JAMES RUSE AGRICULTURAL HIGH SCHOOL

2020

TRIAL HIGHER SCHOOL CERTIFICATE EXAMINATION

Physics

General Instructions

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

Total marks - 100

Section I – 20 marks (pages 2–11)

- Attempt Questions 1–20
- Allow about 35 minutes for this section

Section II – 80 marks (pages 14–35)

- Attempt Questions 21–35
- 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 satellite is moved from a higher orbit to a low Earth orbit.

   Which statement about the orbit change is correct?

   A. The gravitational potential energy of the satellite increases.
   B. The change in gravitational potential energy is independent of the mass of the satellite.
   C. The work done is the energy required to move the satellite from a very large distance away to the lower orbit.
   D. The work done is the difference between the gravitational potential energy of the higher orbit and that of the low Earth orbit.

2. A buggy is rounding a banked circular track on the Moon. In order to safely negotiate the bend, what will the critical speed depend on?

   A. The banking angle, the sideways frictional force between the tyres and the tracks and the radius of the circular track
   B. The banking angle, the radius of the circular track and the gravitational field strength of the Moon
   C. The radius of the circular track, the sideways frictional force between the tyres and the tracks and the gravitational field strength
   D. The banking angle, the sideways frictional force between the tyres and the track and the gravitational field strength

3. When a nucleus of the radioactive isotope $^{65}_{28}Ni$ decays, a β^- particle and an anti-neutrino are emitted.

How many protons and neutrons are there in the resulting daughter nucleus?

	Number of protons	*Number of neutrons*
A.	29	36
B.	29	65
C.	28	65
D.	30	35

4. Fission and fusion are both nuclear processes.

Which of the following statements is correct for both processes?

A. Neutrons are released.

B. No harmful radiation is produced.

C. The binding energy per nucleon increases.

D. The total mass increases.

5. The activity of a source is equal to one-half of its initial value after 360 s.

What is the decay constant of the radioactive nuclide in the source?

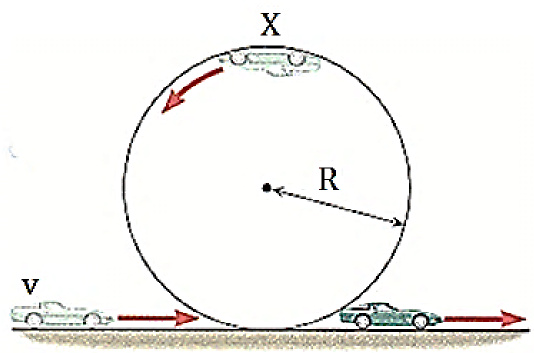
A. $1.93 \times 10^{-3}\ s^{-1}$

B. $2.57 \times 10^{-3}\ s^{-1}$

C. $3.85 \times 10^{-3}\ s^{-1}$

D. $7.70 \times 10^{-3}\ s^{-1}$

6. A toy car, moving with speed v, successfully completes a manoeuvre in a circular track, as shown in the diagram below.



Which of the following descriptions best analyses the forces acting on the car while at position marked X?

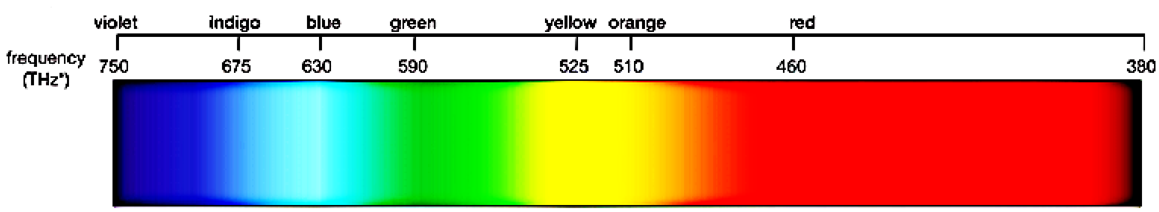
A. The normal force equals the centripetal force.

B. The weight force equals the centripetal force.

C. The sum of the normal and weight forces equals the centripetal force.

D. The difference between the normal and weight forces equals the centripetal force.

7. The colour of a of a certain star, assumed to be a black body, is predominantly red in the night sky.



Given the above chart of the visible spectrum and that $1\ \text{THz} = 1 \times 10^{12}$ Hz, what is the approximate surface temperature of this star?

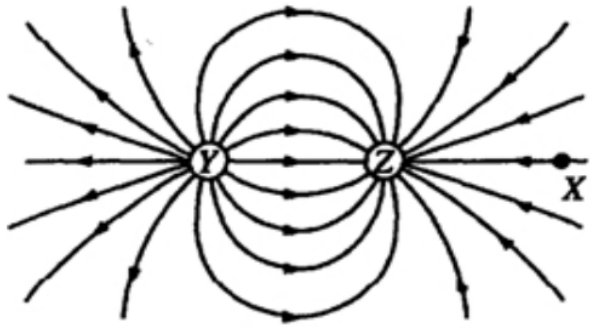
A. $3443\ K$

B. $4443\ K$

C. $5443\ K$

D. $6443\ K$

8. The diagram below shows electric field lines in an isolated region of space containing two small charged spheres, Y and Z.



Which of the following statements is true?

A. The charge on Y is negative and the charge on Z is positive.

B. The strength of the electric field is the same everywhere.

C. The electric field is zero midway between Y and Z.

D. A small negatively charged object placed at point X would tend to move toward the right.

9. Which row of the table shows the correct relationship between the escape velocity, v_{esc} and orbital velocity, v_{orb}, and the relationship between the total energy, E and kinetic energy, K and / or potential energy, U of a satellite in orbit?

	Relationship between v_{esc} and v_{orb}	*Relationship between E, K and/or U*
A.	$v_{orb} = \sqrt{2}v_{esc}$	$K = -\frac{1}{2}U$
B.	$v_{esc} = \sqrt{2}v_{orb}$	$E = \frac{1}{2}U$
C	$v_{esc} = \sqrt{2}v_{orb}$	$K = \frac{1}{2}U$
D.	$v_{orb} = \sqrt{2}v_{esc}$	$E = -\frac{1}{2}U$

10. In an experiment to investigate the photoelectric effect, monochromatic light is incident on a metal surface. The photoelectric current and the maximum kinetic energy of the photoelectrons are measured.

Which row of the table correctly shows the change, if any, in the photoelectric current and in the maximum kinetic energy of the photoelectrons when light of the same intensity but higher frequency is incident on the same metal surface?

	photoelectric current	*maximum kinetic energy*
A.	no change	increases
B.	decrease	no change
C.	decreases	increases
D.	no change	decreases

11. An alpha particle moves at right angles to a uniform magnetic field and experiences a force F. A beta particle moves at right angles to a magnetic field of half the magnetic flux density but at ten times the velocity of the alpha particle.

What will be the magnitude of the force on the beta particle?

A. 0.25 F

B. 0.40 F

C. 2.5 F

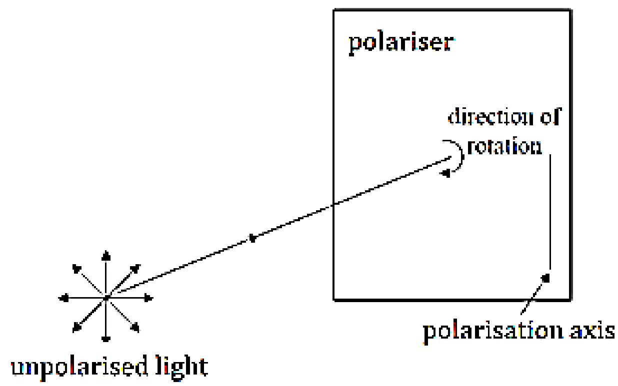
D. 5.0 F

12. Intensity maxima are produced on a screen when a parallel beam of monochromatic light is incident on a diffraction grating. Light of a longer wavelength can be used or the distance from the diffraction grating to the screen can be increased.

Which row gives the change in appearance of the maxima when these changes are made independently?

	Longer wavelength	*Distance from grating to screen increased*
A.	closer together	more widely spaced
B.	more widely spaced	more widely spaced
C.	more widely spaced	closer together
D.	closer together	closer together

13. A beam of unpolarised light of intensity I_0, is incident on a polariser. The polarisation axis of the polariser is initially vertical, as shown.



How does the intensity I, of the transmitted light vary with the rotation angle, from 0^0 to 180^0?

