due to the gravitational force of the Sun.
Together these forces provide the centripetal force required for DSCOVR to orbit the Sun in a circular orbit with the same period as the earth.
We need to write down Newton's 2nd law for DSCOVR as:

$$\Sigma F = ma$$

$$\frac{GM_S m}{(R-d)^2} - \frac{GM_E m}{d^2} = \frac{mv^2}{(R-d)}$$

To find the orbital speed of DSCOVR, we need to use the information that its period is the same as Earth's orbital period, so

$$v = \frac{2\pi(R-d)}{T_E}$$

So our final equation is

$$\frac{GM_S}{(R-d)^2} - \frac{GM_E}{d^2} = \frac{4\pi^2(R-d)}{T_E^2}$$

Which could be solved to find d using the quadratic formula.

Question 34 (11 marks)

Cobalt-60 is an isotope that is used to treat some type of cancers. One of the products of the decay is a β-particle.

(a) Show that the rest mass of the β-particle is equivalent to 0.511 MeV. **1**

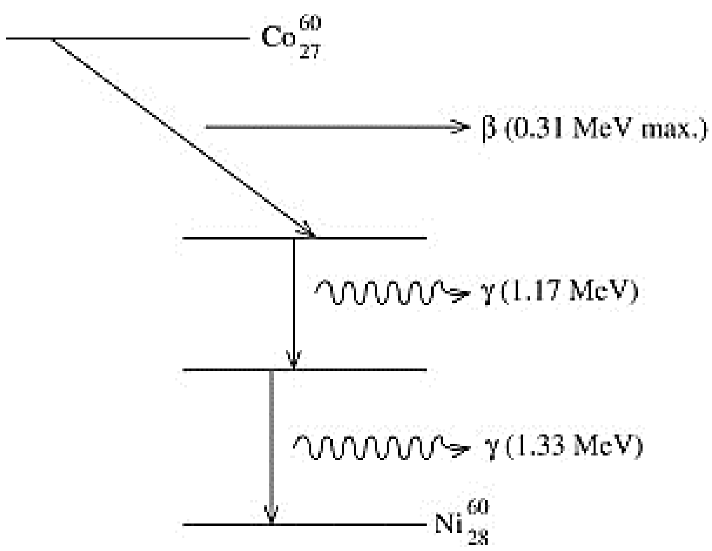
Marking criteria	Marks
Full working	1

$E=mc^2$ $m = 9.1 \times 10^{-31}$ kg, $c = 3 \times 10^8$ ms^{-1}
$E = 9.1 \times 10^{-31} \times (3 \times 10^8)^2 = 8.19 \times 10^{-14}$ J
1 eV = 1.602×10^{-19} J
1 J = $1/(1.602 \times 10^{-19})$ eV
8.19×10^{-14} J = $8.19 \times 10^{-14}/(1.602 \times 10^{-19}) = 5.11 \times 10^5$ eV = 0.511 MeV

Cobalt-60 undergoes radioactive decay according to the following equation:

$$^{60}_{27}Co \rightarrow {}^{60}_{28}Ni + {}^{0}_{-1}e + 2{}^{0}_{0}\gamma$$

This can be represented diagrammatically, as shown below:



producing stable nickel-60, a β-particle with a maximum 0.31 MeV kinetic energy, two γ photons and an antineutrino (not shown). The γ photons are responsible for killing rapidly dividing cells, specifically the tumour cells.

(b) The mass of a cobalt-60 nucleus is 59.919015 u. Calculate the mass of the nickel-60 nucleus. **3**

Marking criteria	Marks
Calculates energy change Calculates mass change Calculates mass of Ni nucleus Consistent units	3
2 of the following: Calculates energy change Calculates mass change Calculates mass of Ni nucleus OR 1 error in calculation	2
1 of the following: Calculates energy change Calculates mass change Calculates mass of Ni nucleus OR 2 errors in calculation	1

Change in energy = 0.511 + 0.31 + 1.17 + 1.33 = 3.321 MeV
Change in mass (in u) = 3.321/931.5 = 0.003565
Mass of Ni nucleus = 59.919015 – 0.003565 = 59.91545 u

Comments: a large number of students forgot to include the mass of the β-particle, despite calculating it in part (a), some forgot the KE or the mass converted to photons . There was also some vey bad setting out, please show your working in a neat and ordered manner, as part mark are possible if it clear to the marker what you were doing. A few students tried to add up the mass of the protons and neutrons, this does not account for binding energy, some also considered only the mass defect for a neutron, again if you made these error, please revise binding energy of nuclei. Please be careful when using significant figures, we keep the same number of decimal places when adding/subtracting.

(c) Small pellets, about the size of a grain of rice, are injected into the tumour and left for a set period of time before being removed. **2**

The cobalt-60 pellets typically have an activity of 18.5 GBq per pellet when fresh, where 1Bq = 1 decay per second.

Each pellet can be used for many treatments, but they need to be replaced once the activity has decreased to 7.0 GBq per pellet. The half-life for cobalt-60 is 5.27 years.

Assuming the activity is proportional to the amount of Cobalt-60 present, how frequently would the cobalt-60 pellets need to be replaced to maintain sufficient activity?

