Sydney Boys High School

Student Number:

Multiple Choice Answer Sheet

Select the alternative A, B, C or D that best answers the question. Fill in the response oval completely.

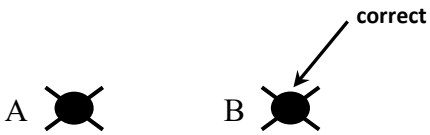
Sample: 2 + 4 = (A) 2 (B) 6 (C) 8 (D) 9

A ○ B ● C ○ D ○

If you think you have made a mistake, put a cross through the incorrect answer and fill in the new answer.

A ● B ⊗ C ○ D ○

If you change your mind and have crossed out what you consider to be the correct answer, then indicate the correct answer by writing the word **correct** and drawing an arrow as follows.



A ⊗ B ⊗ C ○ D ○

Start Here ➔

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

Sydney Boys High School

Student Number:

Physics

August 2020
Trial Exam

General Instructions

- Reading time: 5 minutes
- Working time: 3 hours
- Write using black pen
- Draw diagrams using pencil
- SHOW ALL WORKING
- Calculators approved by NESA may be used
- A data sheet, formulae sheet and Periodic Table are provided at the back of this paper
- Write your student number in ALL of the boxes provided

Total marks: 100

Section I – Multiple Choice
- 20 marks
- Allow about 35 minutes for this section

Section II – Free Response
- 80 marks
- Allow about 2 hours and 25 minutes for this section

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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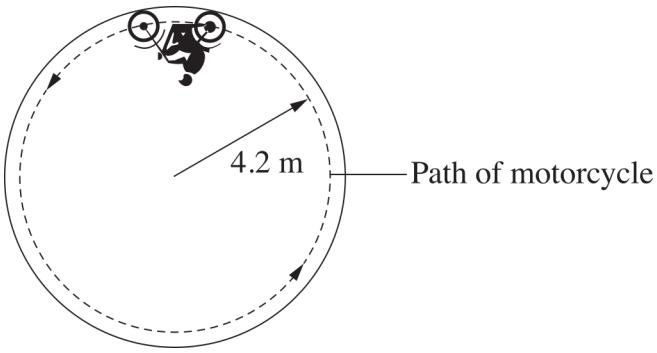
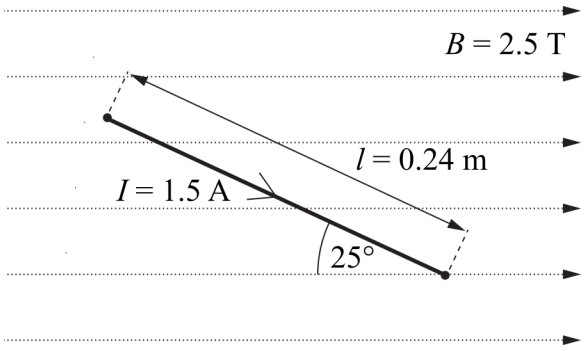
1. A motorcycle travels around a vertical circular path of radius 4.2 m at a constant speed. The combined mass of the rider and motorcycle is 360 kg.



What is the minimum speed, in m s^{-1}, at which the motorcycle must travel to maintain the circular path?

A. 0.49
B. 2.3
C. 6.4
D. 41

2. The diagram shows a current-carrying conductor in a magnetic field.



What is the magnitude of the force on the conductor?

A. 0 N
B. 0.38 N
C. 0.82 N
D. 0.90 N

3. The length of a spaceship is measured by an observer to be 13.2 m as the spaceship passes with a velocity of 0.75c.

At what velocity would the spaceship be moving relative to the observer if its measured length was 10.5 m?

A. 0.606c
B. 0.633c
C. 0.795c
D. 0.850c

4. The table lists the first generation of quarks and antiquarks.

	Name	*Symbol*	*Charge*
Quarks	Up	u	$+\frac{2}{3}\text{e}$
	Down	d	$-\frac{1}{3}\text{e}$
Antiquarks	Antiup	$\bar{u}$	$-\frac{2}{3}\text{e}$
	Antidown	$\bar{d}$	$+\frac{1}{3}\text{e}$

The Standard Model of matter states that baryons, such as protons and neutrons, are comprised of three quarks, while mesons, like the pions π^+ and π^-, are comprised of one quark and one antiquark.

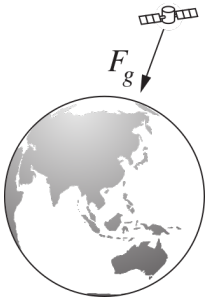
Using the table, which of the following represents the quark composition for a proton and a negative pion, respectively?

A. udd and $\bar{u}d$
B. udd and $u\bar{d}$
C. uud and $\bar{u}d$
D. $uud$and $u\bar{d}$

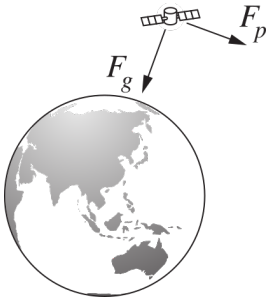
5. Which of the following diagrams correctly represents the force(s) acting on a satellite in a stable circular orbit around Earth?

F_g = gravitational force	F_p = propulsive force
F_c = centripetal force	F_N = normal force

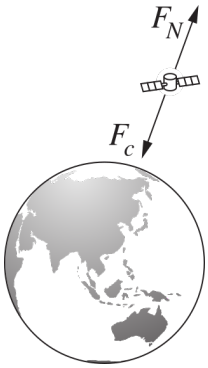
A.



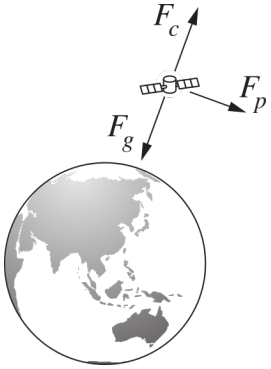
B.



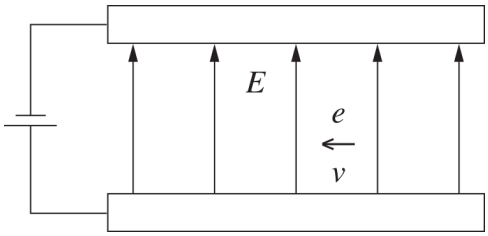
C.



D.



6. An electron, e, travelling with a velocity, v, passes through an electric field, E, between two parallel plates.



What is the direction of the force that this electric field exerts on the electron?

A. ↓
B. ↙
C. ↖
D. ↑

7. Which statement describes how an electromagnetic wave is propagated?

A. An oscillating magnetic field causes an oscillating electric field parallel to the magnetic field.
B. An oscillating magnetic field causes a constant electric field perpendicular to the magnetic field.
C. An oscillating electric field causes a constant magnetic field parallel to the electric field.
D. An oscillating electric field causes an oscillating magnetic field perpendicular to the electric field.

8. JJ Thomson determined the charge/mass ratio of the electron by constructing a device which contained

A. perpendicular electric fields.
B. perpendicular magnetic fields.
C. perpendicular electric and magnetic fields.
D. parallel electric and magnetic fields.

9. A ball is launched horizontally from a cliff with an initial velocity of u m s^{-1}. After three seconds, the ball's velocity is in the direction 60° from the horizontal.

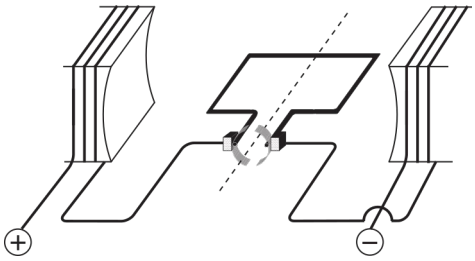
What is the magnitude of the velocity in m s^{-1} at three seconds?

A. 0.6 u
B. 1.7 u
C. 29.4
D. 33.9

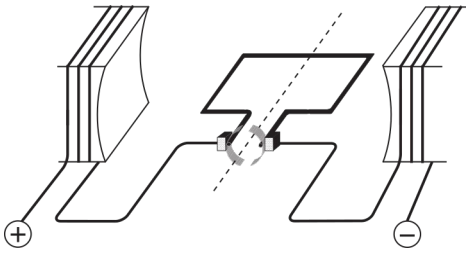
10. The diagrams show possible ways to connect the coils and rotor of a DC motor to a DC power supply.

In which circuit will the rotor turn in an anticlockwise direction?

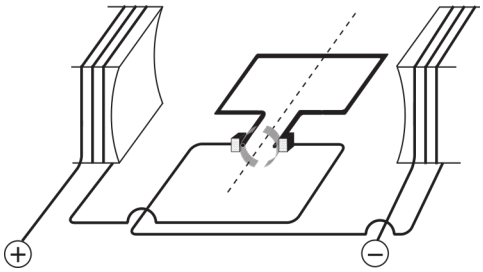
A.



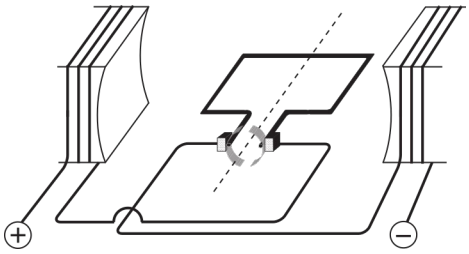
B.



C.

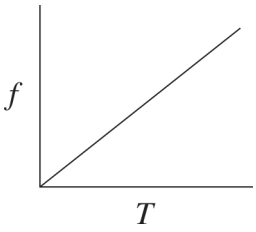


D.

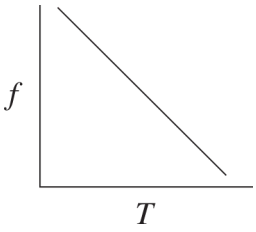


11. Which graph correctly shows the relationship between the surface temperature of a black body (T) and the frequency (f) at which the maximum intensity of light is emitted?

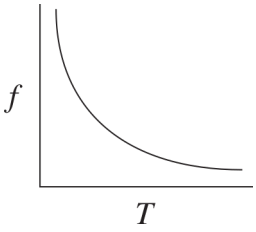
A.



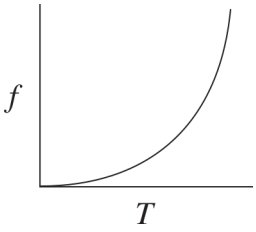
B.



C.



D.