	I *from* 0^0 *to* 90^0	I *from* 90^0 *to* 180^0
A.	constant at I_0	constant at I_0
B.	increases	decreases
C.	constant at $\frac{1}{2}I_0$	constant at $\frac{1}{2}I_0$
D.	decreases	increases

14. Part of the energy production process in the Sun involves the fusion of two protons which forms into a deuteron. This results in the release of 0.42 MeV of energy.

What is the mass equivalent of this energy release?

A. $\frac{0.42}{931.5}$ u

B. $\frac{0.42}{c^2}$ kg

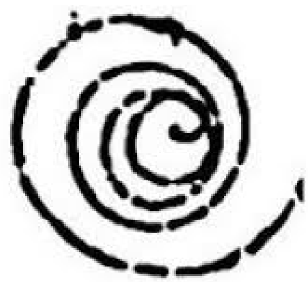
C. 0.42×931.5 u

D. $\frac{0.42 \times 1.602 \times 10^{-19}}{c^2}$ kg

15. A bubble chamber is an instrument containing liquid hydrogen which permits the paths of charged particles to be observed. Bubbles are formed along the path followed by a charged particle as it collides with molecules of hydrogen.

The figure represents a bubble chamber photograph of a moving electron which is spiralling in a plane towards the centre under the influence of a force due to a constant magnetic field.

As the electron spirals in, what must be the effect of the force and its speed due to magnetic field?



A. The speed is increasing and the size of the force on it is increasing.

B. The speed is decreasing and the size of the force on it is decreasing.

C. The speed is constant and the force on it is constant

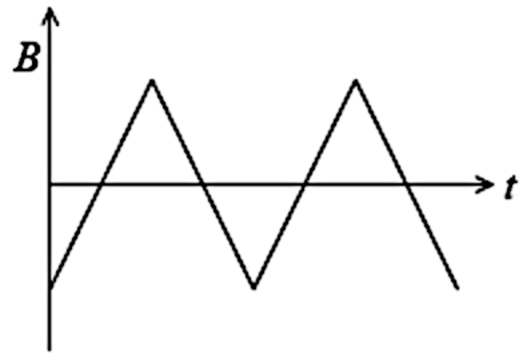
D. The speed is increasing and the size of the force on it is decreasing

16. A transformer has an efficiency of 80%. It has 7000 turns on its primary coil and 175 turns on its secondary coil. When the primary of the transformer is connected to a 240 V ac supply, the secondary current is 8.0 A.

What are the primary current and secondary voltage?

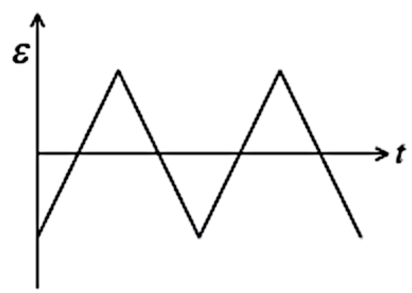
	Primary current I. (mA)	*Secondary voltage (V)*
A.	250	6.0
B.	160	6.0
C.	250	9600
D.	160	9600

17. A magnetic field of strength B links a coil. The direction of the field is normal to the plane of the coil.

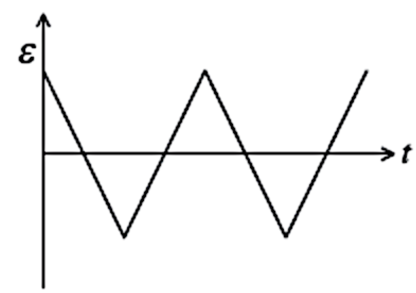


Which of the following graphs shows how the induced emf, $\mathcal{E}$ in the coil varies with t?

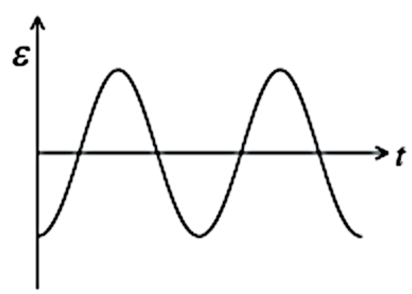
A.



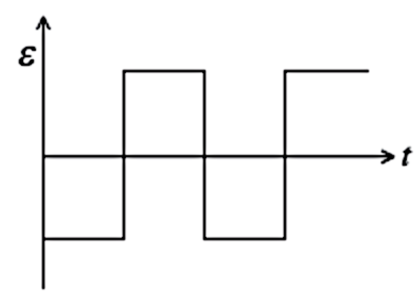
B.



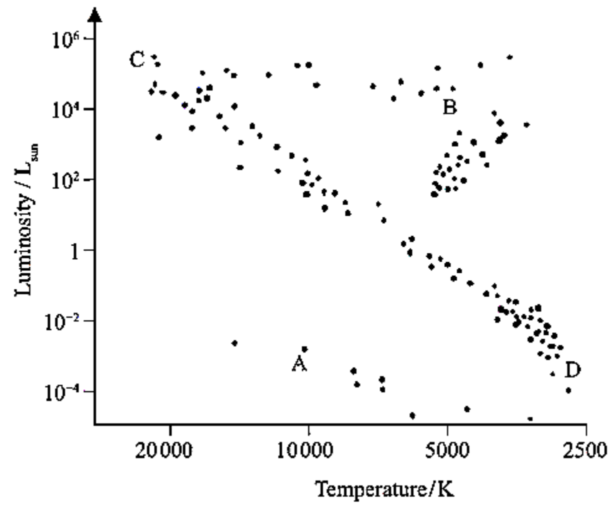
C.



D.



18. T Tauri stars are very young low mass stars, still in the process of gravitational contraction. The Hertzsprung-Russell diagram below shows data for a range of stars.



Identify in which area, A, B, C or D, on the Hertzsprung-Russell diagram T Tauri stars are likely to be found.

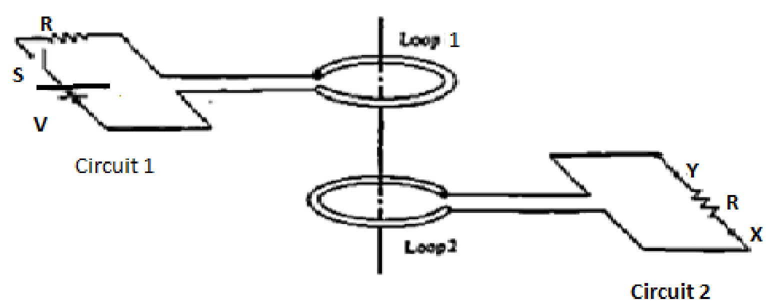
A. A

B. B

C. C

D. D

19. How does the current flow through the resistor R in circuit 2 behave once the switch S in circuit 1 is closed?



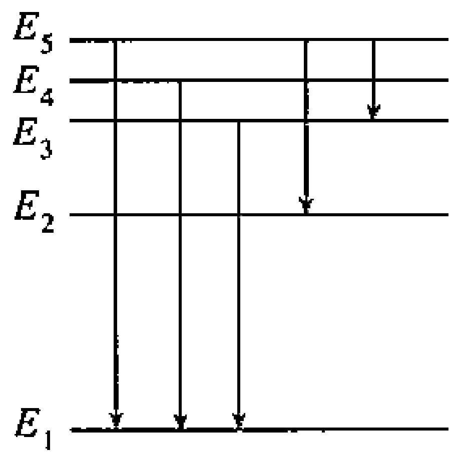
A. From point Y to X

B. From point X to Y

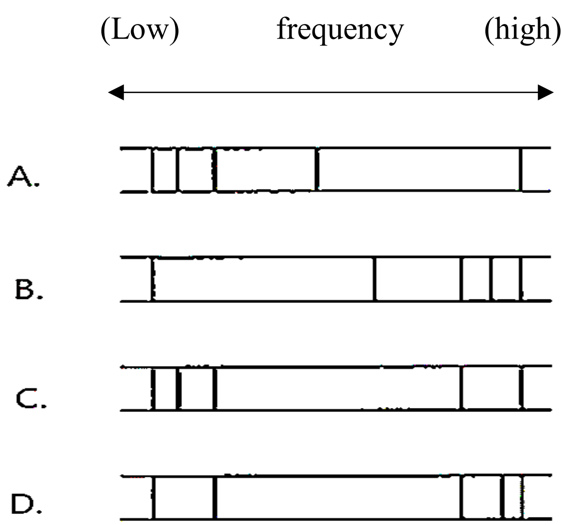
C. The current oscillates between X and Y

D. There is no current through the resistor

20. The figure below shows five energy levels of an atom X. Five transitions between the levels are indicated, each of which produces a photon of definite frequency.