Marking criteria	Marks
Calculates time of replacement for Co-60	2
Calculates decay constant OR Calculates replacement time based on incorrect decay constant	1

$\lambda = \ln 2/t_{1/2}$ $t_{1/2} = 5.27$ years
$\lambda = \ln 2/5.27 = 0.1315$ years^{-1}
$N_t = N_o\, e$^(- λt) $N_t = 7.0$ GBq, $N_0 = 18.5$GBq
7 = 18.5 e^(- 0.1315t)
Ln(7/18.5)=-0.1315t
t = 7.4 years

Comments: please be careful with rounding when you are doing calculations. Keep extra significant figures until the final number, particularly when using exponentials.

(d) In one treatment regime, a fresh pellet is inserted into the tumour and removed after 10 minutes.

(i) Calculate the change in temperature of a 60 kg patient caused by the ejected particles. **3**

Assume:

- the specific heat capacity of the patient is 3.5×10^3 J kg^{-1} K^{-1}
- the activity remains constant during the 10 minutes.
- $1\text{ GBq} = 10^9\text{ Bq}$
- $Q = m\,c\,\Delta T$

Marking criteria	Marks
Calculates change in temperature	3
As above with 1 error	2
As above with 2 errors	1

Number of decays in 10 minutes = 60 x 10 x 18.5 x 10^9 = 1.11 x 10^{13}
Energy per decay = 0.31 + 1.17 + 1.33 MeV = 2.81 MeV = 2.81 x 10^6 x 1.602 x 10^{-19} = 4.5 x 10^{-13} J
Energy released in 10 minutes = 1.11 x 10^{13} x 4.5 x 10^{-13} = 4.997 J

m = 60 kg
c = 3.5×10^3 J kg^{-1} K^{-1}

Q = mcΔT
4.997 = 60 x 3.5 x 10^3 x ΔT
ΔT = 4.997/(60 x 3.5 x 10^3) = 0.0000238 = 2 x 10^{-5} K (an increase)

Comments: A number of students did not carefully read the assumptions that you were instructed to make, in particular that the activity remained constant for 10 minutes (not unreasonable given the half-life of 7.4 years. The mass of the β-particle is not included in the calculation here (as it would remain an electron), but its KE should be as it will likely be captured by the tissue and converted to heat. Again, setting out is important, as is writing units as you go so that you can see that you haven't forgotten to use a conversion factor.

(ii) Identify TWO other significant physical assumptions that you made in your calculation above. **2**

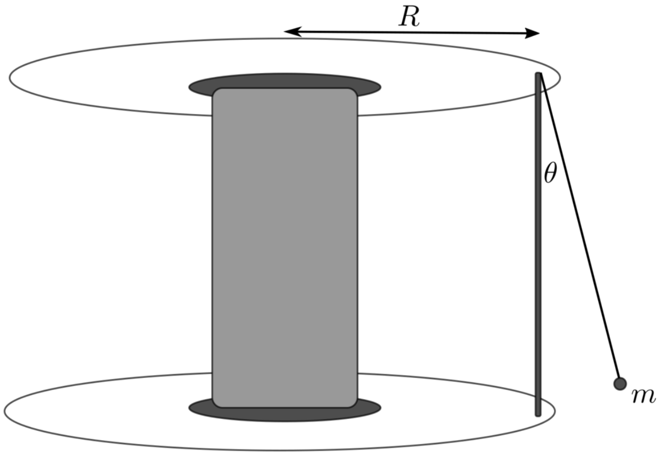
Marking criteria	Marks
Two suitable significant assumptions	2
One suitable significant assumptions	1

All of the energy is converted to heat energy/absorbed by the body.
All of the beta particles have close to the max KE.
The temperature change is uniformly distributed throughout the body.

Comment: the question was about significant assumptions made about the energy due to the ejected particles. Significant in this sense means an assumption that would change your answer by at least 10% (given that the mass was only to 1 sig fig)

Question 35 (5 marks)

A carousel (below, left) is a children's ride that rotates at a constant angular velocity. A mass m is attached by a string to one of the vertical bars at a distance R from the center of the carousel (below, right). The mass hangs at an angle θ when the ride is rotating with a constant angular velocity of ω.



a) Draw a free body diagram showing the forces acting on the mass, to scale. Indicate the net force with a dotted arrow. **2**

Criteria	Marks
Draws: - a tension force acting in the direction of the string - a weight force acting directly downwards such that: - the vertical component of the net force is zero - the horizontal component of the net force is equal to the horizontal component of the tension force, and points to the center of the carousel.	2
Correctly identifies at least one of the forces acting on the mass	1

b) Explain, qualitatively and quantitatively, how the angle θ would change if the string was attached to a pole at a distance $\frac{1}{2}R$ from the center of the carousel while it is still rotating at the same constant angular velocity ω. You may assume the angle θ is small. **3**

Criteria	Marks
A correct qualitative and quantitative explanation.	3
A correct qualitative explanation (e.g. θ is smaller as required F_C is smaller) OR A general algebraic expression that is not evaluated to answer the question OR Derives an expression relating θ and R (eliminating v) but makes the incorrect substitution $\omega = vr$ (to obtain θ doubles instead of halves)	2
Provides some relevant information, e.g. formula for centripetal force.	1

Qualitative explanation:
The string hangs at a **smaller angle** as a smaller centripetal force (provided by the horizontal component of tension) is required to move it in uniform circular motion when the radius is smaller and the angular speed remains constant.