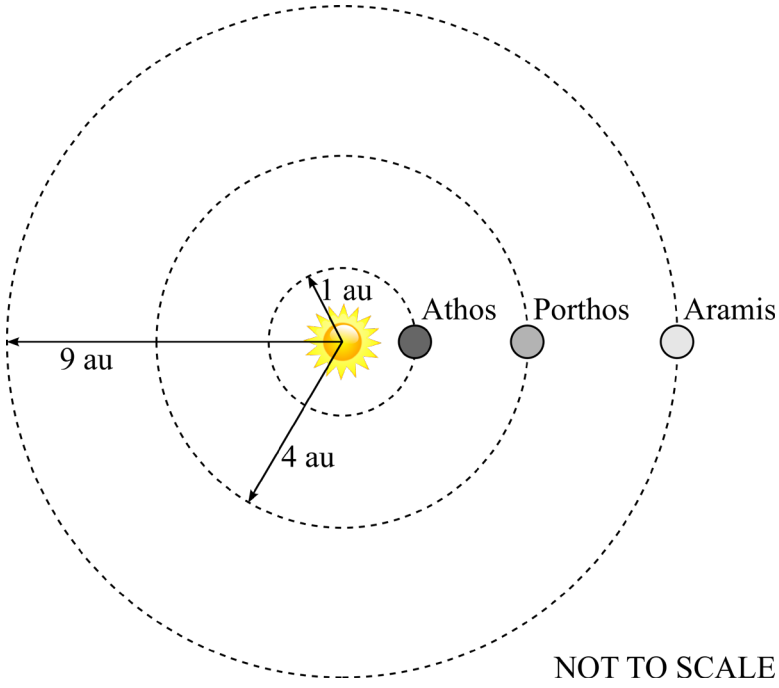
12. An experiment was conducted to model Millikan's oil drop experiment. In the experiment, different numbers of identical coins were placed inside five identical boxes. The boxes were then sealed and weighed. The table shows the mass of each sealed box and some preliminary analysis.

Box number	*Mass of box (including coins) (g)*	*Difference in mass from previous box (g)*
1	12.8	—
2	20.3	7.5
3	25.3	5.0
4	37.8	12.5
5	57.8	20.0

What is the best value for the mass of a single coin?

A. 1.5 g
B. 2.5 g
C. 5.0 g
D. 7.5 g

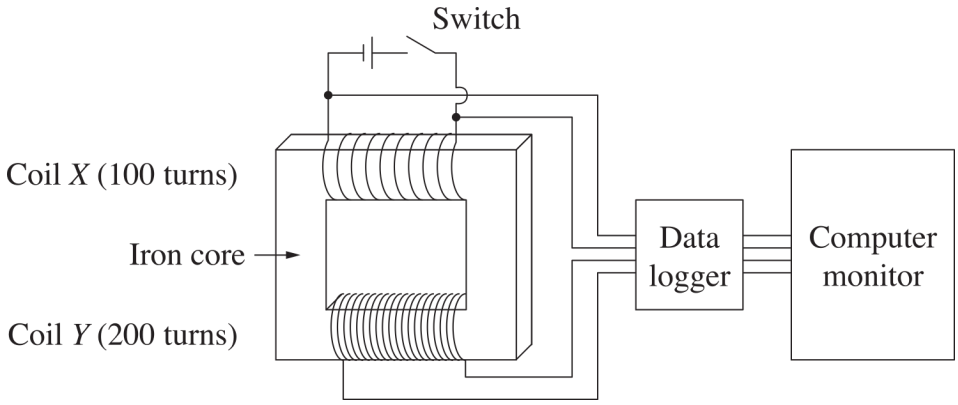
13. A solar system has three planets, Athos, Porthos and Aramis, orbiting the same star. On a given date, all three planets are aligned, as shown below.



If a civilisation lives on the planet Athos, and they celebrate this alignment with a festival, how many Athos years will they have to wait until the next festival?

A. 6
B. 14
C. 36
D. 216

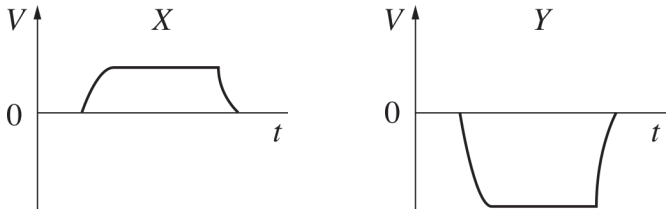
14. The apparatus shown is designed to investigate the operation of a transformer.



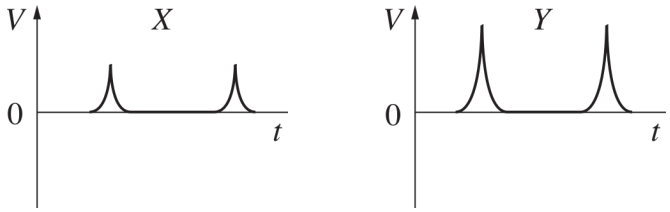
A student closes the switch for a short time, then opens it. The data logger records values of voltage for both coils for the duration of the investigation. The data logger software displays the results as a pair of voltage–time graphs on a computer monitor.

Which pair of graphs best depicts the student's results?

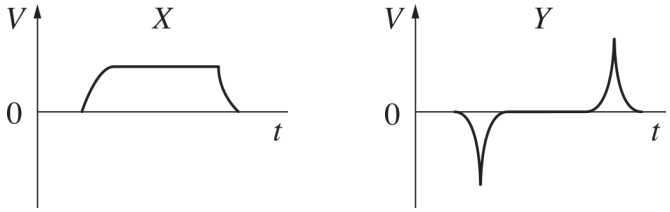
A.



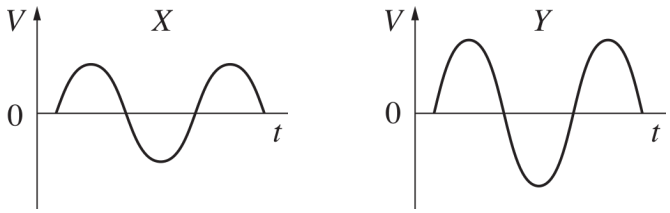
B.



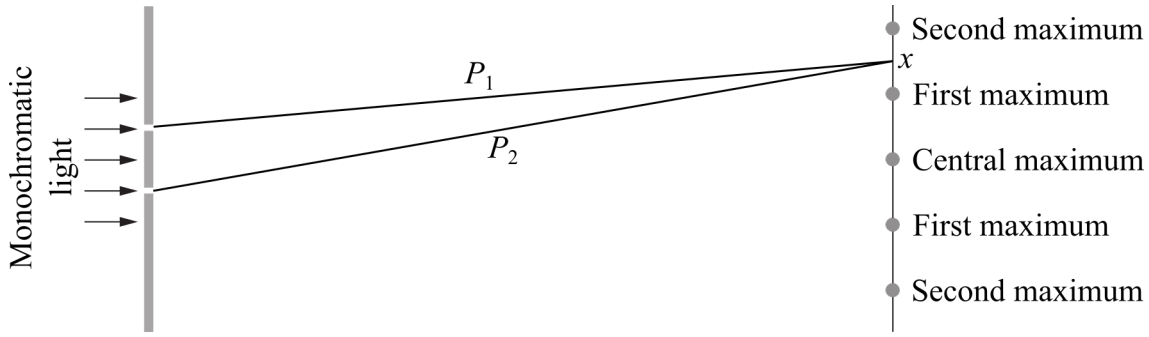
C.



D.



15. Monochromatic light passes through two slits to produce an interference pattern. Light from the top slit travels along path P_1 and light from the bottom slit travels along P_2, meeting at x.



What is the difference in length between P_1 and P_2?

A. $\frac{1}{2}\lambda$

B. λ

C. $\frac{3}{2}\lambda$

D. 2λ

16. The following equation describes the natural decay process of polonium-210.

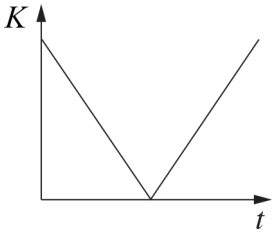
$$^{210}_{84}\text{Po} \longrightarrow {}^{206}_{82}\text{Pb} + {}^{4}_{2}\text{He}$$

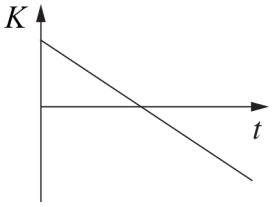
Which row of the table describes the changes in total mass and total binding energy in the decay of polonium-210?

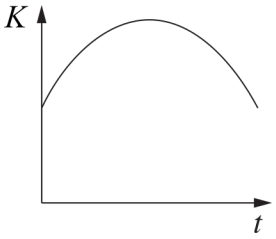
	Total mass	*Total binding energy*
A.	Decreases	Decreases
B.	Decreases	Increases
C.	Increases	Decreases
D.	Increases	Increases

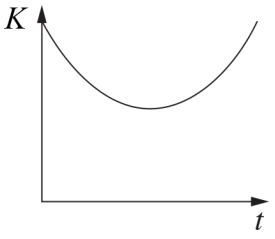
17. A ball was thrown upward at an angle of 45°. It landed at the same height as thrown.

Which graph best represents the kinetic energy of the ball during its time of flight?

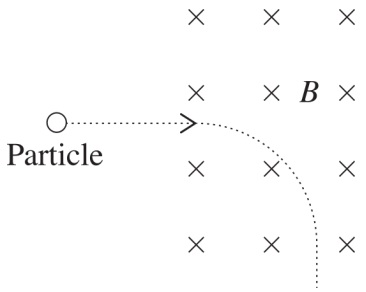
A. 

B. 

C. 

D. 

18. A particle of mass m and charge q travelling at velocity v enters a magnetic field of magnitude B and follows the path shown.

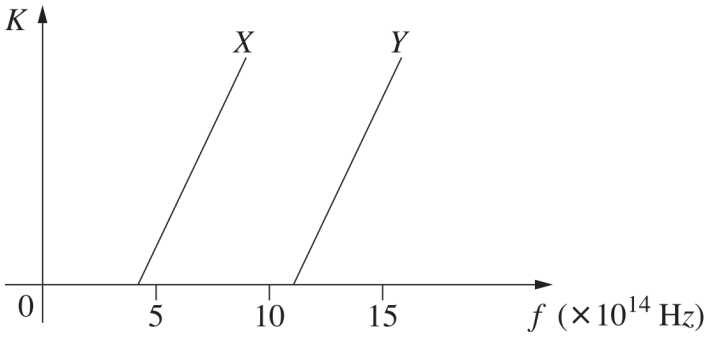


A second particle enters a magnetic field of magnitude $2B$ with a velocity of $\frac{1}{2}v$ and follows an identical path.

What is the charge and mass of the second particle?

	Charge	*Mass*
A.	q	m
B.	$\frac{1}{2}q$	$2m$
C.	q	$4m$
D.	q	$\frac{1}{2}m$

19. The graph shows the maximum kinetic energy (K) with which photoelectrons are emitted as a function of frequency (f) for two different metals X and Y.



The metals are illuminated with light of wavelength 300 nm.

What would be the effect of doubling the intensity of this light without changing the wavelength?

A. For metal X, the number of photoelectrons emitted would not change but the maximum kinetic energy would increase.

B. For metal X, the number of photoelectrons emitted would increase but the maximum kinetic energy would remain unchanged.

C. For both metals X and Y, the number of photoelectrons emitted would not change but the maximum kinetic energy would increase.

D. For both metals X and Y, the number of photoelectrons emitted would increase but the maximum kinetic energy would remain unchanged.

20. The table shows the quantum numbers of the four lowest states of the hydrogen atom, together with the energies of those states.

Quantum number	*Energy (eV)*
1	−13.6
2	−3.4
3	−1.5
4	−0.85

Which quantum transition will absorb a photon of wavelength 122 nm?