Which of the spectrum correctly corresponds to the transitions indicated?



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James Ruse Agricultural High School

Student Number

TRIAL HSC EXAMINATION 2020

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 ◯

Student Number

Mark

Section II - 80 marks

Attempt Questions 21 – 35

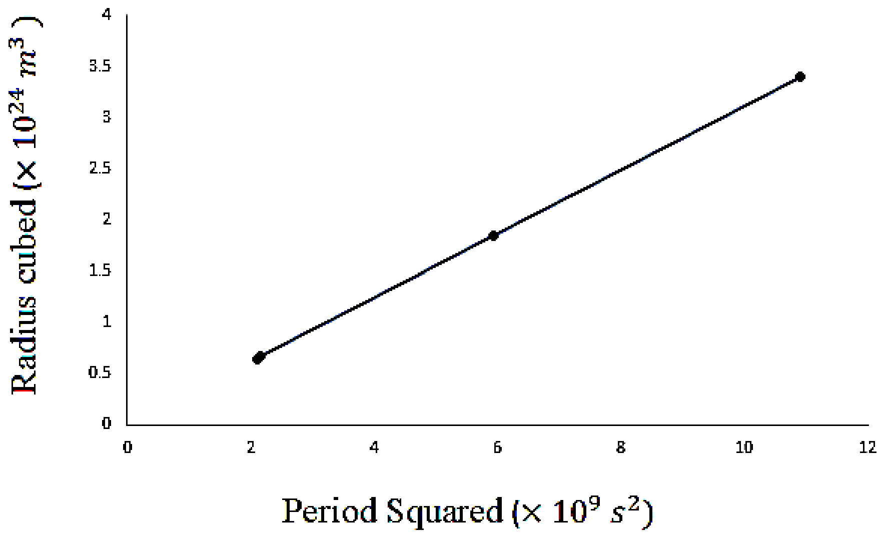
Allow about 2 hours and 25 minutes for this part

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 questions you are answering and direct the examiner to your answer.

Question 21 (2 marks)

A group of scientists investigated Kepler's laws of planetary motion. They collected data on four moons of Jupiter and drew to scale, a graph of the radius cubed against the period squared, as shown below.



Use the graph to determine the mass of Jupiter. **2**

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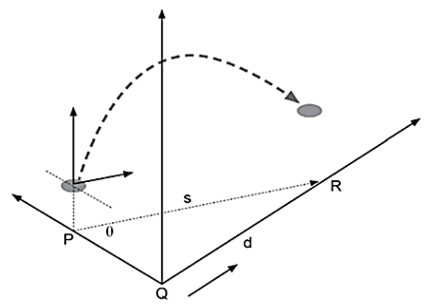
Question 22 (4 marks)

Paul kicks a ball from point P to point R. At the same instant, Quinn starts from point Q and runs forward, to catch the ball at point R. The initial vertical velocity (u_y) of the ball is $12.0\ m\ s^{-1}$ and its horizontal velocity (u_x) is 10.0 m s^{-1}.

Ignore air resistance throughout this question.



(a) Calculate the initial velocity of the ball. **2**

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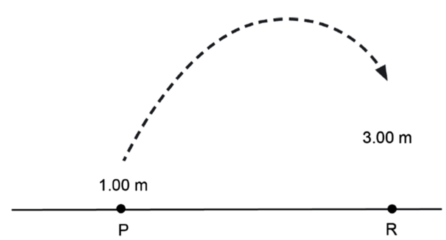
(b) Paul kicks the ball from a point 1.00 m above the ground. Quinn jumps and catches the ball when it is 3.00 m above the ground at point R.



If the ball travels for 2.27 s in the air, determine the horizontal distance (s) the ball will cover before Quinn catches it at point R. **2**

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Question 23 (5 marks)

Artificial satellites are used to monitor weather conditions on Earth, for surveillance and for communications. Such satellites may be placed in a geostationary orbit or low-Earth orbits.

(a) Describe the features of the geostationary orbit and the advantages it offers when a satellite is used for communications. **2**

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(b) Calculate the total energy of a 750 kg satellite when it is raised from the Earth's surface into a Low-Earth orbit, 400 km above the Earth's surface. **3**

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Question 24 (5 marks)

Muons are created in the upper atmosphere with speeds of $0.99c$ or more. Their average lifetime is 2.2 μs measured at low speeds in the laboratory. A simple calculation shows that most should only travel about 653.4 m before decaying. Thus, very few muons should ever reach sea level.

(a) Using relativistic mechanics, calculate how far a muon can travel according to an observer on Earth. **3**

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(b) Explain why many more muons reach the surface of Earth than predicted classically. **2**

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Question 25 (4 marks)

An experiment was conducted to investigate the nature of light. A parallel beam of monochromatic light was directed at a very small spherical object and a white screen was positioned behind the object (Diagram 1).

The pattern observed on the white screen is shown in Diagram 2.

(Note: diagrams not to scale.)

Diagram 1

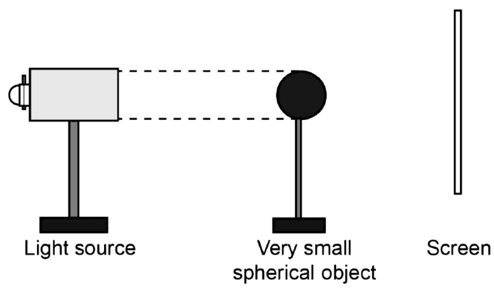
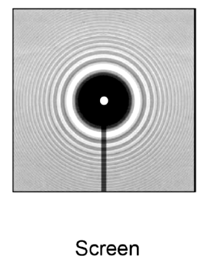


Diagram 2



(a) Explain how the pattern in Diagram 2 was produced. **3**

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(b) From this experiment, what conclusion can be made regarding the nature of light? **1**

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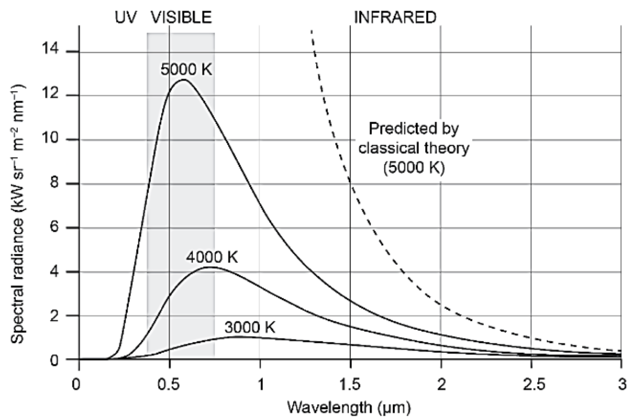
Question 26 (4 marks)

Describe a black body and show how the experimental evidence gathered from the blackbody radiation curves contributed to a changed model of light. **4**



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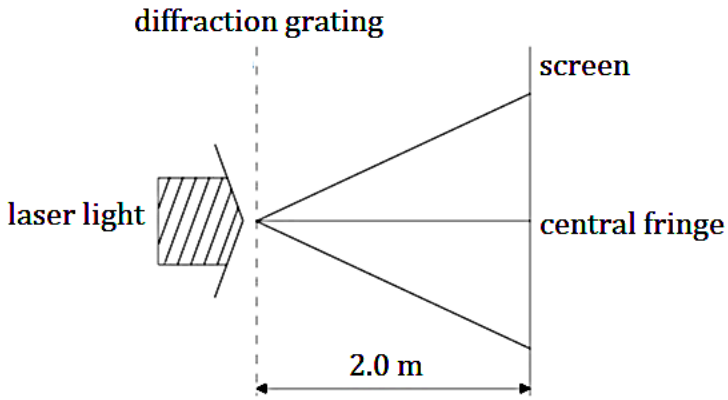
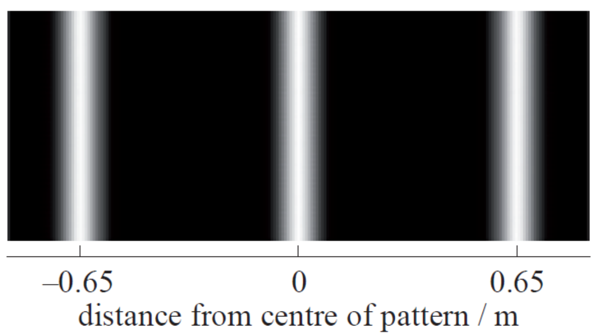
Question 27 (3 marks)

A beam of laser light is incident normally on a diffraction grating which has 600 lines per millimetre. A fringe pattern is formed on a screen 2.0 m from the diffraction grating.