Quantitative explanation:
Applying Newton's 2nd law to the mass in the vertical direction, where the acceleration is zero, we have

$$\Sigma F_x = ma_x$$
$$T \cos\theta - mg = 0$$

So

$$T \cos\theta = mg$$

Applying Newton's 2nd law in the vertical direction and assuming θ is small enough that the radius of the circular motion equals R, we have

$$\Sigma F_y = ma_y$$
$$T \sin\theta = m\frac{v^2}{R} = mR\omega^2$$

Eliminating the tension, we have:

$$\tan\theta = mR\omega^2$$

If θ is small, then this approximately equals

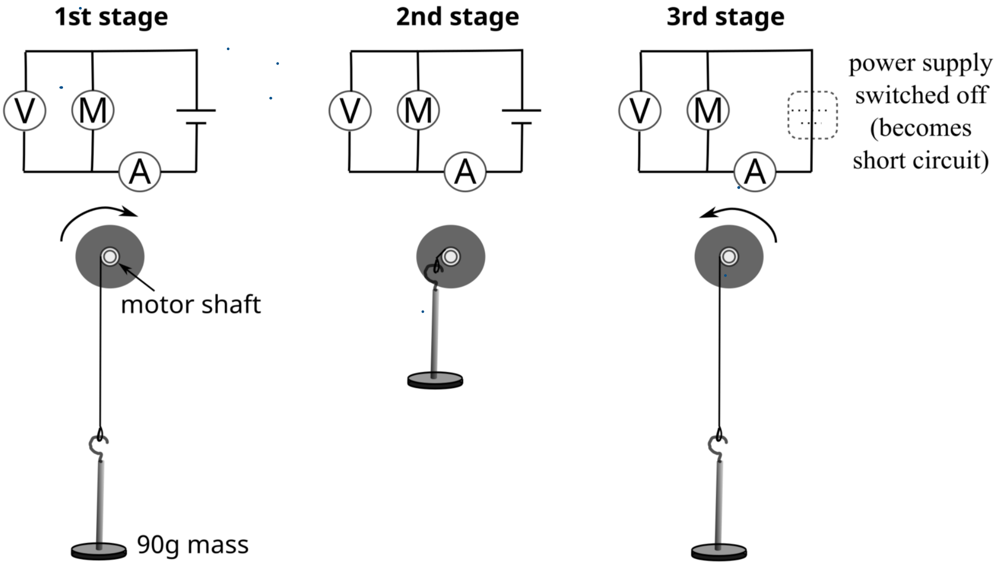
$$\theta = mR\omega^2$$

So halving the radius (for the same angular speed) will halve the angle.

Question 36 (9 Marks)

A 90 g mass is attached via a light string to the shaft of a DC motor.
An investigation is performed consisting of three stages:

Stage 1: The power supply is switched on and the mass moves up.
Stage 2: The string is fully wound up and the shaft is stationary.
Stage 3: The power supply is switched off and the mass moves down.



The vertical velocity of the mass during each stage is measured using video analysis and is shown below.

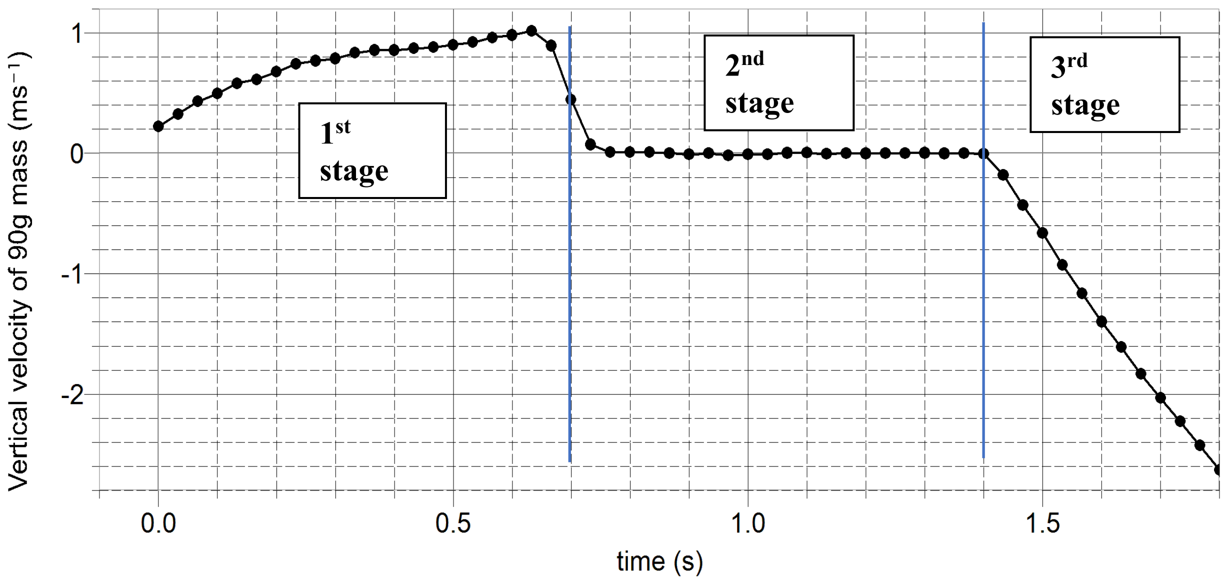


Figure 1: Vertical velocity of 90 g mass versus time

Question 36 continues on page 41

The current through the motor and the potential difference (voltage) across the motor were also measured during each stage and are shown below.