A. 1 to 2

B. 1 to 3

C. 2 to 1

D. 3 to 1

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Student Number:

Sydney Boys High School 2020 Trial

Physics

Section II Answer Booklet

80 marks
Attempt Questions
Allow about 2 hours and 25 minutes for this section

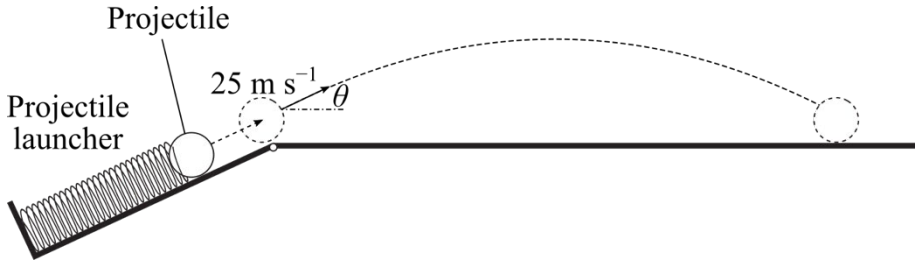
Instructions

- Write your Student Number at the top of this page.
- 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 question you are answering.

Please turn over

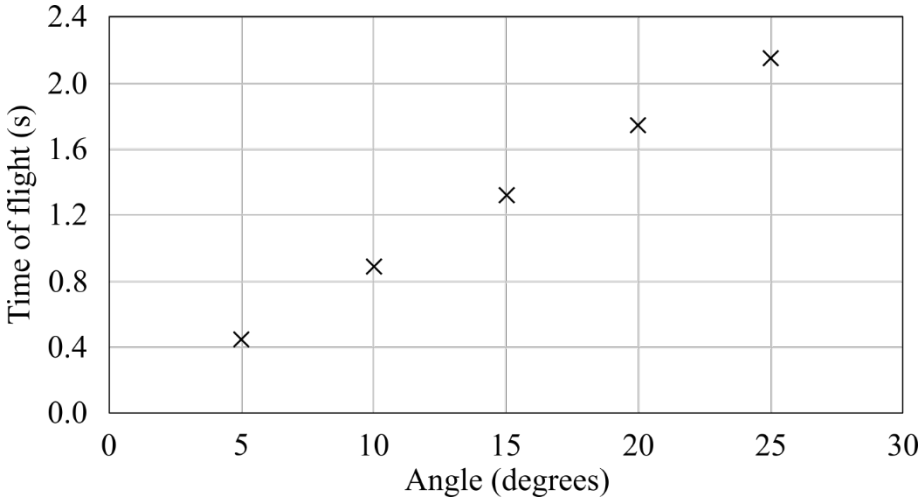
Question 21 (6 marks)

A student carried out an experiment to investigate the effect of the angle at which a projectile is launched and its time of flight. The projectile launcher is designed to launch the projectile with an initial velocity of 25 m s^{-1}, and it can be tilted to change the launch angle, as shown.



Video analysis allowed the time of flight to be accurately determined.

The data from the experiment is graphed below.



Question 21 continues on page 15

Question 21 (continued)

The student concluded that the time of flight (t) was proportional to the launch angle (θ) and proposed the mathematical model

$$t = k\theta$$

where $k = 0.087$ s degree^{-1}

(a) Justify the validity of the student's model using information from the graph. **3**

(b) What happens to the accuracy of the model's predictions as the angle increases beyond 25°? Justify your answer with reference to a different mathematical model. **3**

End of Question 21

Question 22 (7 marks)

The primary winding of a transformer contains 2500 turns. The primary AC voltage is 5000 V and the output voltage is 45 000 V.

(a) Calculate the number of turns on the secondary winding. **2**

(b) If the current in the primary winding of the transformer is 80 A, and the secondary winding has a resistance of 1200 Ω, what is the power loss in the secondary winding, assuming there is no power loss in the primary winding? **3**

(c) Explain why AC is preferable to DC as an input current for transformers. **2**

Question 23 (6 marks)

A laser emits a 1 W beam of blue light with a wavelength 425 nm.

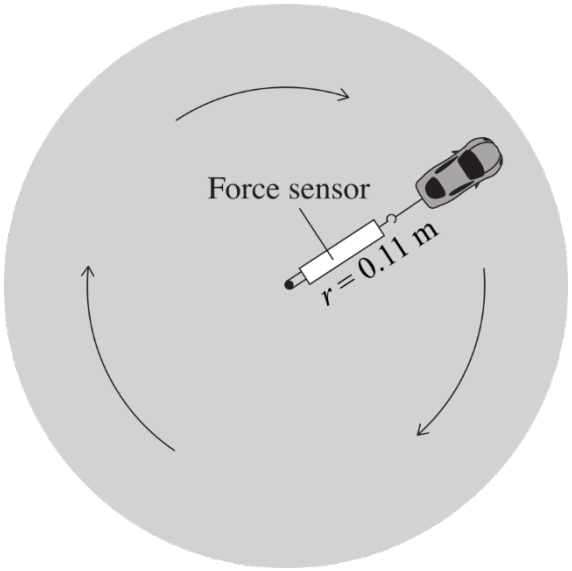
(a) Calculate the number of photons which are required to transfer 5.50×10^{-4} J of energy. **2**

(b) If the laser is shone on the surface of a potassium plate, $\phi = 2.29$ eV, calculate the maximum kinetic energy of the photoelectrons. **2**

(c) With reference to the particle model of light, contrast the 1 W beam of blue light and a 1 W beam of red light. **2**

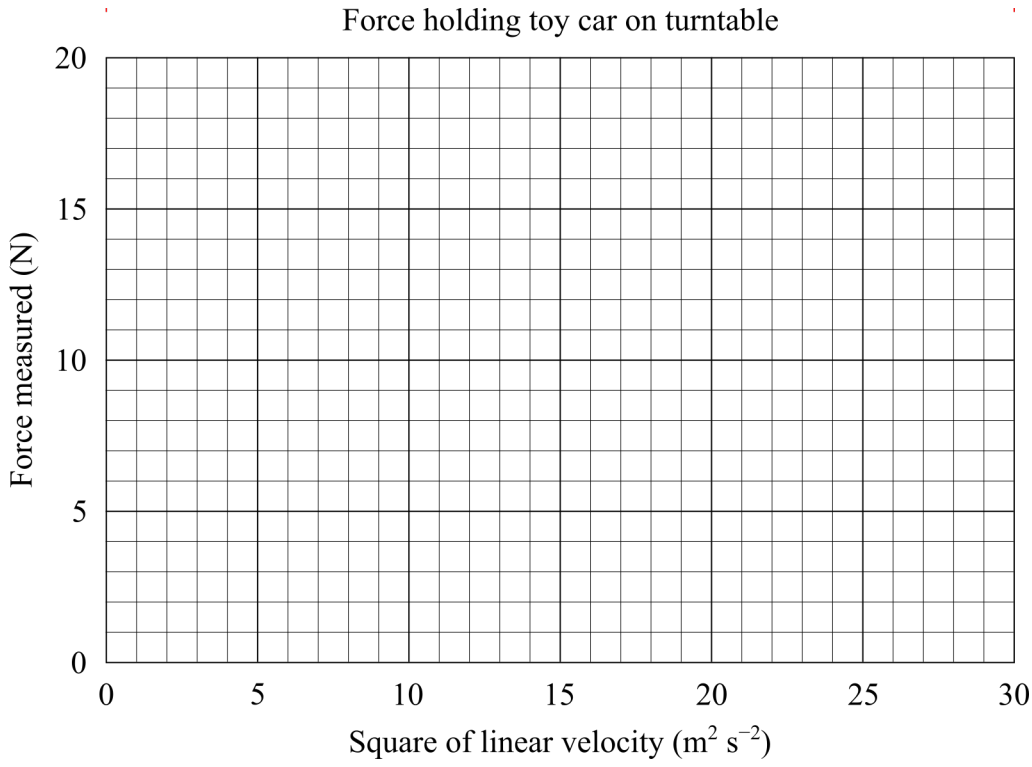
Question 24 (9 marks)

A toy car was placed facing outwards on a rotating turntable. The car was held in place by a force sensor connected to the centre of the turntable. The centre of mass of the car was 0.11 metres from the centre of the turntable. The reading from the force sensor was recorded at varying speeds of rotation. A stopwatch was used to time the rotation of the turntable. The linear velocity was calculated from the period of rotation. The graph shows the force measured versus the square of the linear velocity of the car and the results are shown in the table.



Square of linear velocity ($m^2\ s^{-2}$)	*Force measured (N)*
1.0	0.0
4.0	0.5
9.0	4.5
16.0	9.0
25.0	16.0

(a) Plot the data and draw the line of best fit. **2**



Question 24 continues on page 18

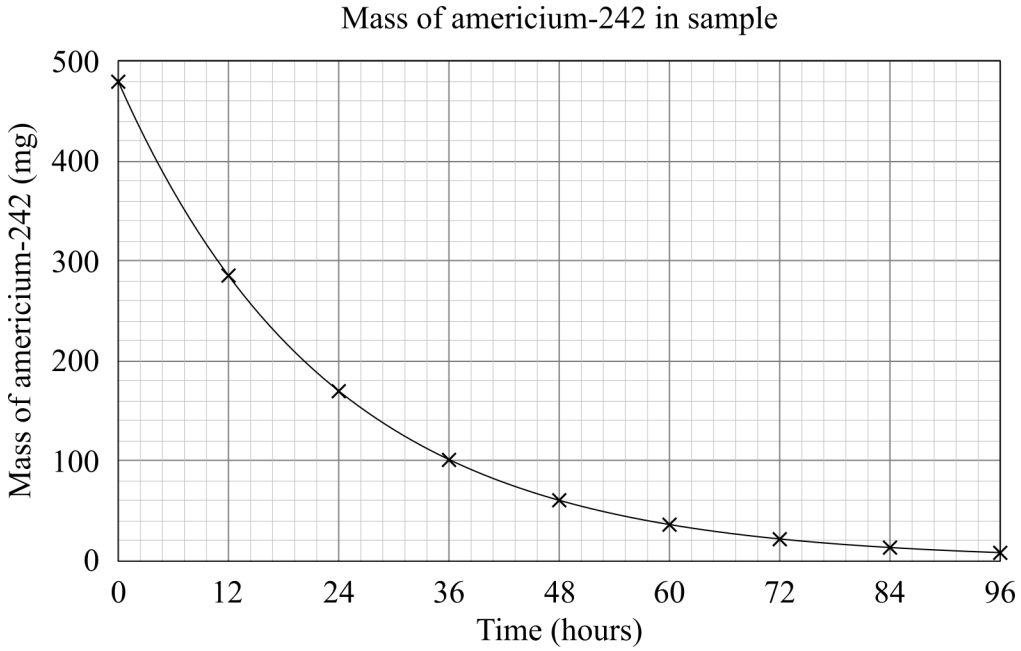
(b) Use the line of best fit to determine the mass of the car. **3**

(c) Identify possible errors in the experimental method and outline how to reduce their effects on the results. **4**

End of Question 24

Question 25 (4 marks)

A scientist investigated the radioactivity of a sample of americium-242. She measured the mass of americium remaining in the sample every 12 hours over a period of 4 days. The results are shown in the graph below.