The fringe pattern formed on the screen is shown below.



Determine the wavelength of the laser light. **3**

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Question 28 (7 marks)

A student conducted an experiment to determine Planck's constant. The experiment involved setting up five individual, single frequency light emitting diodes (LEDs).

Each LED only emits one frequency of light when a turn on voltage (voltage above a certain threshold value) is applied across its terminals.

The relationship between the frequency of the emitted light and the voltage is given by the equation:

$hf = q(V_0 + k)$, where

h is Planck's constant
f is the frequency of light emitted by the LED,
q is the charge on an electron,
V_0 is the turn on voltage and
k is the threshold voltage (constant dependent on the material)

The results obtained by the student were tabulated below.

LED Colour	*Maximum wavelength,* λ (nm)	*Turn on Voltage,* V_0 (V)	$\frac{1}{\lambda}$ $(\times 10^6\ m^{-1})$
Blue	346	2.22	
Green	395	1.95	
Yellow	439	1.75	
Red	532	1.45	
Infra-red	685	1.12	

(a) Complete the table above for values of $\frac{1}{\lambda}$. **1**

(b) Plot a graph of voltage (on the vertical axis) against $\frac{1}{\lambda}$, and draw a line of best fit. **4**

Question 28 continues on page 23

Question 28 (continued)

(c) Use the gradient of the line of best fit to determine a value for Planck's constant. **2**

Question 29 (6 marks)

Describe the subsequent experimental evidence that supported Newton and Huygens proposed models of light. **6**

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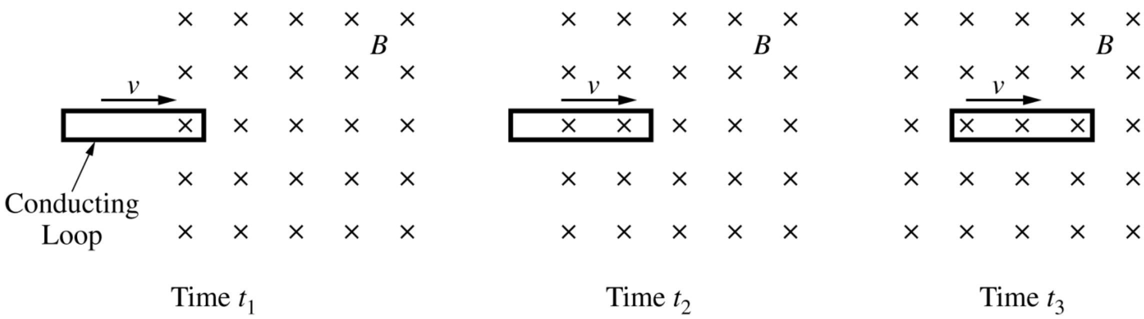
Question 30 (10 marks)

The figures below show a rectangular conducting loop at three instants in time. The loop moves at a constant speed into and through a region of constant, uniform magnetic field B directed into the page. The magnetic field is zero outside the region.



(a) Compare the magnitude and direction of the current at times t_1, t_2 and t_3.

Include an explanation of why there is or is not a current and the direction of the current if one is present using physics concepts and principles. **5**

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Question 30 continues on page 26

Question 30 (continued)

(b) The loop is removed. A proton travelling to the right in the plane of the page, as shown below, then enters the region of magnetic field with a speed of 3.0×10^5 ms^{-1}. The magnitude of the field is 0.030 T. The effects of gravity are negligible.

(i) Calculate the magnitude of the force on the proton as it enters the field. **1**

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(ii) On the figure below, sketch a possible path of the proton as it travels through. the magnetic field. Clearly label the path P1. **1**

Question 30 continues on page 27

Question 30 (continued)

(iii) A second proton now enters the magnetic field at the same point and from the same direction but at a greater speed than the first proton.

On the figure in part ii (page 26) draw the path of the second proton as it travels through the field.
Clearly label the path P2. **1**

(iv) Next an electric field is applied in the same region as the magnetic field, such that there is no net force on the first proton as it enters the region.

Calculate the magnitude and indicate the direction of the electric field **2**

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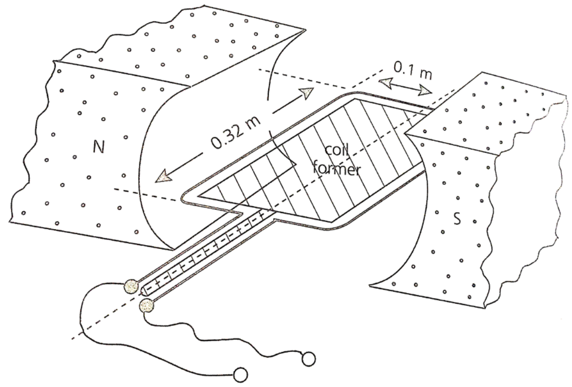
End of Question 30

Question 31 (4 marks)



An electric motor consists of a 100-turn coil of wire on a frame that is free to rotate in a radial field as shown in the figure above. The field strength is 25.0 mT and the coil dimensions are 0.32 m in length and 0.1 m wide. The effective voltage driving the motor is 120 V DC.

If each of the turns on the coil has an effective resistance of 0.018 ohms, determine:

(a) The current flow from the power supply. **2**

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(b) The effective torque supplied by the motor. **2**

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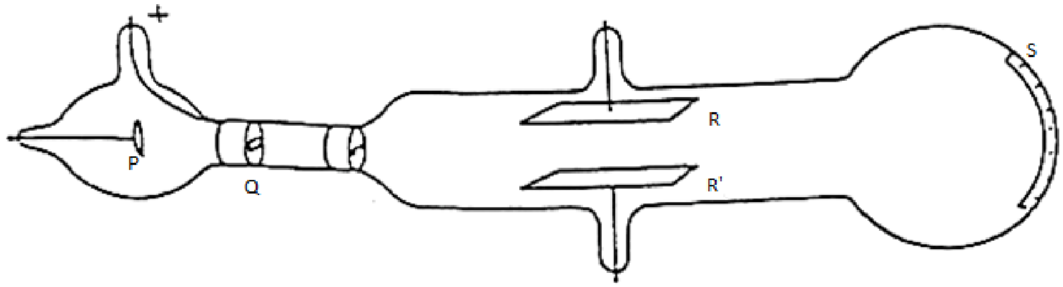
Question 32 (3 Marks)

The figure below shows the basic structures in Thomson's apparatus



From: Thomson, J.J., 1897. "Cathode Rays", *Philosophical Magazine*, 44: 293–316.

Identify and describe the function of the structures labelled P-Q, R-R' and S. **3**

P-Q……………………………………………………………………………………………

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R-R'…………………………………………………………………………………………..

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S……………………………………………………………………………………………..

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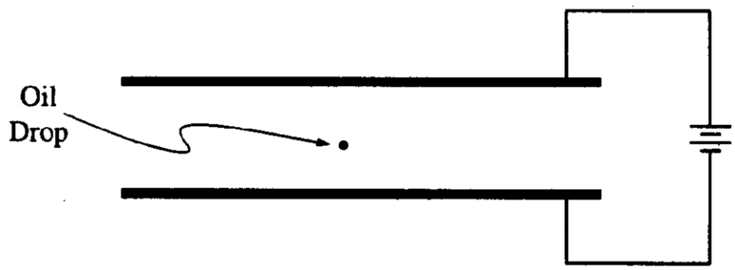
Question 33 (7 marks)

Robert Millikan received a Nobel Prize for determining the charge on the electron. To do this, he set up a potential difference between two horizontal parallel metal plates. He then sprayed drops of oil between the plates and adjusted the potential difference until drops of a certain size remained suspended at rest between the plates, as shown below.



Suppose that when the potential difference between the plates is adjusted until the electric field is 10 000 NC^{-1} downward, a certain drop with a mass of 3.27×10^{-16} kg remains suspended.