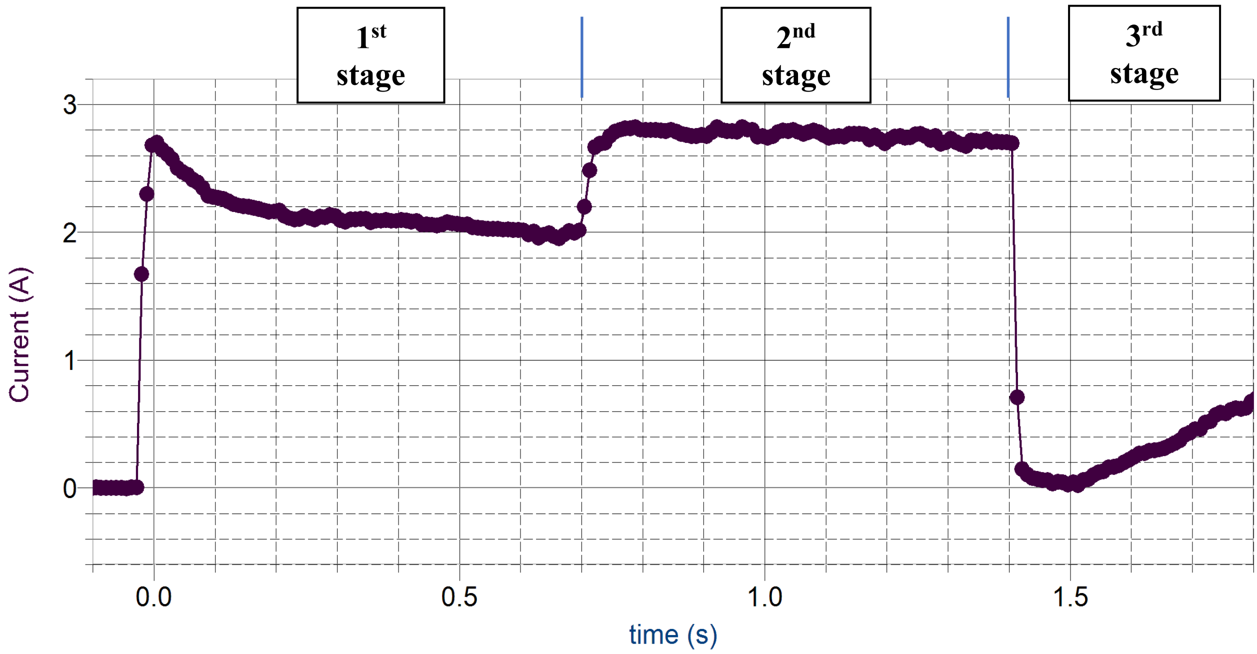


Figure 2: Current versus time

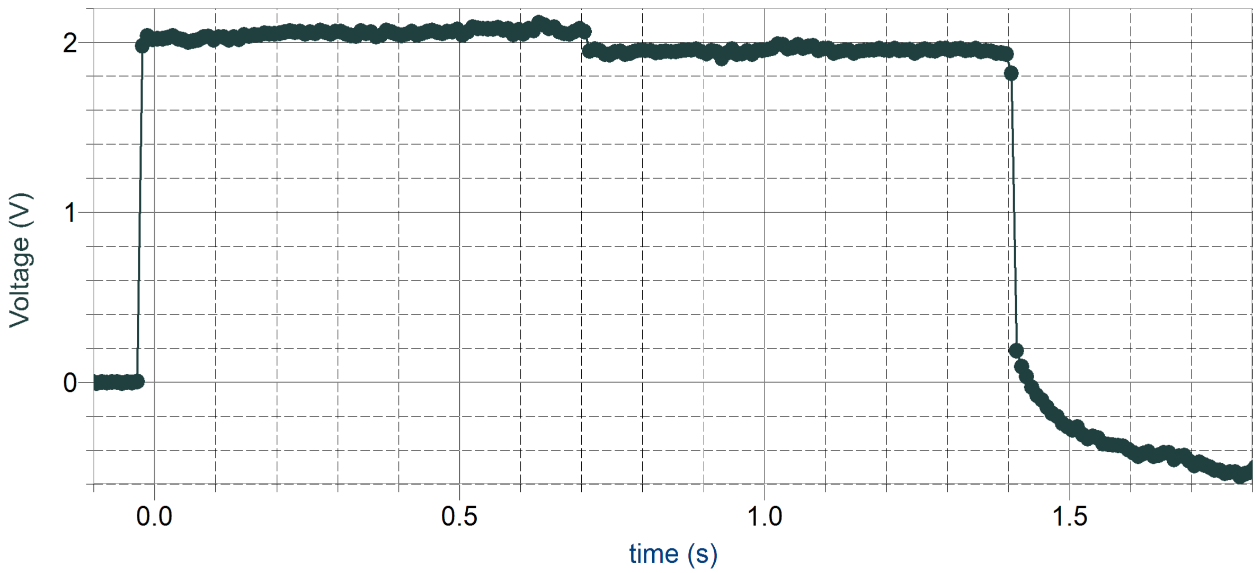


Figure 3: Potential difference versus time

Analyse the physics involved, and as well as how the law of conservation of energy applies to the system consisting of the 90 g mass and the motor during each of the three stages of the investigation. **9**

Your analysis should include both qualitative and quantitative information.