(a) From the graph, determine the half life of americium-242. **1**

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(b) Calculate the decay constant of americium-242 in SI units. **1**

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(c) Americium-242 undergoes β^- decay. Write the full nuclear equation for this radioactive decay. **2**

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Question 26 (4 marks)

An electric motor can be used to propel a vehicle. The electric motor can be made to operate as a generator when the vehicle is moving. This will have a braking effect on the vehicle. **4**

Explain the physics principles involved in the propelling and braking of this vehicle.

Question 27 (4 marks)

Explain how particle accelerators provide evidence for the Standard Model of matter. **4**

Question 28 (6 marks)

How did Einstein's theory of special relativity and his explanation of the photoelectric effect lead to the reconceptualisation of the model of light? **6**

Question 29 (6 marks)

A satellite of mass 2000 kg is launched from Earth's surface into a uniform circular orbit of radius 8.0×10^6 m.

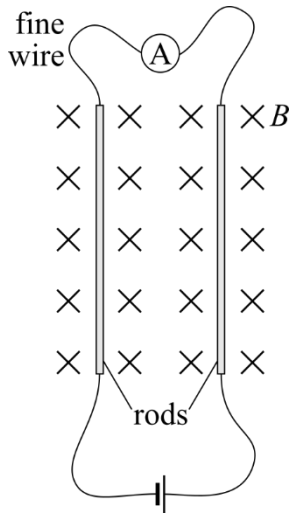
(a) Calculate the magnitude of the gravitational potential energy of the satellite in this orbit. **1**

(b) Calculate the orbital velocity of the satellite. **2**

(c) The satellite uses its thrusters to move into a uniform circular orbit with double the original orbital radius. In doing so, it loses half of its mass in fuel used. Calculate the chemical energy contained in the used fuel. **3**

Question 30 (4 marks)

Two metal rods, each of length l, lie on a frictionless surface inside a magnetic field of strength B, and are connected in series by fine wire to a power supply and an ammeter that reads the current I, as shown. **4**



Show that the rods will reach an equilibrium distance between them given by

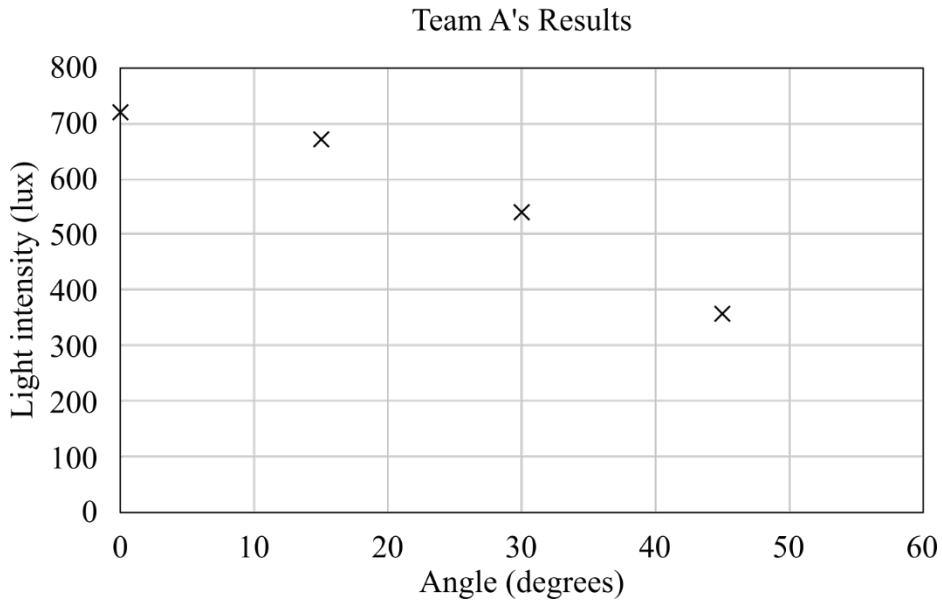
$$r = \frac{\mu_0}{2\pi}\frac{I}{B}.$$

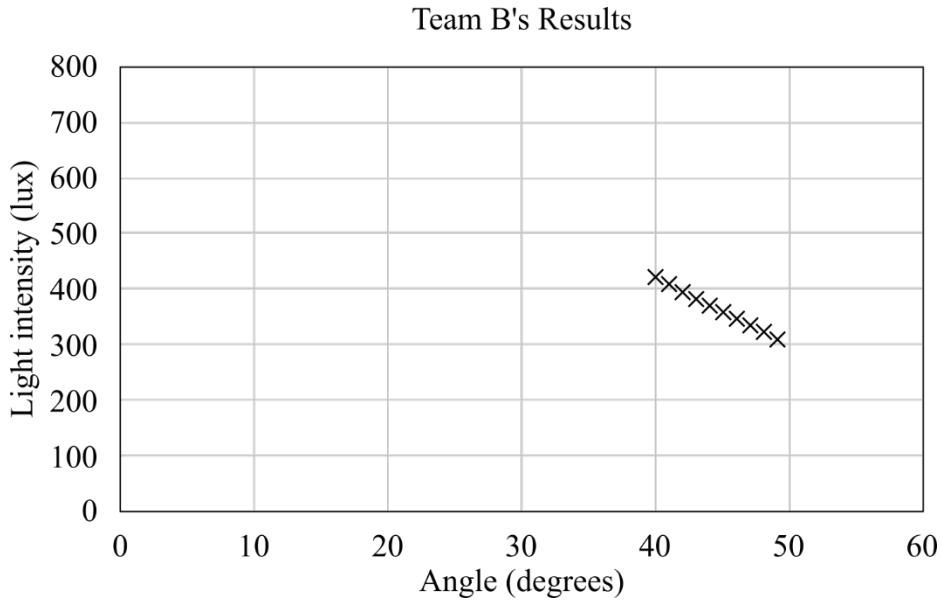
Justify your answer.

Question 31 (5 marks)

Two teams carried out independent experiments with the purpose of investigating Malus's Law. Each team used the same procedure to accurately measure the intensity of light after passing through two polarisers with different angles between their transmission axes.

The following graphs show the data collected by each team.





Question 31 continues on page 26

(a) Compare and contrast, qualitatively, the relationship between light intensity and angle in the graphs. **2**

(b) Assess the appropriateness of Team A's data and Team B's data in achieving the purpose of the experiments. **3**

End of Question 31

Question 32 (8 marks)

"Nuclear fission reactions, such as ${}^{235}_{92}\mathrm{U} + {}^{1}_{0}n \longrightarrow {}^{144}_{56}\mathrm{Ba} + {}^{89}_{36}\mathrm{Kr} + 3{}^{1}_{0}n$, can be used as a source of energy." **8**

Use the data below to evaluate this statement with reference to the contributions of Rutherford, Einstein and Fermi to the development of nuclear power.

Nuclide	*Mass (u)*
${}^{235}_{92}\mathrm{U}$	235.0439299
${}^{144}_{56}\mathrm{Ba}$	143.9229529
${}^{89}_{36}\mathrm{Kr}$	88.9176306
${}^{1}_{0}n$	1.0086649

Question 32 continues on page 28

Question 32 (continued)

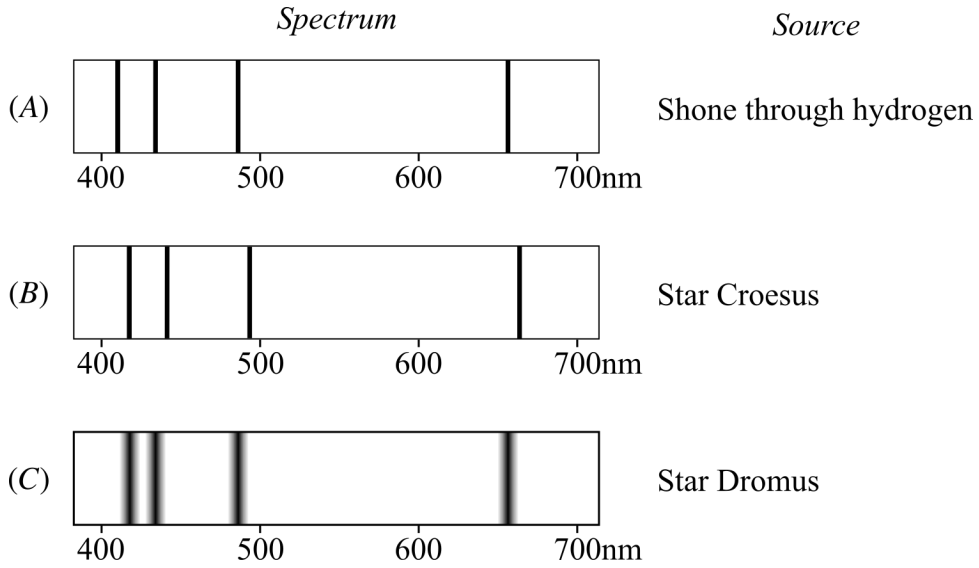
End of Question 32

Question 33 (7 marks)

Part *A* of the figure shows the absorption spectrum of light, produced by an incandescent filament, after it has been shone through a quantity of hydrogen gas.

Also shown in the figure are the spectra obtained from two stars, Star Croesus in part *B* and Star Dromus in part *C*.

The dark lines are absorption bands in *A*, *B* and *C*.



(a) Explain how the spectrum in *A* provides experimental evidence in support of Bohr's model of the hydrogen atom. **3**

Question 33 continues on page 29

(b) For each star, Croesus and Dromus, identify the principal way in which its spectrum differs from the spectrum shown in part *A* of the figure. **2**

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(c) For each star, Croesus and Dromus, state what its spectrum tells us about the motion of that star. **2**

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End of Question 33

Question 34 (4 marks)

An electron and a proton particle are fired into a uniform magnetic field with the same speed from opposite sides as shown. Their trajectories are initially perpendicular to the field. **4**

Explain ONE similarity and ONE difference in their trajectories as they move in the magnetic field.

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End of paper

Section II extra writing space

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

Sydney Boys High School

Student Number:

Physics

August 2020
Trial Exam

General Instructions

- Reading time: 5 minutes
- Working time: 3 hours
- Write using black pen
- Draw diagrams using pencil
- SHOW ALL WORKING
- Calculators approved by NESA may be used
- A data sheet, formulae sheet and Periodic Table are provided at the back of this paper
- Write your student number in ALL of the boxes provided

Total marks: 100

Section I – Multiple Choice
- 20 marks
- Allow about 35 minutes for this section

Section II – Free Response
- 80 marks
- Allow about 2 hours and 25 minutes for this section

Sydney Boys High School

Student Number:

Multiple Choice Answer Sheet

Select the alternative A, B, C or D that best answers the question. Fill in the response oval completely.

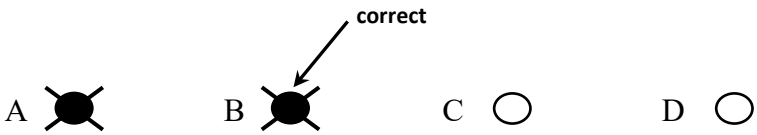
Sample: 2 + 4 =

(A) 2 (B) 6 (C) 8 (D) 9

A ○ B ● C ○ D ○

If you think you have made a mistake, put a cross through the incorrect answer and fill in the new answer.

If you change your mind and have crossed out what you consider to be the correct answer, then indicate the correct answer by writing the word **correct** and drawing an arrow as follows.