(a) What is the magnitude of the charge on this drop? **2**

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(b) Explain why, although the electric field is downward, the electric force on the drop is upward. **2**

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Question 33 continues on page 31

Question 33 (continued)

(c) If the distance between the plates is 0.01 m, what is the potential difference between the plates? **1**

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(d) The oil in the drop slowly evaporates while the drop is being observed, but the charge on the drop remains the same.

Indicate whether the drop remains at rest, moves upward, or moves downward. Give a reason for your answer. **2**

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End of Question 33

Question 34 (8 marks)

Beginning in the late 19th and early 20th centuries, experimental discoveries revolutionised accepted understanding of the nature of matter. The work of Rutherford and Bohr, and later Schrodinger gave us a better way to understand the structure of the atom.

Assess the contributions of Rutherford, Bohr and Schrodinger to our deeper understanding of the atomic model. **8**

Question 34 continues on page 33

Question 34 (continued)

TURN OVER PAGE

Question 35 (8 marks)

(a) Calculate the binding energy, in MeV, of a nucleus of ${}^{59}_{27}Co$.

Given nuclear mass of ${}^{59}_{27}Co$ = 58.93320 u
proton mass = 1.00728 u
neutron mass = 1.00867 u **2**

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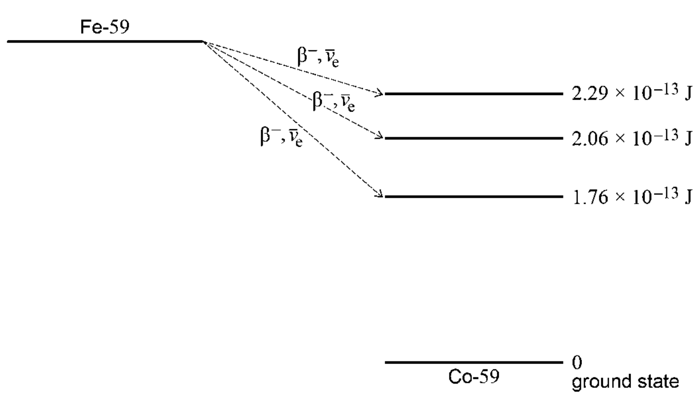
(b) A nucleus of iron Fe-59 decays into a stable nucleus of cobalt Co-59. It decays by β− emission followed by the emission of γ-radiation as the Co-59 nucleus de-excites into its ground state.
The total energy released when the Fe-59 nucleus decays is 2.52×10^{-13} J.

The Fe-59 nucleus can decay to one of three excited states of the cobalt-59 nucleus as shown in the figure below.
The energies of the excited states are shown relative to the ground state. **2**



Question 35 continues on page 35

Question 35 (continued)

Calculate the maximum possible kinetic energy, in MeV, of the β− particle emitted when the Fe-59 nucleus decays into an excited state that has energy above the ground state.

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(c) Following the production of excited states of $^{59}_{27}Co$, γ-radiation of discrete wavelengths is emitted. **1**

State the maximum number of discrete wavelengths that could be emitted.

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(d) Calculate the longest wavelength of the emitted γ-radiation. **3**

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JAMES RUSE AGRICULTURAL HIGH SCHOOL

TRIAL HSC EXAMINATION 2020

Physics ANSWERS

Multiple Choice

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

Question 21 (2 Marks)

Sample Answer:

$$slope = \frac{\Delta r^3}{\Delta T^2} = \frac{(2.5 - 1) \times 10^{24}}{(7.9 - 3.4) \times 10^9} = 3.33 \times 10^{15}\ m^3\ s^{-2}$$

From Kepler's law, $\frac{r^3}{T^2} = \frac{GM}{4\pi^2} = slope$

Hence $M = 4\pi^2 \times \frac{slope}{G}$

$= 4\pi^2 \times \frac{3.33 \times 10^{15}}{6.67 \times 10^{-11}}$

$= 1.97 \times 10^{27}\ kg$

Marking criteria	Marks
Correct slope obtained (with correct working) and mass correctly computed	2
Correct slope obtained (with correct working) or some relevant information provided	1

Question 22 (4 Marks)

(a) Sample Answer:

$u = \sqrt{u_x^2 + u_y^2}$

$= \sqrt{12^2 + 10^2}$

$= 15.6\ m\ s^{-1}$, $\theta = \tan^{-1}\left(\frac{12}{10}\right) = 50.2°$ above the horizontal

Marking criteria	Marks
Correct magnitude and correct direction	1
One of the above	

(b) Sample Answer:

$s_x = u_x t = 10 \times 2.27$

$= 22.7\ m$

Marking criteria	Marks
Correct substitution in correct formula to get correct displacement	2
Correct formula selected or some relevant information provided	1

Question 23 (5 Marks)
Artificial satellites are used to monitor weather conditions on Earth, for surveillance and for communications. Such satellites may be placed in a geostationary orbit or low-Earth orbits.

Sample Answer:
(a)

- Period: 24 hours, or same as the Earth's period of rotation
- Maintains a fixed position relative to the Earth
- Travels westwards along the equatorial plane
- Same angular speed as Earth
- Altitude $\pm 42\ 000\ km$
- Orbital speed, $\pm 3000\ m\ s^{-1}$

Advantage/s:

- offers uninterrupted communication/surveillance between transmitter and receiver
- moveable dish/antennae not necessary

<u>The following were some of the less significant advantages that were accepted</u>:

- ❖ GEO experiences less drag compared to LEO, and hence less maintenance required
- ❖ Stable, global communication, direct transfer of information, larger area surveyed (wider line of sight)

NOT ACCEPTED:

- o Quick and efficient
- o Information transmitted up and down vertically, constant
- o Or anything vague and hazy!!!!

Marking Criteria	Marks
Correctly provided any **<u>two</u>** features **<u>and</u>** stated one advantage	2
Correctly stated one feature **<u>and/or</u>** one advantage	1

(b) Sample answer

$U = -\frac{GMm}{r}$

$K = \frac{1}{2}mv^2$

$= \frac{1}{2}m\left(\frac{GM}{r}\right)$

$= -\frac{1}{2}U$

$\therefore E = U + K$

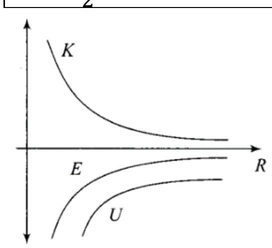
$= U - \frac{1}{2}U$

$= \frac{1}{2}U$

$= \frac{1}{2}\left(-\frac{6.67\times10^{-11}.6\times10^{24}.750}{6.371\times10^{6}+4\times10^{5}}\right)$

$= -2.22\times10^{10}\,J$ (Total energy)

Marking Criteria	Marks
Correctly used the total energy formula and computed the energy <u>OR</u> Correctly computed the gravitational potential energy, the kinetic energy in orbit and hence the total energy	3
Any two of the alternatives $(U\ and\ K)$ above OR $E = \left\lvert\frac{1}{2}U\right\rvert$ OR $E = \Delta U + \Delta K$	2
Any one of the alternative $(U\ or\ K)$ above OR ΔU calculated with correct $(R = r + h)$ OR $E = \frac{1}{2}U,$ with $r = 400\ km$	1



Question 24 (5 Marks)

Sample answer:

$$t_v = \gamma t_0$$

$$= \frac{2.2}{\sqrt{1-0.99^2}}$$

$$= 15.6\ \mu s$$

Distance travelled:

$$d = 0.99ct_v$$
$$= 0.99 \times 3 \times 10^8 \times \left(\frac{2.2 \times 10^{-6}}{\sqrt{1-0.99^2}}\right)$$
$$= 4632\ m$$

Marking criteria	Marks
Correct Lorentz factor, correct time computed, AND correct distance calculated	3
Any two of the above OR If $l_v = 653.8\ m, and\ l_0 = 4679\ m$	2
If $l_0 = 653.8, and\ l_0 = 93.1\ m$	1

(c) Sample answer

The muon's lifetime is dilated according to an observer on Earth, and hence the muon has more time, and thus covers a larger distance, resulting in many more muons reaching the Earth's surface than expected.

Marking criteria	Marks
Correct cause and link provided	2
Any one of the above	1

Question 25 (4 Marks)

(a) Sample Answer:
As the light passes the edges of the spherical object, the light bends, i.e. diffraction occurs. According to Huygen's principle, secondary wavelets are produced at every point on the circular wavefront. These interfere with each other to produce constructive and destructive interference (bright and dark bands). The conditions for bright bands are that the optical path difference must be an integral number of wavelengths, while for dark bands, the optical path difference must be an odd number of half wavelengths. The central bright band corresponds to zeroth order constructive interference due to the fact that point sources on the object are equidistant to the screen.