Criteria	Marks
- Provides a comprehensive, correct, qualitative and quantitative analysis of: o the physics involved in at least two stages (substantially correct for third) o how energy conservation applies in at least two stages (substantially correct for third). - Communicates scientific understanding logically, succinctly, and effectively using correct and precise scientific terms.	9
- Provides a thorough, correct or substantially correct, qualitative and quantitative analysis of: o the physics involved in each of the three stages o how energy conservation applies in each of the three stages. - Communicates scientific understanding logically, succinctly, and effectively using correct and precise scientific terms.	8
- Applies the law of conservation of energy in a substantially correct way to at least one of the stages - Provides a substantially correct analysis of the physics involved in at least one the stages - Some quantitative analysis (not simply transcribing info from graphs) - Communicates scientific understanding logically and effectively using correct scientific terms.	6-7
- Relates the law of conservation of energy in a substantially correct way to at least one of the stages AND/OR - Provides a correct description of some aspects of the physics involved in at least one of the stages AND/OR - Includes quantitative information	4-5
Shows some understanding of conservation of energy and/or the physics involved in the investigation	2-3
Provides some relevant information	1

Physics:	Correct application of $\Sigma F = ma$	Correct application of Conservation of energy	Units used correctly
Communication:	Logical structure	Succinct, precise use of scientific language	Effective/efficient communication via diagrams/annotations/equations

Stg	Qualitative observations	Qualitative analysis	Quantitative observations	Quantitative analysis/calculations
1	- Velocity is positive and increasing - Acceleration is positive and decreasing - Current is initially high then decreases - Two forces act on mass, tension (up) and weight force (down) - The current flowing through the rotor of the motor produces a torque due to the motor effect - KE of the mass increases - GPE of mass increases (if mass and earth the system) OR gravity does negative work on the mass (if mass is the system) - Electrical power is supplied to the motor	- back emf is generated, opposing supply - Acceleration upwards means that T>mg - By COE, total change in KE of mass + work done against gravity (i.e. change in GPE) + total heat generated in coils/bearings = total energy supplied Draws links between: ○ Decreasing acceleration due to ○ reduction in torque, due to ○ decrease in current, due to ○ increased back emf due to ○ increased angular velocity and so ○ increased rate of change of B flux due to velocity increasing over time	- Gradient of v-t graph $\approx 1ms^{-2}$ (spread of values possible here) - Area under graph $A \approx 0.4m$ - N's 2nd law for mass $T - mg = ma$ - Torque due to ME is $\tau = nBIA$ - The tension and torque due to ME are connected via $\tau = rT$ - There is a back emf in the motor due to Faraday's law $\epsilon_{back} = -N\frac{\Delta\Phi}{\Delta t}$ which opposes the supply voltage. - Electrical energy $W_E = Pt = VIt$ - Change in Kinetic energy of mass $\Delta KE = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$ - Work done by gravity $W_G = mg\Delta y$	- Acc of mass $a \approx 1ms^{-2}$ - Area under graph is displacement of mass $A \approx 0.4m$ - Tension $T = 0.09kg(9.8+1)ms^{-2} \approx 1N$ - Electrical energy $W_E = Pt = VIt \approx 2V \times 2.1A \times 0.7s \approx 3.0J$ - Change in KE of mass $\Delta KE = \frac{1}{2}mv^2 - \frac{1}{2}mu^2 = 0.5 \times 0.09kg \times (1ms^{-1})^2 \approx 0.05J$ - Work done by gravity $W_G = mg\Delta y = 0.09kg \times 9.8ms^{-2} \times 0.4m \approx -0.4J$ (negative as mass moves up) - I^2R heat during stage 1 is $\Delta T_{th} = W_E + W_G - \Delta KE = 3J - 0.4J - 0.05J \approx 2.5J$
2	- The net force on the mass is zero - There is a normal force from the casing of the motor downwards (**HARD**) (This normal force down + weight down = tension from string up) - Current and Voltage constant - Power supplied to the motor is constant as voltage and current are constant.	Draws links between: ○ Large constant current due to ○ Zero back emf, due to ○ Constant B flux - As there is no change in KE or GPE of the mass, all the electrical power is dissipated as heat in the coils. - Resistance should increase as motor gets hot and $R \propto T$	- $P = VI$ - $E = Pt$ - $R_{coils} = \frac{V}{I}$ - $P_{coils} = I^2R$	- $P = VI = 1.9V \times 2.7A \approx 5.1W$ - $E = Pt = 5.1W \times 0.7s = 3.6J$ - $R_{coils} = \frac{V}{I} = \frac{1.9}{2.7} = 0.70\Omega$
3	- The motor acts as a generator. - Mass moves with an increasing negative velocity - Constant negative acceleration of mass - Tension is less than the weight force - Current flows in the <u>same</u> direction as in stages 1 and 2 - Voltage across the motor is in the <u>opposite</u> direction to stages 1 and 2	- Work done by gravity converted to KE and electrical energy, which is converted to heat - The tension force in the string exerts a torque $\tau = rT$ on rotor, so ω id increasing - Increasing speed produces increasing emf - By N's 3rd law, the reaction force is the back torque acting due to F = BIL force acting on the generated current. (**HARD**) Draws links between: ○ shaft rotating in the opposite direction to stage 1 means that ○ the generated emf is in the *opposite direction* to the back emf in stage 1, accounting for: ○ Why current is same direction as S1 (**HARD**) ○ Why voltage is negative in S3 (**HARD**)	- Gradient v-t graph $\approx \frac{-2-0}{1.7-1.4} = -6.7ms^{-2}$ - The induced emf is given by Faraday's law $\epsilon = -N\frac{\Delta\Phi}{\Delta t}$ - Distance mass falls is area under v-t graph - $W_G = mg\Delta y$ - $\Delta KE = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$	- Acceleration of mass is $a = -6.7ms^{-2}$ - $\Sigma F = ma = 0.09kg \times (-6.7) = 0.60N$ downwards. - $\Sigma F = T - mg$, so $T = -0.6N + 0.09 \times 9.8 = 0.28N$ upwards. - $\Delta y = \frac{1}{2}2.6ms^{-1} \times 0.4s = 0.52m$ - $W_G = mg\Delta y = 0.09kg \times (-9.8ms^{-2}) \times (-0.52m) = 0.46J$ - $\Delta KE = \frac{1}{2}mv^2 - \frac{1}{2}mu^2 = \frac{1}{2} \times 0.09kg \times (2.6ms^{-1})^2 = 0.30J$ - By conservation of energy $W_G = \Delta KE + \Delta E_E$, so $\Delta E_E = 0.46J - 0.3J = 0.16J$ - Thermal energy = electrical energy = 0.16J