Start Here ➔

1.	A○	B○	C●	D○	2016 Q18	**11.**	A●	B○	C○	D○	2019 Q6
2.	A○	B●	C○	D○	2018 Q5	**12.**	A○	B●	C○	D○	Sample p. 67
3.	A○	B○	C○	D●	2017 Q20	**13.**	A○	B○	C○	D●	
4.	A○	B○	C●	D○	Sample p. 79	**14.**	A○	B○	C●	D○	2006 Q10
5.	A●	B○	C○	D○	2015 Q11	**15.**	A○	B○	C●	D○	Sample p. 54
6.	A●	B○	C○	D○	2011 Q19	**16.**	A○	B●	C○	D○	Sample p. 77
7.	A○	B○	C○	D●	Sample p. 52	**17.**	A○	B○	C○	D●	2010 Q4
8.	A○	B○	C●	D○	2010 Q17	**18.**	A○	B●	C●	D○	2017 Q18
9.	A○	B●	C○	D●	2014 Q20	**19.**	A○	B●	C○	D○	2013 Q20
10.	A○	B○	C○	D●	2010 Q20	**20.**	A●	B○	C○	D○	Sample p. 75

Student Number:

Sydney Boys High School 2020 Trial

Physics

Section II Answer Booklet

80 marks
Attempt Questions
Allow about 2 hours and 25 minutes for this section

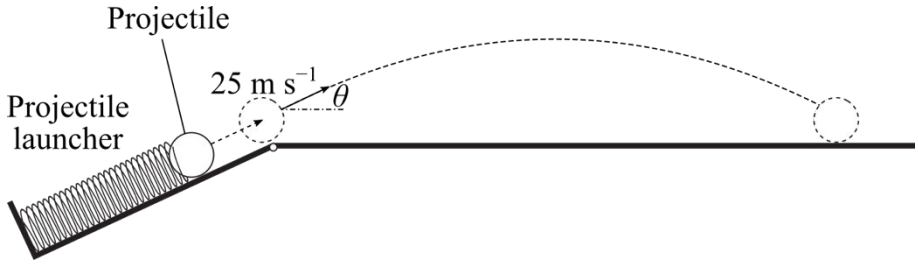
Instructions

- Write your Student Number at the top of this page.
- 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 question you are answering.

Please turn over

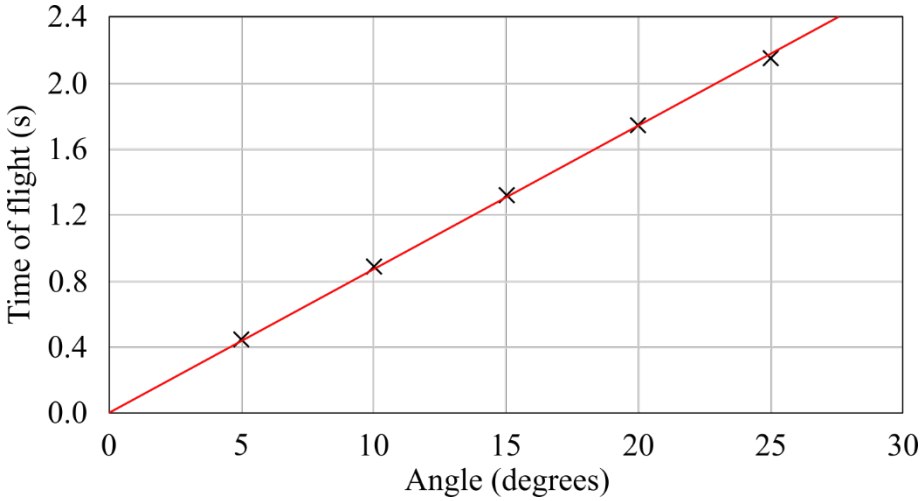
Question 21 (6 marks) 2019 Q26

A student carried out an experiment to investigate the effect of the angle at which a projectile is launched and its time of flight. The projectile launcher is designed to launch the projectile with an initial velocity of 25 m s^{-1}, and it can be tilted to change the launch angle, as shown.



Video analysis allowed the time of flight to be accurately determined.

The data from the experiment is graphed below.



Question 21 continues on page 5

Question 21 (continued)

The student concluded that the time of flight (t) was proportional to the launch angle (θ) and proposed the mathematical model

$$t = k\theta$$

where $k = 0.087$ s degree^{-1}

(a) Justify the validity of the student's model using information from the graph. **3**

Marking:
✓ identifies linear trend of data
✓ calculates gradient of linear trend (shows all working)
✓ statement of validity relating to k=0.087

Sample answer:
The data on the graph shows a clear linear trend, with all of the data points being on or very close to the line of best fit. In addition, the line of best fit passes through the origin, indicating that the there is a direct linear relationship. From the line of best fit:

$$gradient = \frac{y_2 - y_1}{x_2 - x_1} = \frac{2.4 - 0}{27.5 - 0} = 0.087$$

Therefore, the constant of proportionality, k, is equal to 0.087 s degree^{-1}.

(b) What happens to the accuracy of the model's predictions as the angle increases beyond 25°? Justify your answer with reference to a different mathematical model. **3**

Marking:
✓ identifies decreasing accuracy for $\theta > 25°$
✓ identifies better model ($t = \frac{2u}{a_y}\sin\theta$)
✓ justifys decreasing accuracy relates to small angle approximation/sin θ

Sample answer:
The student's model of $t = k\theta$ will decrease in accuracy as the angle increases beyond 25°. This is because the time of flight is related to the launch angle through $v_y = u_y + a_y t$. Given the symmetry of the parabolic trajectory, $v_y = -u_y$ and $-u_y = u_y + a_y t$. Therefore:

$$t = -\frac{2u_y}{a_y} = \frac{2u}{g}\sin\theta$$

The small angle approximation $\theta \approx \sin\theta$ only applies to smaller angles (in radians), as the name implies. Beyond 25°, the small angle approximation becomes less true, and the equation $t = k\theta$ will become less and less accurate.

End of Question 21

Question 22 (7 marks) 2014 Q24/2005 Q26

The primary winding of a transformer contains 2500 turns. The primary AC voltage is 5000 V and the output voltage is 45 000 V.

(a) Calculate the number of turns on the secondary winding. **2**

Marking:
✓ correct equation
✓ correct substition

Sample answer:

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

$$N_s = N_p \frac{V_s}{V_p} = 2500 \times \frac{45000}{5000} = 22500 \text{ turns}$$

(b) If the current in the primary winding of the transformer is 80 A, and the secondary winding has a resistance of 1200 Ω, what is the power loss in the secondary winding, assuming there is no power loss in the primary winding? **3**

Marking:
✓ use of correct equations
✓ correct calculation of I_s
✓ correctly relates I_s to P

Sample answer:

$$V_p I_p = V_s I_s$$

$$I_s = I_p \frac{V_p}{V_s} = 80 \times \frac{5000}{45000} = 8.89 \text{ A}$$

$$P_{loss} = I^2 R = 8.89^2 \times 1200 = 94815 \text{ W} = 95 \text{ kW}$$

note: watch units

(c) Explain why AC is preferable to DC as an input current for transformers. **2**

Marking:
✓ contrasts AC & DC current
✓ relates ΔI to function of transformer

Sample answer:
AC is preferable because it involves a constantly changing current. A constantly changing current is necessary for transformers to function because it will leads to a changing flux in the primary and secondary coils. This will lead to an induced EMF, or voltage, in the secondary coils (according to Faraday's Law). Therefore, the changing input current leads to an output voltage. DC, on the other hand, has a constant current and will not lead to an induced EMF.

Question 23 (6 marks) 2011 Q29

A laser emits a 1 W beam of blue light with a wavelength 425 nm.

(a) Calculate the number of photons which are required to transfer 5.50×10^{-4} J of energy. **2**

Marking:
✓ correct energy of photon
✓ correct answer

Sample answer:

$$E_{photon} = hf = \frac{hc}{\lambda} = \frac{6.626\times10^{-34}\times3.00\times10^{8}}{425\times10^{-9}} = 4.68\times10^{-19}\text{ J}$$

$$n = \frac{E_{laser}}{E_{photon}} = \frac{5.50\times10^{-4}}{4.68\times10^{-19}} = 1.18\times10^{15}\text{ photons}$$

(b) If the laser is shone on the surface of a potassium plate, $\phi = 2.29$ eV, calculate the maximum kinetic energy of the photoelectrons. **2**

Marking:
✓ correct equation & substitution (carry on allowed)
✓ correct conversion between J & eV

Sample answer:

$$E_J = E_{eV}e = 2.29\times1.602\times10^{-19} = 3.67\times10^{-19}\text{ J}$$

$$K_{max} = hf - \phi = E_{photon} - \phi = 4.68\times10^{-19} - 3.67\times10^{-19} = 1.01\times10^{-19}\text{ J}$$
$$= 0.630\ eV$$

(c) With reference to the particle model of light, contrast the 1 W beam of blue light and a 1 W beam of red light. **2**

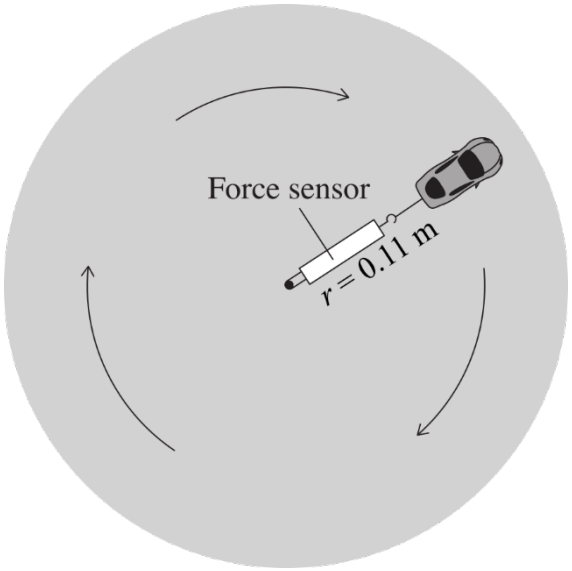
Marking:
✓ distinguishes energy of photons
✓ distinguishes number of photons

Sample answer:
The red light photons have a lower energy than the blue light photons.
Therefore, in order to produce a 1 W beam of light, there must be more photons of red light than photons of blue light.

notes: * both light sources are 1 W of power
* must refer to photons specifically

Question 24 (9 marks) Sample p. 19

A toy car was placed facing outwards on a rotating turntable. The car was held in place by a force sensor connected to the centre of the turntable. The centre of mass of the car was 0.11 metres from the centre of the turntable. The reading from the force sensor was recorded at varying speeds of rotation. A stopwatch was used to time the rotation of the turntable. The linear velocity was calculated from the period of rotation. The graph shows the force measured versus the square of the linear velocity of the car and the results are shown in the table.