Marking criteria	Marks
Correctly provides the cause and effect for this phenomenon, including (i) Huygen's principle, (ii) conditions for constructive and destructive interference, and (iii) an explanation for the central bright band i.e. (D, C&D, PD), (D, H, C&D) or (D, C&D, B)	3
Provides a moderate explanation for the phenomenon i.e. omitting one of D, C&D, H, PD, B in the 3 setups above	2
Provides some relevant information	1

(b) Sample Answer:
Light is wave in nature.

Marking criteria	Marks
Provides correct conclusion	1

Question 26 (4 Marks)
Sample Answer
A black body is a theoretical body that absorbs all incident electromagnetic radiation (EMR) falling on it and emits this EMR when equilibrium has been reached. No EMR is reflected in the process.

Experimentally, i.e. according to the curves, as the temperature increases the intensity increases; and the wavelength at which the intensity peaks, decreases.

Classically, this implies that as the temperature increases ad-infinitum, the intensity of the radiation emitted, will increase without bound. This occurs closer to the UV end of the spectrum (shorter wavelengths). This violates the law of conservation of energy and is referred to as the UV catastrophe.

To provide an explanation for these black body radiation curves and to overcome the supposed mismatch between classical physics and experimental findings, Max Planck postulated that the light (EMR) emitted by a black body is emitted in discrete amounts/packets, called quanta (photon), proportional to its frequency. By doing so, the UV catastrophe was avoided.

Marking criteria	Marks
Correctly describes what a black body is (1), describes the trends (1) and shows how the need for the UV catastrophe to be avoided by the quantisation concept of the energy emitted by a black body (2)	4
Any three of the above	3
Any two of the above	2
Any one of the above	1

Question 27 (3 Marks) **3**
Sample Answer:

$d = \frac{1}{600}\ mm\ ,\ x = 0.65\ m\ , L = 2\ m$

$$d \sin\theta = n\lambda$$

$$\Rightarrow \lambda = \frac{dx}{Ln}$$

$$= \frac{\frac{1}{600}\times 10^{-3}\times 0.65}{2\times 1}$$

$$= 541\ \ nm \quad \text{OR} \quad 515\ nm \text{ if } \theta = \tan^{-1}\left(\frac{0.65}{2}\right)$$

Marking criteria	Marks
Correctly determines the spacing between slits, substitutes correctly in correct formula and hence determines the wavelength	3
Any two of the above	2
Any one of the above	1

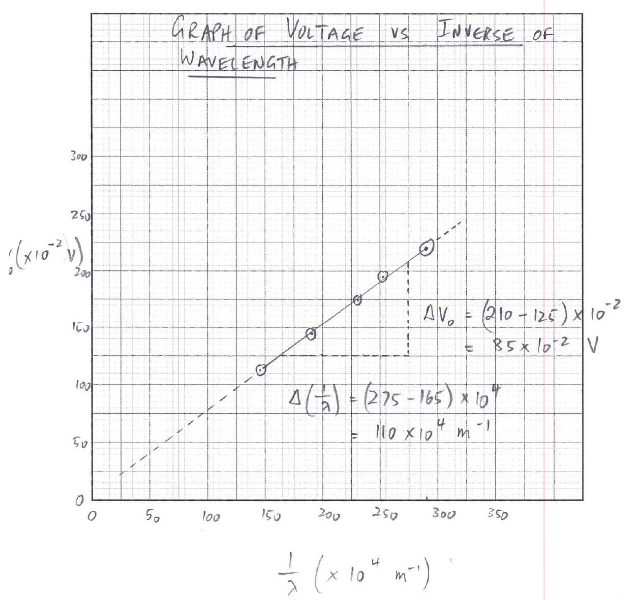
Question 28 (7 Marks)

LED Colour	Maximum wavelength, λ (nm)	Turn on Voltage, V_0 (V)	$\frac{1}{\lambda}$ $(\times 10^6\ m^{-1})$
Blue	346	2.22	2.89
Green	395	1.95	2.53
Yellow	439	1.75	2.28
Red	532	1.45	1.88
Infra-red	685	1.12	1.46

(a)

Marking criteria	Marks
1 for all correct	1

(b)



$hf = q(V_0 + k)$

$V_0 = \frac{hf}{q} - k = \frac{hc}{\lambda q} - k$

$\therefore$ slope $= \frac{hc}{q}$

$h = \frac{q}{c} \times$ slope

$= \frac{1.602 \times 10^{-19}}{3 \times 10^8} \cdot \frac{85 \times 10^{-2}}{110 \times 10^4}$

$= 4.13 \times 10^{-34}$ J.s

Marking criteria	Marks
Correct plotting, line of best fit, labelled axes, appropriate scale	4
Any three of the above	3
Any two of the above	2
Any one of the above	1

(c) Sample answer:

From $hf = q(V_0 + \ k)$,

$$V_0 = \frac{hf}{q} - k$$
$$= \frac{hc}{\lambda q} - k$$
$$= \left(\frac{hc}{q}\right)\frac{1}{\lambda} - k$$

Hence slope equals $\frac{hc}{q}$

i.e. $1.3 \times 10^{-6} = \frac{h \times 3 \times 10^{8}}{1.602 \times 10^{-19}}$

$$h = \frac{1.3 \times 10^{-6} \times 1.602 \times 10^{-19}}{3 \times 10^{8}} = 6.94 \times 10^{-34}$$

Marking criteria	Marks
Correct working for slope and correct value for Planck's constant	2
Any one of the above	1

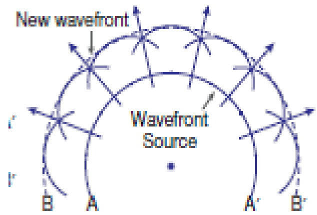
Question 29 (6 Marks)

Marking Criteria	Marks
Outlines Newtons and Huygens models of light (1 each) Describes the respective experimental and supporting evidence (one each of refraction (Foucault), reflection, polarisation AND diffraction (Young's double slit) for wave nature; AND/OR photoelectric effect for particle nature of light 3 – Newton (1 for initial proposal, 2 for experimental evidence, some description) 3 – Huygen (1 for initial proposal, 2 for experimental evidence) For maximum 6 must include Young's Double slit and/or Photoelectric effect	5-6
Moderate description	3-4
Superficial description	1-2

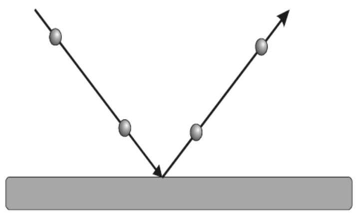
Sample Answer:

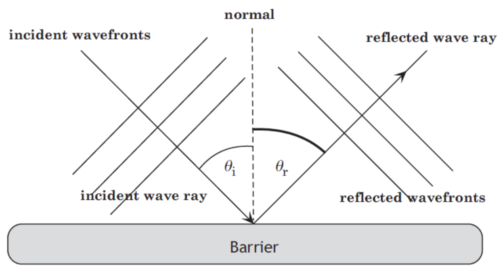
Newton (1650 – 1700) proposed that light consists of very tiny almost massless particles known as 'corpuscles'. The corpuscles on emission from the source travel in straight lines with high velocity, like objects falling through air.

Huygen, on the other hand proposed a wave model for light, in which points on a wavefront are sources of secondary circular waves (wavelets).

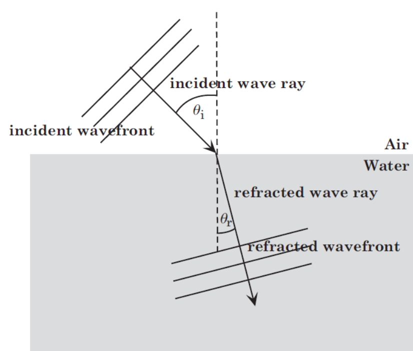


Newton showed that, in an elastic collision between hard spheres, the angle of incidence equals the angle of reflection. Huygen had a similar proposal for reflection.



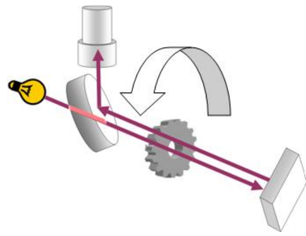


Newton explained refraction by comparing the movement of the particles of light with that of a ball descending an inclined plane. According to Newton, the particles of light will accelerate as they pass from air to water. Newton claimed that water attracted the particles of light, predicting that the speed of light would be faster in water than in air.
The vertical component of their velocities increases and hence they bend towards the normal, thus speeding up in denser media.