Sample answer

Note: This sample answer is *thorough*, as it is designed to illustrate the variety of material that can be discussed in response to the question.

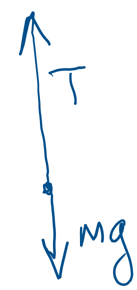
Stage 1

Physics Involved:

Current flowing through the coils in the DC motor experiences a force due to the motor effect $F = ILB\sin\theta_1$. This force produces a torque $\tau = rF\sin\theta_2$ (where θ_2 is the angle between r and F, and r is the radius of the rotor) on the motor shaft. This torque exerts a tension force on the string of $T = \tau/r_{shaft}$.

Figure 1 shows that the average acceleration of the mass during stage 1 is:

$a_{av1} = \frac{(1-0.5)m/s}{(0.6-0.1)s} = 1.0ms^{-2}$



Drawing a free body diagram from the 90g mass (right) and applying Newton's 2nd law ($\Sigma F = ma$) in the vertical direction we have:

$$T - mg = ma$$

So the tension in the string is (on average) $T = m(a+g) = 0.09 \times (9.8 + 1.0) = 0.97N$.

The average net force acting on the 90g mass during stage 1 is then

$\Sigma F = 0.09kg \times 1.0ms^{-2} = 0.09N$

A back emf is produced in the motor due to Faraday's law $\epsilon_{back} = -N\frac{d\phi_B}{dt}$ in a direction which opposes the supply voltage (due to Lenz's law) in order to satisfy conservation of energy.

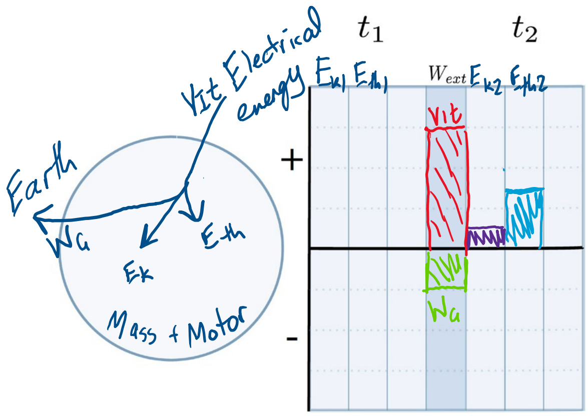
As the rate of rotation of the motor increases the magnitude of the back emf increases, so the current flowing through the motor decreases, as seen in figure 2 from $t = 0s$ to $t = 0.7s$.

The current is given by $I_{rot} = \frac{\epsilon_{supply} - \epsilon_{back}}{R_{coils}}$. As the torque is proportional to the current, this means that the tension force decreases over time, so the net force and therefore the acceleration decreases.

Conservation of Energy:

One way to organize our thinking about conservation of energy is to use an energy flow diagram and energy bar chart *before* writing down an equation for conservation of energy, just as we would draw a free body diagram before we apply Newton's 2nd law.

Here the system has been chosen to be the mass and the motor (alternatively we could include the earth in the system as well). It is not an isolated system as energy is transferred *in* to the system in the form of electrical energy and transferred *out* of the system in the form of work done against the external force of gravity (if the system was chosen to include earth this would be an increase in gravitational potential energy). Energy transformations include increasing kinetic energy of the mass and increasing thermal energy in the system (primarily due to I^2R heating in the coils of the motor).



The information in our energy bar chart expresses conservation of energy:
The sum of the initial energy + work done (by power supply and gravity) = Final energy of the system

$$E_{th1} + E_{k1} + W_E - W_G = E_{th2} + E_{k2}$$

Expressing this in terms of changes:

$$\Delta E_{th} + \Delta E_k = W_E - W_G$$

Alternatively, if earth was included in the system, we could express this as:

$$\Delta E_{th} + \Delta E_k + \Delta E_G = W_E$$

When the rotor is turning, the power supply does electrical work to drive current against the back emf and dissipates electrical energy as heat in the coils of the motor. The work done against the back emf provides the energy to raise the mass against the external force of gravity as well as to increase the kinetic energy of the mass.