Square of linear velocity ($m^2\ s^{-2}$)	*Force measured (N)*
1.0	0.0
4.0	0.5
9.0	4.5
16.0	9.0
25.0	16.0

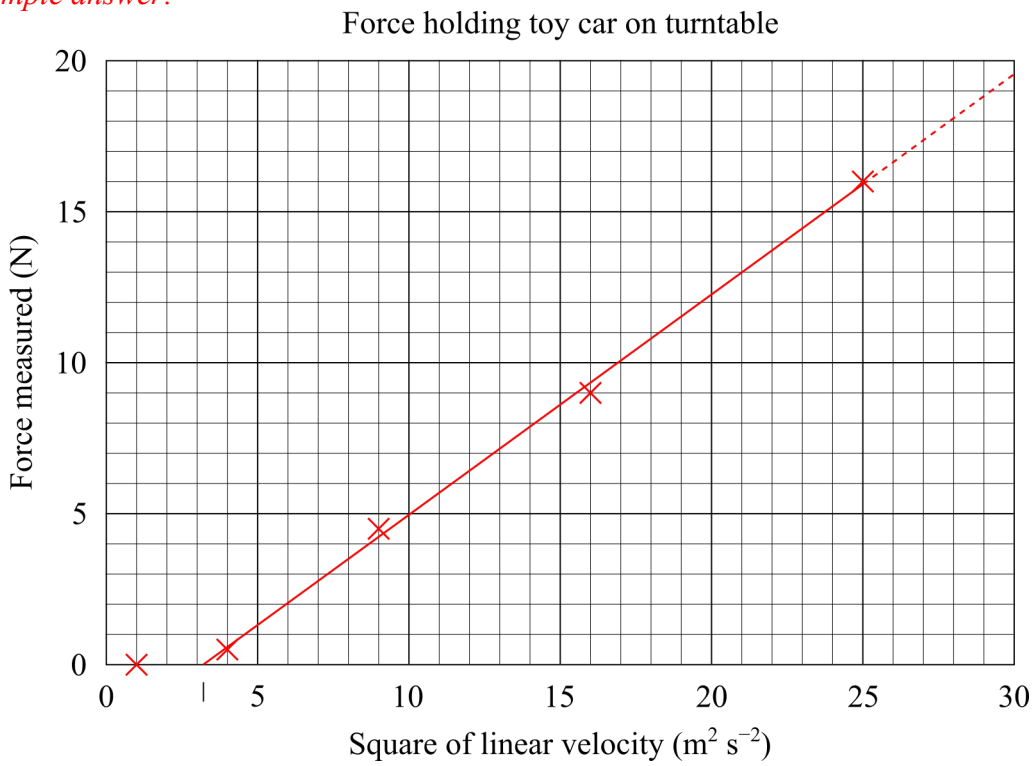
(a) Plot the data and draw the line of best fit. **2**

Marking:

✓ correctly plotted data using appropriate symbols

✓ appropriate LOBF drawn with a ruler (ignores first data point)

Sample answer:



(b) Use the line of best fit to determine the mass of the car. **3**

Marking:
✓ correct calculation of gradient from LOBF
✓ correctly related *gradient* to *mass*
✓ calculated answer with correct units WITHIN 0.002KG

Sample answer:

$$gradient = \frac{y_2 - y_1}{x_2 - x_1} = \frac{16 - 2}{25 - 6} = 0.7368$$

For circular motion: $F = \frac{mv^2}{r}$

$$gradient = \frac{rise}{run} = \frac{F}{v^2} = \frac{m}{r}$$

Therefore, $m = gradient \times r = 0.7368 \times 0.11 = 0.081 \text{ kg} = 81 \text{ g}$ (0.079-0.083kg)

(c) Identify possible errors in the experimental method and outline how to reduce their effects on the results. **4**

Marking:
✓ first valid error
✓ first valid improvement that addresses error
✓ second valid error
✓ second valid improvement that addresses error

Sample answer:

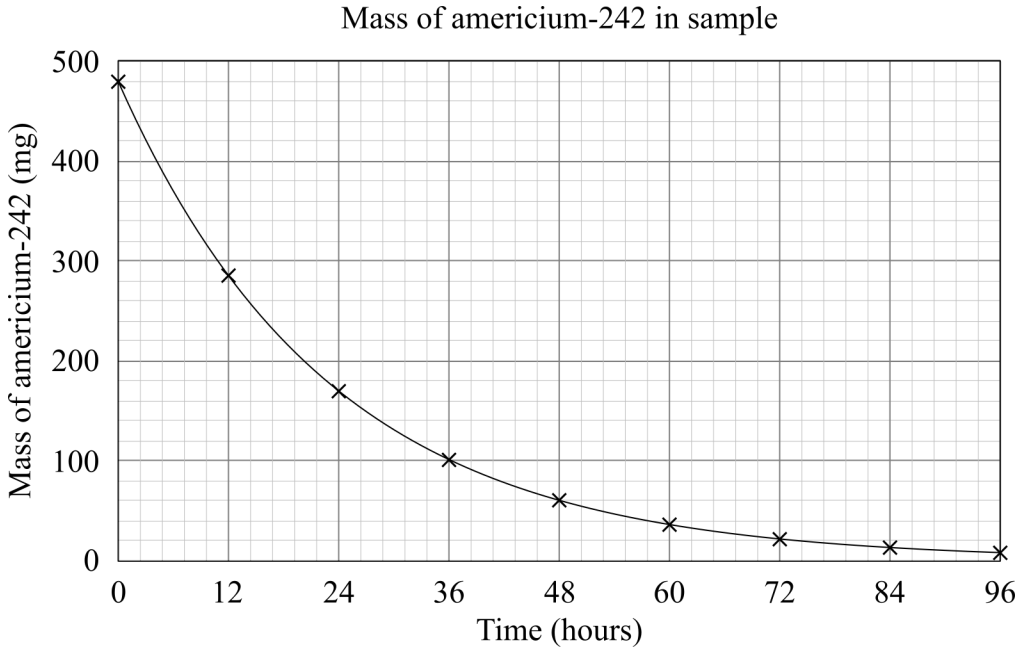
Error	*Improvement*
friction of the toy car*	using very low-friction surface on turntable and/or low-friction bearings in axles of toy car
calibration of the force sensor*	calibration of the force sensor by the weight of a suspended calibration mass from the sensor
reaction time for manual measurement of time with stopwatch	measuring time over a number of rotations and averaging OR video record from above and using frame-by-frame analysis for the time
uneven distribution of mass around centre of mass of car	use a symmetrical solid car rather than a car with different materials/gaps/openings
measurement error of distance between centre of mass of car and centre of turntable	use a precise measuring device (such vernier calipers or a laser rangefinder)
consistency of circular motion of turntable	repeat period & force measurements many times (5+ repetitions) and average the values

* not a valid error if the LOBF passes through the origin

End of Question 25

Question 25 (4 marks)

A scientist investigated the radioactivity of a sample of americium-242. She measured the mass of americium remaining in the sample every 12 hours over a period of 4 days. The results are shown in the graph below.



(a) From the graph, determine the half life of americium-242. **1**

Marking:
✓ correct value (±0.1 h) & units

Sample answer:
Each half life halves mass: 480 mg → 240 mg → 120 mg → 60 mg
From graph, 60 mg (3 half lives) corresponds to 48 hours. Therefore half life is 16 hours.

(b) Calculate the decay constant of americium-242 in SI units. **1**

Marking:
✓ correct equation & substitution

Sample answer:
$$\lambda = \frac{\ln 2}{t_{\frac{1}{2}}} = \frac{\ln 2}{16 \times 60 \times 60} = 1.2 \times 10^{-5}\ \text{s}^{-1}$$

(c) Americium-242 undergoes β^- decay. Write the full nuclear equation for this radioactive decay. **2**

Marking:
✓ equation includes correct parent & daughter nuclei
✓ equation includes antineutrino

Sample answer:
$^{242}_{95}\text{Am} \longrightarrow {}^{242}_{96}\text{Cm} + {}^{0}_{-1}e + {}^{0}_{0}\bar{\nu}$

Question 26 (4 marks) 2013 Q27

An electric motor can be used to propel a vehicle. The electric motor can be made to operate as a generator when the vehicle is moving. This will have a braking effect on the vehicle. **4**

Explain the physics principles involved in the propelling and braking of this vehicle.

Marking:
✓ identify use of motor effect
✓ outline how motor effect results in propulsion
✓ identify role of faraday's law/lenz's law in electromagnetic induction
✓ explain braking in terms the Law of Conservation of Energy

Sample answer:
The electric motor passes a current through a conducting coil located within a magnetic field. The *motor effect* results in a rotating force that acts on the coil, causing it to rotate. The coil is attached to the axle, thereby causing the wheels to rotate and propel the vehicle.

If the current is turned off, the moving vehicle continues to turn the coil within the magnetic field. The changing flux through the coil results in *electromagnetic induction* according to *Faraday's Law* ($\varepsilon \propto \frac{\Delta\Phi}{\Delta t}$), which induces an EMF and, therefore, a current in the coil. Due to the *Law of Conservation of Energy*, this electrical energy must come at the expense of the kinetic energy of the vehicle that causes the coil to rotate. Therefore, the kinetic energy of the vehicle decreases and the motor now operates as an electric generator that has a braking effect on the vehicle.

note: * Many responses confused the Faraday effect for motor effect
* Back EMF only applies in a motor, NOT a generator
* Many responses confused the passive EM braking via eddy currents (not used in this instance) with the operation of a generator
* Conservation of energy was missed by many students

Question 27 (4 marks) Sample p. 89

Explain how particle accelerators provide evidence for the Standard Model of matter. **4**

Marking:
✓ outline operation of particle accelerators
✓ apply $E = mc^2$ to collisions
✓ identify new particles formed
✓ relate new particles to Standard Model

Sample answer:

The Standard Model predicts the existence of fundamental particles that make up matter called quarks and leptons, along with force carrying particles called bosons. Particle accelerators are used to accelerate charged particles to very high energies. The speeds are so high that their momentum increases due to relativistic effects. They then collide with other particles and are converted to energy, according to Einstein's mass-energy equivalence ($E = mc^2$). This energy will then transform back to mass, but can form different particles to those collided, even forming new particles not previously observed. These new particles can either be directly detected, or their decay products can be detected and analysed to determine the mass and energy of the products and/or the new particles. This can provide further insight into the structure of matter in terms of the fundamental particles and the forces that control their interactions. These fundamental particles and forces form the basis of the Standard Model, thus providing evidence for its support.

note: * Neutrons and neutrinos are neutral particles, thus cannot be accelerated using the technologies within the scope of the syllabus. A mark was lost if this was the mentioned
* Particles need to be collided, acceleration alone does not provide information about particles
* $E=mc^2$ needs to be explicitly mentioned; many responses omitted this
* Appending the phrase "thus providing evidence for the standard model" is not suffecient satisfy the last marking criterea. You need to identify what the standard model is, and what it predicts.

Question 28 (6 marks) 2008 Q24

How did Einstein's theory of special relativity and his explanation of the photoelectric effect lead to the reconceptualisation of the model of light? **6**

Marking:
✓ describe aether model
✓ outline Einstein's two postulates
✓ relate postulates to reconceptualisation
✓ describes limitation of wave model
✓ outline Einstein's light quanta (identify $E=hf$ or $K_{max} = hf - \phi$)
✓ relate light quanta to reconceptualisation

Sample answer:
Once the wave model of light was firmly established, and Maxwell developed his electromagnetic wave theory of light, the aether model was proposed to explain the propagation of light, particularly through the vacuum of space. The model was based on the idea that the aether was stationary in space and acted as the absolute inertial frame of reference for the universe. Light propagated through the aether at c, and any motion relative to the aether would affect the measured speed of light accordingly. However, Michaelson and Morley's experiment was inconsistent with this model. Einstein proposted in his theory of special relativity that any inertial frame of reference was valid and the laws of physics were identical. In particular, the speed of light will always be c in a vacuum. Thus, light was a self-sustaining electromagnetic wave that travelled at c in a vacuum in any inertial frame of reference, irregardless of it's relative velocity.