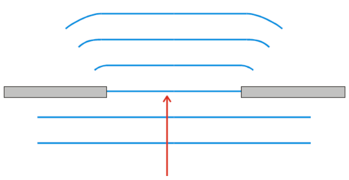
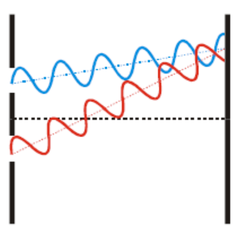
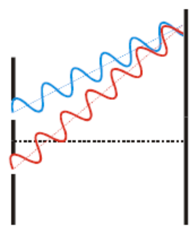
Refraction while passing from the air to water, a light ray deviates towards the normal. Huygens' wave theory explained this deviation by proposing that the speed of the wave decreases in the heavier medium. Snell's Law can be derived from Huygens' geometry. Huygens' model predicts that the speed of light is less in water than in air. This explanation goes against Newton, who predicted that the speed of light is greater in water. Thus, determining the speed of light becomes a "critical experiment," which provides definitive support for one theory and eliminates the other.

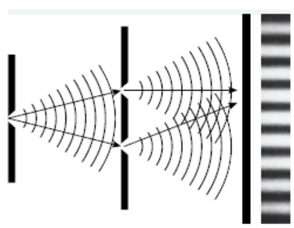
Foucault provided verification for the decrease in speed during refraction in a denser medium, supporting Huygen's view on refraction.



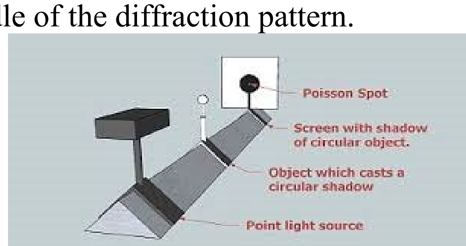
Newton's model was unable to explain interference and diffraction phenomena.

When a wave passes by a barrier, it bends (diffraction). If the opening is narrow enough (compared to the wavelength), the waves will emerge as circular waves. In this way, as waves pass through two thin slits, a pattern of constructive and destructive interference occurs. A similar pattern of interference occurs with light. When two crests or two troughs meet, light is enhanced and a bright area can be seen. When a crest meets a trough, destructive interference occurs and a dark area is seen. The interference pattern shows up as a series of alternating light and dark bands. This was experimentally obtained by Thomas Young (1800).

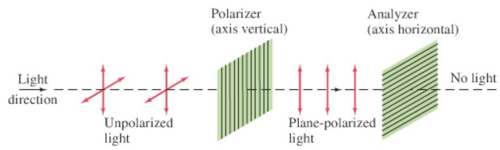



Poisson's Spot: When light is diffracted around a spherical object (like a steel ball bearing), a bright spot appears in the middle of the diffraction pattern.



Some History:
In 1818, Fresnel presented a paper on the theory of diffraction to the French Academy. Contrary to Newton's corpuscular model, Fresnel's theory represented light as a wave. Poisson, a member of the judging committee for the competition, was very critical of the wave theory of light. Using Fresnel's own theory, Poisson deduced that light diffracted around a circular obstacle would produce a bright spot behind the object. Poisson believed that this was an absurd outcome that

falsified Fresnel’s theory. However, another member of the judging committee, Arago, produced the spot experimentally and Fresnel won the competition.
So, the Poisson or Arago Spot was experimental evidence for the wave nature of light.
Malus’s Law (Polarisation) provides evidence about the transverse nature of light.



Heinrich Hertz (1890) noticed that when certain metal surfaces are exposed to an ultraviolet light, negative charges are emitted from the metal.
Could the emission of negative charges, using the particle and wave models of light be explained?
To dislodge an electron of a metal surface, it is necessary to communicate a certain quantity of energy to the electron. The wave model predicts that the energy distributed along the wave will eventually build up and release a package of electrons at the same time. According to the wave model, light of any frequency should demonstrate the photoelectric effect. Lower frequencies would just take longer to build up enough energy to release the electrons. A low frequency wave with high intensity should eventually be able to dislodge an electron.
This, however, is not the case. Only certain threshold frequencies emit electrons. The wave model fails to accurately predict the photoelectric phenomenon.
Prediction of the particle model was made by Einstein (1905) who proposed that light consists of packets of energy called “photons,” and that the quantity of energy of each photon is fixed and depends on its frequency. Thus, the particle model predicts that individual photons knock out electrons and that only photons with enough energy (above the threshold frequency) can do this.

COMMENTARY – about dual nature of Light:

As the predictions of the particle and wave models of light are evaluated, it is found that each model explains some phenomena and each model has difficulty explaining other phenomena.
Initially, it is thought that the determination of the speed of light and the explanation of diffraction were critical experiments that eliminated the particle model in favour of the wave model.
However, the photoelectric effect seems to do the opposite: it favours the particle model and cannot be explained by the wave model.
This brings up the question: “Can there ever be a critical experiment that eliminates one theory and favours another?”
The answer is that there is no such thing as a critical experiment because some other explanation could always exist. It is obvious that light is not just a particle or a wave. Light has a dual nature, a property that physicists call the wave-particle duality of light. We cannot draw pictures or visualize this duality.
As humans, we are restricted to thinking only about particles and waves independently. Niels Bohr, the Danish physicist, declared in his principle of complementarity that, “to understand a specific experiment, one must use either the wave or photon theory but not both.” To understand light, one must understand the characteristics of both particles and waves. The two aspects of light complement each other.

Question 30 (10 marks)

(a)

Marking criteria	*Marks*
For indicating that the currents at t_1 and t_2 have equal nonzero magnitudes At t_1 and t_2 currents are in the same direction At t_1 and t_2 currents are anticlockwise (counter clockwise) For indicating that there is no current at t_3 because there is no change in flux For correctly indicating that the emf induced and the induced current depend on the change in flux through the loop or the forces on the charges moving in the field Faraday's law and Lenzs's law. OR For either explaining that the direction of the current generates a magnetic field that opposes the change in flux or analysing the force on the charge carriers in each segment of the loop 2	1 1 1 1 1

Sample Answer

At t_1 and t_2 there is a current which is equal in magnitude and flowing in the same direction. The direction of the current in the loop is anticlockwise at t_1 and t_2.

At t_3, there is no current in the loop.

Explanation:
At t_1 and t_2, as the loop enters the constant, uniform magnetic field, there is a change in flux through the loop. As the speed of the loop is constant, this rate of change in flux is constant and hence constant emf induced (Faraday's law) and hence magnitude of current is the same.

$$\mathcal{E} = -N\frac{\Delta\Phi}{\Delta t}$$

The direction of the current generates a magnetic field that opposes the change in flux and hence the current flows in an anticlockwise direction. At t_3, there is no current in the loop because there is no change in flux and hence no emf induced and hence no current.

(b)

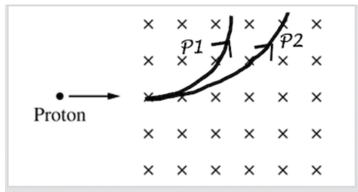
(i) Calculate the magnitude of the force on the proton as it enters the field.