The electrical energy provided by the power supply in the first stage is the product of the potential, current and time (the area under the current-time graph times average voltage). This is approximately:

$$Pt = VIt = 2V \times 2.1A \times 0.7s = 2.94J$$

The work done against the external force of gravity is the force due to gravity times the displacement (area under the v-t graph):

$$W_G = Fs\cos\theta = Fvt = 0.09 \times 9.8 \times (0.7s \times 0.4m/s + 0.5 \times 0.6m/s \times 0.7s) = 0.43J$$

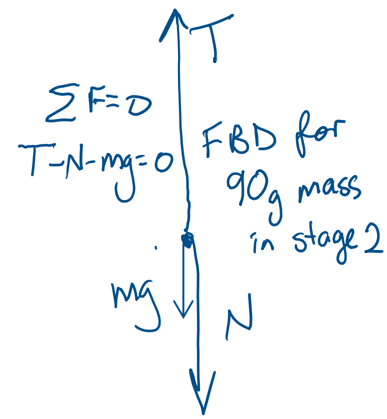
The change in kinetic energy is $\Delta E_k = \frac{1}{2}mv^2 = 0.5 \times 0.09 \times 1^2 = 0.05J$

It can be seen from conservation of energy that the bulk of the electrical energy supplied by the power supply is dissipated as heat in the coils.

$$\Delta E_{th} = W_E - W_G - \Delta E_k = 2.94 - 0.05 - 0.43 = 2.5J$$

Stage 2

Physics Involved:
The rotor is stationary as the torque acting on the motor shaft due to the tension (from the string) and the motor effect (as discussed in the first stage) is equal (zero net torque).
Alternatively, we can consider the forces acting on the mass. These are the weight force, the tension force due to the string upwards and the normal force on the mass due to the motor casing pushing on the mass once they make contact. Using Newton's 2nd law, and the fact that the mass has zero acceleration, we can reason that the sum of these forces is zero (see FBD, right).

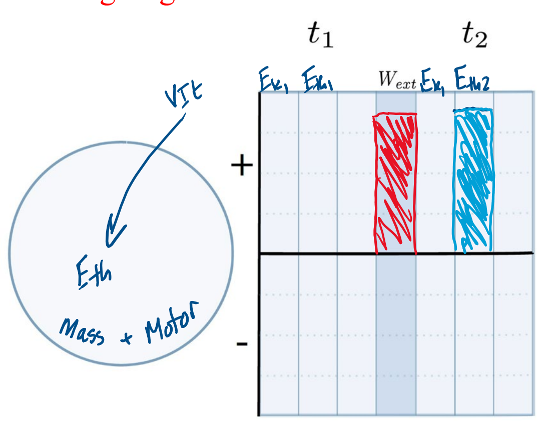


As the coil is not rotating in stage 2, there is no back emf (there is no change in B flux through the coil, so no emf as a result of Faraday's law).
When the shaft is stationary the current is given by $I_{stat} = \frac{\epsilon_{supply}}{R_{coils}}$ which is *larger* than when the coil was rotating.
As the current flowing through the coils determines the torque provided by the motor, via $\tau = nBIA$, this means that the torque due to the motor effect is also larger in stage 2 than it was in stage 1, and so the tension in the string is larger as $\tau_{max} r_{shaft} = T$.

Using information from figures 2 and 3, the resistance of the coils (+ contacts) is

$$R_{coils} = \frac{1.9V}{2.7A} = 0.70\Omega$$

Conservation of Energy:
Electrical energy continuously flows into the mass & motor system from the power supply at an (almost) constant rate in stage 2. This electrical energy is transformed into heat in the coils of the rotor during stage 2.



The total electrical energy transformed to thermal energy in the motor during stage 2 is
$Pt = VIt = 1.9V \times 2.7A \times 0.7s = 3.6J$.

<u>Stage 3</u>

Physics Involved:
During this stage the motor acts as a generator.
Using figure 1, the average acceleration of the 90g mass is $a_{av3} = \frac{(-2-0)m/s}{0.3s} = -6.7ms^{-2}$

$\Sigma F = ma$ FBD for 90g mass
$T - mg = ma$ T, mg

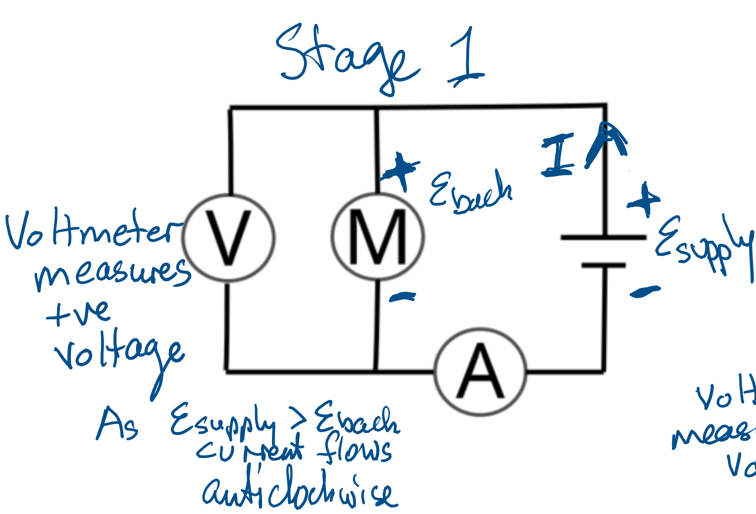
A net force downwards acts on the 90g mass equal to