As stated above, the electromagnetic wave model of light was accepted as the "true" nature of light. However, this model could not explain the photoelectric effect. In particular, the threshold frequency could not be explained by a wave model, since a lower energy light wave should have sufficient energy to emit photoelectrons with sufficient time or intensity. However, no condition of light with a frequency below the threshold frequency would lead to the emission of photoelectrons. Einstein's "light quanta" model overcame this issue by considering light as a particle. He proposed that light quanta would transfer all or none of its energy to the electrons, and if the energy was sufficient, according to $K_{max} = hf - \phi$, then the electron would be emitted with kinetic energy, K. This reconceptualisation of the model of light introduced the concept of wave-particle duality, that provides a more complete model of light.

note: * To answer *reconceptualisation*, you need to mention the previous model of light (aether), and discuss the limitations (wave model unable completely to explain photoelectric effect)

* Both of Einstein's SR postulates are needed! Lorentzian transforms are a *consequence* due to these two postulates, not the other way around. Many responses either only included one postulate (constancy of light) or used the transforms incorrectly

* Detailed explainations of the thought experiments for SR not required

Question 29 (6 marks) 2003 Q17

A satellite of mass 2000 kg is launched from Earth's surface into a uniform circular orbit of radius 8.0×10^6 m.

(a) Calculate the magnitude of the gravitational potential energy of the satellite in this orbit. **1**

Marking:
✓ correct answer & units

Sample answer:
$$U = -\frac{GMm}{\mathrm{r}} = -\frac{6.67\times10^{-11}\times6.0\times10^{24}\times2000}{8.0\times10^{6}} = -1.0\times10^{11}\ \mathrm{J}$$

(b) Calculate the orbital velocity of the satellite. **2**

Marking:
✓ uses correct equations
✓ correct answer & units

Sample answer:
$F_c = F_g$
$$\frac{mv^2}{r} = \frac{GMm}{r^2}$$
$$v = \sqrt{\frac{GM}{r}} = \sqrt{\frac{6.67\times10^{-11}\times6.0\times10^{24}}{8.0\times10^{6}}} = 7.1\times10^{3}\ \mathrm{m\ s^{-1}}$$

(c) The satellite uses its thrusters to move into a uniform circular orbit with double the original orbital radius. In doing so, it loses half of its mass in fuel used. Calculate the chemical energy contained in the used fuel. **3**

Marking:
✓ uses correct equation for total energy
✓ correct initial E OR final E
✓ correct answer & units

Sample answer:
The chemical energy of the used fuel provides the work to increase the gravitational potential energy of the satellite, which is equal to the change in the satellite's total energy.
Initially, $E = \frac{1}{2}U = -5.0\times10^{10}$ J
Given that $E = \frac{1}{2}U = -\frac{GMm}{2r}$, then doubling r & halving m will give $E_{final} = \frac{1}{4}E_{initial}$.
Therefore, $\Delta E = E_{final} - E_{intial} = \frac{1}{4}E_{initial} - E_{intial} = -\frac{3}{4}E_{intial} = 3.75\times10^{10}$ J.
Used fuel contained 3.75×10^{10} J.

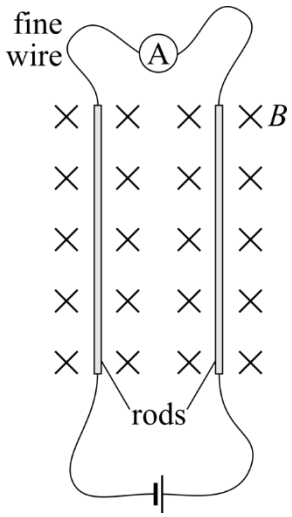
note: * Read the question carefully! Radius is already given, not orbital altitude

* Derivation of orbital velocity via Kepler's law accepeted, but not the most efficient route

* part (c) This question requires the use of total mechanical energy, not $E=mc^2$.

Question 30 (4 marks)

Two metal rods, each of length l, lie on a frictionless surface inside a magnetic field of strength B, and are connected in series by fine wire to a power supply and an ammeter that reads the current I, as shown. **4**



Show that the rods will reach an equilibrium distance between them given by

$$r = \frac{\mu_0}{2\pi}\frac{I}{B}.$$

Justify your answer.

Marking:
✓ describes directions of forces on rods
✓ shows $F_{rods} = F_B$ with correct equations
✓ clearly identifies $\sin\theta = 1$
✓ shows detailed working

Sample answer:
Currents in parallel rods are in opposite directions, so they will repel each other. The right-hand-palm-rule means that the external magnetic field will push the rods together. Equilibrium will occur when these forces are equal:

$F_{rods} = F_B$

$\frac{\mu_0}{2\pi}\frac{I_1 I_2}{r} l = lIB\sin\theta$

Given that the currents in the rods are the same (i.e. $I_1 = I_2 = I$), the lengths in the equations are the same, and the rods are perpendicular to the field (i.e. $\theta = 90 \Rightarrow \sin 90 = 1$):

$\frac{\mu_0}{2\pi}\frac{I^2}{r} = IB$

$\frac{\mu_0}{2\pi}\frac{I}{r} = B$

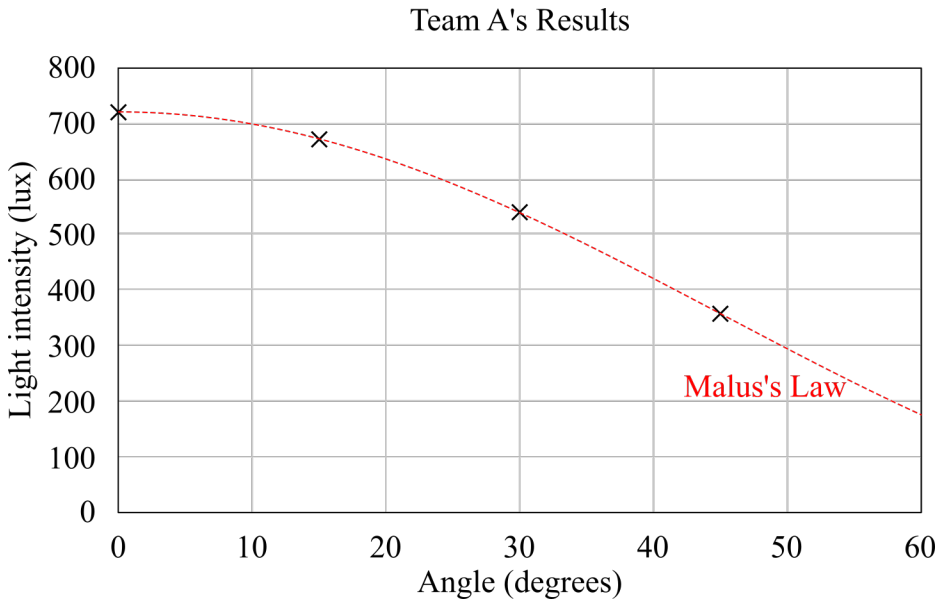
$r = \frac{\mu_0}{2\pi}\frac{I}{B}$

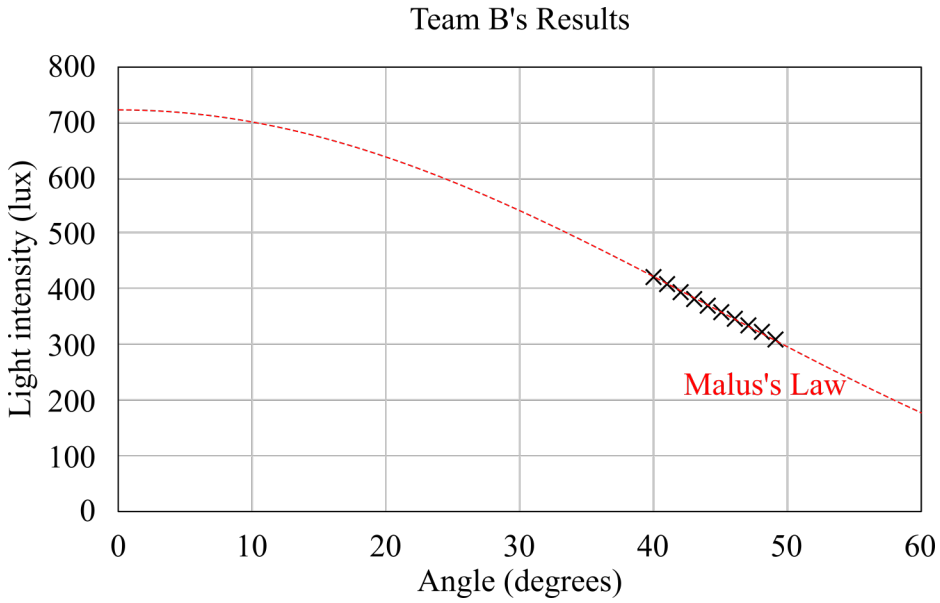
note: the external magnetic field does not make the rods "attract" each other (attraction & repulsion involve forces *within* the interaction not from an external force)

Question 31 (5 marks) 2016 Q25

Two teams carried out independent experiments with the purpose of investigating Malus's Law. Each team used the same procedure to accurately measure the intensity of light after passing through two polarisers with different angles between their transmission axes.

The following graphs show the data collected by each team.





note: both teams' results are consistent with Malus's Law

Question 32 continues on page 18

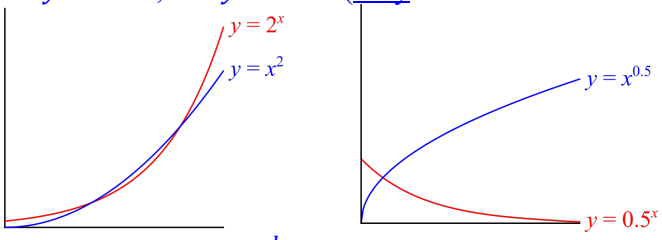
Question 32 (continued)

(a) Compare and contrast, qualitatively, the relationship between light intensity and angle in the graphs. **2**

Marking:
✓ describes one similarity of relationships
✓ describes one difference between relationships

Sample answer:
Both graphs show a decreasing light intensity with increasing angle between the transmission axes. More specifically, Team A's graph has a decreasing intensity with an increasing rate as the angle increases (a downwards curve relationship), whereas Team B's graph shows a constantly decreasing intensity with increasing angle (a linear relationship).

notes: * you must compare & constrast separately
* Team A's graph is not exponential, nor sinusoidal, nor parabolic (it is $\cos^2$)
* exponential means $y = kn^x$, not $y = kx^n$ (very different relationships)



* an "inverse" relationship means $y = \frac{k}{x}$, not $y = -kx$
* proportional means $y = mx$ (graph passes through origin)

(b) Assess the appropriateness of Team A's data and Team B's data in achieving the purpose of the experiments. **3**

Marking:
✓ appropriate judgements of data
✓ discusses ranges of data points for Teams A & B
✓ discusses number of data points for Teams A & B

Sample answer:
Team A has obtained a good range of data, with a wide range of angles. However, there are limited data points, which reduces the ability to determine a clear relationship, particularly at higher angles (>45°). Therefore, the data set is not appropriate.
Team B has obtained a large number of data points, allowing for a detailed relationship to be determined. However, the range is far too narrow, meaning the relationship is incorrectly shown. Therefore, the data set is not appropriate.