1

Marking criteria	*Marks*
For correct substitutions into a correct expression and correct units on the final answer $F = qvB = (1.6 \times 10^{-19})(3.0 \times 10^{-5})(0.03)$ $F = 1.4 \times 10^{-15}$ N	1

Sample Answer

$F = qvB = (1.6 \text{ x} 10^{-19})\ (3.0\text{x}10^{-5})\ (0.03)$
$F = 1.4 \text{ x} 10^{-15}$ N
(ii) and (iii)
Sample answer:



Marking criteria (ii)	*Marks*
For drawing a curved arc through the field, curved upward where the proton enters (Anything greater than a semi-circle or a path that does not reach the edge of the field does not earn credit. Any path after exiting the field is ignored)	1

(iii)

Marking criteria (iii)	*Marks*
For drawing a path with a **larger radius** that is consistent with answer to (b)(ii) (Anything greater than a semi-circle or a path that does not reach the edge of the field does not earn credit. Any path after exiting the field is ignored)	1

(iv)

Marking criteria	*Marks*
For indicating a direction of the electric field that is consistent with the response to (b)(ii) For equating the electric and magnetic forces and substituting into the correct expression using values consistent with the response to (b)(i) and correct units	2
Any one of the above	1

Sample answer:

Given the correct response to (b)(ii) illustrated above, the electric field must be directed toward the bottom of the page

$qE = qvB$ (Implicitly equating the calculated magnetic force to the electric force is acceptable.)
$E = vB$
$= (3.0 \text{ x } 10^{5} \text{ ms}^{-1})\ (0.03)$
= **9000 NC^{-1}**

Question 31 (4 marks)

(a)

Marking criteria	*Marks*
For correct substitutions into two correct expressions and correct units on the final answer	2
For correct substitutions into one correct expression and correct units on the final answer	1

Sample answer

The current flow from the power supply is:

R = 100 x 0.018
= 1.8 Ohms

I = V/R
= 120/1.8
= 67 A

(b)

Marking criteria	*Marks*
For correct substitution into correct expressions and correct units on the final answer	2
For correct substitutions into one correct expression and no units	1

Sample answer

The effective torque supplied by the motor is 5.3 N m
Torque = n B I A
= 100 x 25 x 10^{-3} x 66.7 x (0.32 x 0.1) = 5.33 Nm

Question 32 (3 Marks)

P -Q Electron gun: to fire narrow beam of high speed cathode rays

R-R' electric plates/fields for deflecting the beam of cathode rays

S Phosphorescent screen (with scale) to see where cathode rays land

Question 33 (6 marks)

(a)

$\Sigma F = 0$ gives $qE = mg$ and $q = mg/E = 3.27 \times 10–19$ C 1 m

(b) **2**

Marking criteria	*Marks*
For correct explanation including charge	2
For stating force on a negative charge is opposite to electric field direction	1

The drop must have a net negative charge.
The electric force on a negative charge acts opposite the direction of the electric field.

(c)

Marking criteria	*Marks*
For correct substitution into correct expression and correct	1

$V = Ed = 100$ V

(d)

Marking criteria	*Marks*
For correct motion described and correct reason	2
For correct motion described and incorrect reason	1

The drop moves upward. The reduced mass decreases the downward force of gravity on the drop while if the charge remains the same, the upward electric force is unchanged.

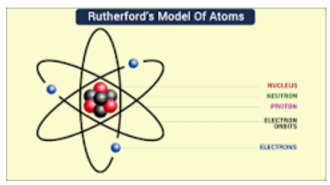
Question 34 (8 marks)

Marking criteria	*Marks*
A **coherent and logical detailed description** of the models proposed by **all three** R, B and S which demonstrating an understanding the advantages and limitations of each of their models of the atom AND making an assessment of each scientist's model.	7-8
Good description of the models proposed by **any two** scientists from R, B and S demonstrating an understanding the advantages and limitations of each of their models of the atom.	5-6
A **superficial description** of the models proposed by **any two** from R, B and S demonstrating an understanding the advantages and limitations of each of their models of the atom.	3- 4
A good description of **any one** of the models demonstrating an understanding the advantages and / or limitations of their models of the atom.	2-1

Sample answer

The model of the structure of the atom developed from the plum-pudding model proposed by JJ Thomson in 1904.

In 1907, **Rutherford** explained the results of the Geiger Marsden experiment and proposed the **planetary or nuclear model** for the structure of atoms in elements. He was the first to propose that the positively charged particles of atoms were concentrated in an extremely small volume and that most of the atom was empty space. He called the small, dense central part of the atom the nucleus. He proposed that the negatively charged electrons surround the nucleus of an atom revolving around it with very high speed in circular paths which he named as orbits.



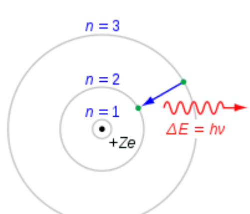
Assessment:

The model was a simple model which became the basis for modification by Bohr and other physicists. His model was the first modern model with a nucleus and was the first to state the relative size of the nucleus compared to the atom.
In 1919, Rutherford predicted that a neutral particle, with a mass equal to that of a proton, must be part of the nucleus and he. Named this article the neutron.

The Rutherford model **had limitations** as it failed to explain why the orbiting electron is not emitting energy and spiral into the nucleus and hence could not explain the stability of the nucleus.
Another limitation is it did not describe the arrangement of electrons in an atom.
His model did not attempt to explain the spectral lines emitted by hot gases.
Although the early models were inaccurate and failed to explain certain experimental results, they were the base for future developments in the world of quantum mechanics.

Bohr

In 1922 Bohr proposed that electrons orbit a positively charged nucleus and these orbits are called electron energy shells. When electrons absorb quanta of energy they move to a higher energy levels and when electrons fall back to lower energy levels, they release quanta of energy as emr. It is this release of emr that forms atomic spectra.



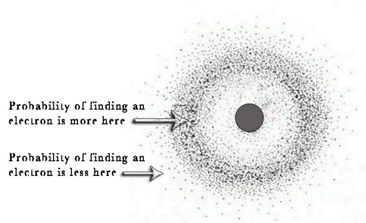
A **success** of the Bohr model was that the equation for predicting the wavelengths of hydrogen spectrum lines could be derived correctly and confirming Balmer's derivation.
His model predicted the ionisation energy of hydrogen.

The **limitations** of his model include the following:
Its inability to explain the varying intensity of the spectral lines,
The existence of the hyperfine spectral lines
The splitting of the spectral lines in an external magnetic field (the Zeeman effect)
Its inability to explain the spectral lines of atoms other than hydrogen.

Schrodinger
In 1926 Schrodinger's work marked a significant turning point in the development of physics. Schrodinger's quantum model of the atom described the electrons in terms of the mathematical probability of finding them in various positions around the nucleus.

He proposed the wave-mechanics model or electron cloud model because it described the electron structure of an atom in terms of mathematical probability of finding electrons in certain regions of space around the nucleus.

Schrodinger's Atomic Model.



In this model, the density represents the probability of finding an electron.

The **success** of this model was that:

- it had more familiar concepts and equations and seemed to do away with difficulty of the developing quantum theory and fitted in with Pauli's exclusion principle (1925)
- the maths was easier and more readily translated into a visual image of the atom
- in 1926 it put proof that matrix and wave mechanics give same results
- it proposed shells within shells (subshells s, p, d, and f)

Schrodinger could not explain all atomic behaviour satisfactorily and this model was refined by later scientists.

Question 35 (8 marks)

(a)

Marking criteria	*Marks*
For correct calculation of mass defect and BE in MeV	2
For correct calculation of mass defect and BE in Joules	1

Sample answer

using mass defect = $\Delta m = Z\, m_p + N\, m_n - M_{Co}$)

$\Delta m = 27 \times 1.00728 + 32 \times 1.00867 - 58.93320$ (u)

$\Delta m = 0.5408$ (u)

Binding Energy = $0.5408 \times 931.5 = 503.8$ (MeV)

(b)

Marking criteria	*Marks*
For correct calculation of energy change from figure in J and conversion to MeV	2
For correct calculation of energy change from figure in J	1

Sample answer

$(2.52 - 1.76) \times 10^{-13} = 7.6 \times 10^{-14}$ J 1 mark

$7.6 \times 10^{-14} / 1.60 \times 10^{-13} = 0.47$ or 0.48 MeV or 0.474 MeV 1 mark

Sample answer

$2\ (2.52 - 1.76) \times 10^{-13} = 7.6 \times 10^{-14}$ J

$7.6 \times 10^{-14} / 1.60 \times 10^{-13} = 0.47$ or 0.48 MeV or 0.475 MeV

(c) 6 (specific wavelengths)

(d)

Marking criteria	*Marks*
For correct identification of longest wavelength and hence lowest frequency and correct calculation of wavelength from fig.	3
For correct identification of longest wavelength and hence lowest frequency and incorrect calculation of wavelength from figure	2
For correct identification of longest wavelength and hence lowest frequency	1

Sample answer

(longest wavelength = lowest frequency = smallest energy)

$(2.29 \times 10^{-13} - 2.06 \times 10^{-13}) = 2.3 \times 10^{-14}$ (J) = hc / λ

λ (= $h\,c / E$) = $6.63 \times 10^{-34} \times 3.00 \times 10^{8} / 2.3 \times 10^{-14}$ = hc / λ

$\lambda = 8.6 - 8.7 \times 10^{-12}$ (m) or (8.64×10^{-12} m)