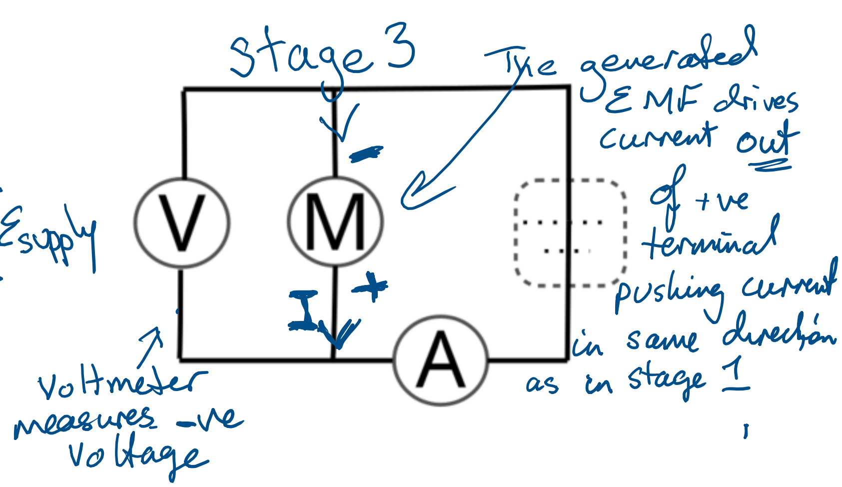
$$\Sigma F = 0.09kg \times (-6.7ms^{-2}) = -0.6N$$

The tension in the string is then:
$T = m(g + a) = 0.09 \times (9.8 - 6.7) = 0.28N$ upwards.
This tension exerts a torque on the shaft of the DC motor, causing an angular acceleration (increasing angular speed). The rotation of the shaft causes a change in magnetic flux and so an induced emf according to Faraday's law $\epsilon = -N\frac{d\phi_B}{dt}$, which drives a current.
A "back torque" is produced by the F = BIL force which acts on the generated current. This back torque produces a force on the string that is the reaction force to the tension force by Newton's 3rd law. If motor was not connected to a complete circuit, the mass would accelerate at close to g as the tension would be close to zero (equal to zero if there was no friction in the shaft), as there would be no back torque.

As the rotation of the shaft is in the opposite direction to stage 1, this means that the induced emf *is in the opposite direction to the induced emf during stage 1*, and is increasing in magnitude (as the rate of rotation is increasing) to a maximum value of 0.3V (from figure 3).

As the back emf during stage 1 would have driven current in the opposite direction to the supply voltage, this means that the induced current during stage 3 has to flow in the *same* direction as current in stages 1 and 2, which is what is observed in figure 2. The measured potential difference across the motor during stage 3 is negative.
To understand why this is the case (i.e. the measured potential difference is negative but the current is positive), consider the back emf during stage 1 (below left):



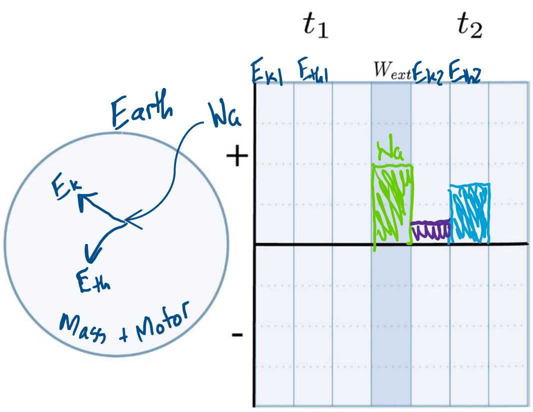


The back emf that appears across each coil in the motor during stage 1 must be in such a direction that it would act as a battery that "opposes" the supply (imagine connecting two batteries with the positive terminals together – current flows in the direction that the battery with the larger potential is trying to drive it – the current flows *against* the back emf, which is how electrical work is done). As the supply voltage is larger than the back emf, current flows out of the positive terminal of the power supply (anticlockwise in the circuit shown).

In stage 3, the "generator" is acting as a source of emf, so current flows *out* of its positive terminal, resulting in a current in the same direction as in stage 1 (see figure above right) *even though the potential difference is opposite in sign to the situation in stage 1.*

Conservation of Energy:
During stage 3, external work done by gravity is transferred to the system (if earth is included in the system this would instead be described as a change in gravitational potential energy).
Some of this work is converted to kinetic energy of the mass, and the remainder is converted to electrical energy, which is then dissipated as heat in the coils of the generator (as these are the only resistance in the circuit in stage 3, the power supply when switched off has no resistance).

Applying conservation of energy:



$W_G = \Delta E_k + \Delta E_{th}$

The work done by gravity is the external force of gravity times the displacement of the 90g mass, which is the weight times the area under the velocity-time graph during stage 3. The mass moves through a distance equal to the area under the velocity-time graph

$$\Delta y = \frac{1}{2} 2.6ms^{-1} \times 0.4s = 0.52m$$

The work done by the force of gravity is then

$$W_G = mg\Delta y = 0.09kg \times (-9.8ms^{-2}) \times (-0.52m) = 0.46J$$

The change in kinetic energy of the mass is

$$\Delta KE = \frac{1}{2}mv^2 - \frac{1}{2}mu^2 = \frac{1}{2} \times 0.09kg \times (2.6ms^{-1})^2 = 0.30J$$

By conservation of energy $W_G = \Delta KE + \Delta E_E$, so the electrical energy produced (which is dissipated as heat in the coils of the motor) is:

$$\Delta E_E = 0.46J - 0.3J = 0.16J$$

Most of the work done by gravity is therefore converted into kinetic energy of the mass, and only a small fraction produces electrical work in the generator.

END OF PAPER