End of Question 32

Question 32 (8 marks) 2010 Q36(g)

"Nuclear fission reactions, such as $^{235}_{92}\mathrm{U} + {}^{1}_{0}n \longrightarrow {}^{144}_{56}\mathrm{Ba} + {}^{89}_{36}\mathrm{Kr} + 3\,{}^{1}_{0}n$, can be used as a source of energy." **8**

Use the data below to evaluate this statement with reference to the contributions of Rutherford, Einstein and Fermi to the development of nuclear power.

Nuclide	*Mass (u)*
$^{235}_{92}\mathrm{U}$	235.0439299
$^{144}_{56}\mathrm{Ba}$	143.9229529
$^{89}_{36}\mathrm{Kr}$	88.9176306
$^{1}_{0}n$	1.0086649

Marking:
✓ describe Rutherford's model
✓ outline Fermi's bombardment of $^{235}\mathrm{U}$ with neutrons
✓ define fission
✓ identify Einstein's mass-energy equivalence
✓ correct mass defect (to at least 3 s.f.)
✓ correct conversion to energy (J or MeV)
✓ relate energy output to nuclear power
✓ judgement of statement (*not* contributions)

Sample answer:
The statement is true, as nuclear power stations generate electricity based on the phenomenon of nuclear fission.

From the results of Geiger and Marsden's gold-foil experiment, Rutherford proposed his model of the atom. The distribution of alpha particles scattered from the gold foil suggested that the atom contained a very dense, positively charged mass at the centre of the atom, which is now called the nucleus. The electrons orbited around the nucleus at a distance much greater than the size of the nucleus, meaning the atom is mostly empty space. Rutherford's later discovery of the proton accounted for the charge of the nucleus, but not all of the mass. This indicated another particle existed – the neutron, which was discovered by Chadwick.

Fermi fired "slow" neutrons at uranium in order to produce transuranic elements (later named Neptunium and Plutonium). However, inconsistent results led to further work that identified much lighter elements in the samples. This led to the discovery of nuclear fission by Meitner and Frisch, whereby the nucleus of a large atom splits into two smaller nuclei. For example:

$$^{235}_{92}\mathrm{U} + {}^{1}_{0}n \longrightarrow {}^{144}_{56}\mathrm{Ba} + {}^{89}_{36}\mathrm{Kr} + 3\,{}^{1}_{0}n$$

Further analysis identified that the masses of the products are less than that of the original reactants:

$$\begin{aligned} m_{defect} &= m_{reactants} - m_{products} \\ &= (m_U + m_n) - (m_{Ba} + m_{Kr} + 3\,m_n) \\ &= (235.0439299 + 1.0086649) - (143.9229529 + 88.917306 + 3 \times 1.0086649) \\ &= 0.1860166\,u = 3.08974 \times 10^{-28}\ \mathrm{kg} \end{aligned}$$

According to Einstein's mass-energy equivalence, the decrease in mass ("mass defect") is transformed into energy according to $E = mc^2$:

$$E_{released} = m_{defect}c^2$$
$$= 3.08974 \times 10^{-28} \times (3.00 \times 10^8)^2$$
$$= 2.78 \times 10^{-11}\ \text{J} = 174\ \text{MeV}$$

This energy released increases the temperature of the uranium, and can be harnessed in a nuclear power station. A controlled nuclear chain reaction can be maintained by absorbing the extra neutrons with control rods, and heavy water can be used to extract the heat to drive a turbine, thereby generating electricity. Thus, the statement that nuclear fission reactions can be used as a source of energy is correct.

notes: * write your judgement at the start & end of your answer
* take some time to formulate a plan – a number of answers jumped around and didn't demonstrate a logical and coherent progression

Band 6 description: *"communicates scientific understanding succinctly, logically, and consistently"*

* must refer to mass-energy "equivalence" for 4th mark (it's in the syllabus *twice*)
* a number of students confused contributions (e.g. Rutherford discovered the neutron, Rutherford discovered fission, Fermi discovered fission, etc.)

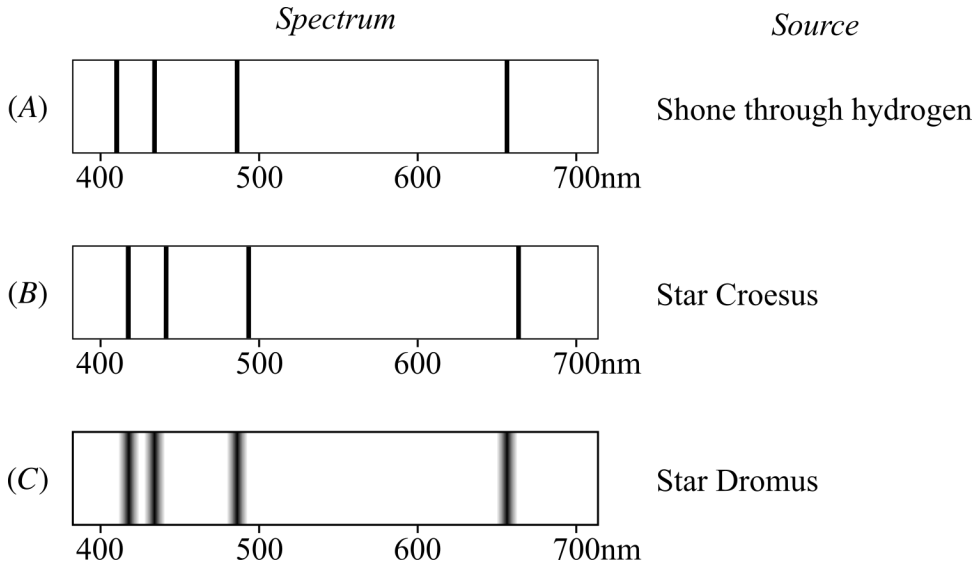
End of Question 33

Question 33 (7 marks) 2005 Q30(a)/2002 Q31(c)

Part *A* of the figure shows the absorption spectrum of light, produced by an incandescent filament, after it has been shone through a quantity of hydrogen gas.

Also shown in the figure are the spectra obtained from two stars, Star Croesus in part *B* and Star Dromus in part *C*.

The dark lines are absorption bands in *A*, *B* and *C*.



(a) Explain how the spectrum in *A* provides experimental evidence in support of Bohr's model of the hydrogen atom. **3**

Marking:
✓ describes Bohr's model
✓ relates first postulate to discrete lines/bands
✓ relates second postulate to *absorption* lines/bands

Sample answer:
Bohr proposed three postulates as his model for the hydrogen atom:
1. electrons orbit the nucleus in discrete, stable "stationary states" of fixed radii
2. electrons transition between stationary states by emitting or absorbing EMR
3. electrons in stationary states have integer angular momentum

The spectrum in *A* is an absorption spectrum with dark absorption lines on the continuous blackbody spectrum from the incandenscent filament. This supports Bohr's second postulate, in that electrons absorb EMR when transitioning to higher stationary states.
The fact that the absorption lines are discrete, separate lines supports Bohr's first postulate that electrons orbit the nucleus in discrete stationary states because the transition must be between specific orbits with specific energies (E), leading to the absorption of specific wavelengths of EMR, according to $\frac{hc}{\lambda} = E_f - E_i$.

note: must refer to spectrum *A* when relating feature(s) of spectrum to feature(s) of Bohr's model

Question 35 continues on page 21

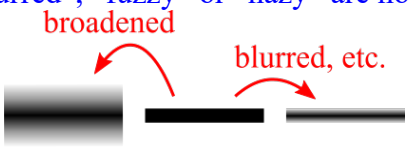
Question 35 (continued)

(b) For each star, Croesus and Dromus, identify the principal way in which its spectrum differs from the spectrum shown in part *A* of the figure. **2**

Marking:
✓ identifies redshift for Croesus
✓ identifies line broadening for Dromus

Sample answer:
For Star Croesus, the spectrum has been redshifted. That is, the absorption lines in spectrum B have moved to longer wavelengths compared to spectrum A.
For Star Dromus, the lines have broadened. That is, the aborption lines in spectrum C are thicker and blurred compared to spectrum A.

notes: * "smudged", "blurred", "fuzzy" or "hazy" are not sufficient for Dromus



* only 1 line is shifted for Dromus (an alignment error), which does not indicate redshift (you cannot have *certain* wavelengths shift, but not others)

(c) For each star, Croesus and Dromus, state what its spectrum tells us about the motion of that star. **2**

Marking:
✓ relates Doppler shift to motion relative to Earth
✓ relates line broadening to rotation

Sample answer:
For Star Croesus, the redshift in the spectrum indicates that the star has a high velocity away from Earth.
For Star Dromus, the line broadening indicates that the star has a high rotational velocity.

note: don't give two different answers for the same question (e.g. Dromus has a high density ***or*** a high rotational velocity)

End of Question 35

Question 34 (4 marks) 2019 Q33

An electron and a proton particle are fired into a uniform magnetic field with the same speed from opposite sides as shown. Their trajectories are initially perpendicular to the field. **4**

Explain ONE similarity and ONE difference in their trajectories as they move in the magnetic field.

Marking:
✓ identifies a similarity in trajectories
✓ relates similarity to characteristics of particles
✓ identifies a difference in trajectories
✓ relates difference to characteristics of particles

Sample answer:
Possible similarities include:

Similarity	*Explanation*
Both the electron and the proton will have circular trajectories.	A moving charge in a magnetic field will experience a constant force of $F_B = qv_\perp B$. According to the right hand palm rule, this constant force will always be *perpendicular* to the velocity, which results in circular motion.
Both the electron and the proton will move towards the bottom of the field.	According to the right hand palm rule, both the electron and the proton will experience an *initial* force downwards (towards the bottom of the field).

Possible differences include:

Difference	*Explanation*
The electron and the proton will deviate in different directions, relative to their initial velocities.	According to the right hand palm rule, the electron will experience a force to the right, turning to the right, relative to its initial velocity. Similarly, the proton will experience of force to the left, turning left, relative to its initial velocity.
The radius of curvature for the proton will be larger than that for the electron (by a factor of about 1800 times).	The radius of curvature of the trajectory is $r = \frac{mv}{qB}$. Given that v, q and B are the same for both particles, the radius is only dependent on the mass (i.e. $r \propto m$). Since the proton is heavier that the electron (by a factor of about 1800 times), the radius of the proton's trajectory will be larger than that for the electron (by a factor of about 1800 times).

notes: * if more than ONE similarity or difference was provided, only the first was marked
* force and acceleration are not characteristics of trajectory
* you must say *initial* force being down the page (changes direction as the particle turns)

End of paper