PΣΛK

PHYSICS MOCK EXAM

NESA Number

2020 HIGHER SCHOOL CERTIFICATE EXAMINATION

Physics

General Instructions

- Reading time – 5 minutes
- Working time – 3 hours
- Write using black or blue pen
- Draw diagrams using pencil
- Calculators approved by NESA may be used
- Write your NESA number where required

Total marks: 100

Section I – 20 marks (pages 2-7)

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

Section II – 80 marks (pages 8-22)

- Attempt Questions 21-35
- Allow about 2 hours and 25 minutes for this section

Section I: Multiple Choice Questions (20 marks)
Attempt Questions 1 − 20
Allow about 35 minutes for this part

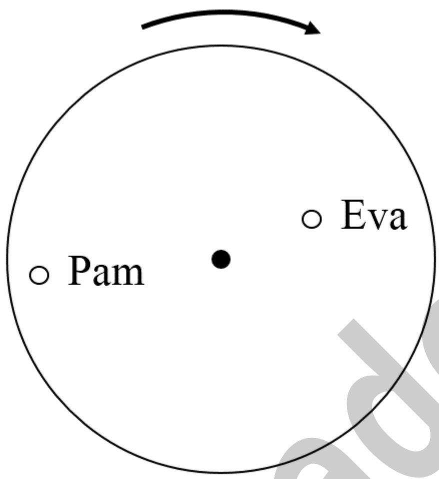
Use the multiple choice answer sheet for Questions 1 − 20.

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

1. During an experiment, a double-slit interference pattern is produced on a screen. If the screen is moved further away from the slits, the fringes will be

   (A) Closer together.
   (B) Further apart.
   (C) In the same positions.
   (D) Fuzzy and out of focus.

2. Eva and Pam stand on a rotating circular platform as shown below.



   Which of the following correctly compares the magnitude of their linear and angular velocities?

   (A) Pam has the greater linear velocity but their angular velocities are equal.
   (B) They both have equal linear and angular velocities.
   (C) They have the same angular velocity but Eva has a larger linear velocity.
   (D) Pam has a smaller angular velocity and their linear velocities are equal.

3. Mercury has a mass of 3.285×10^{23} kg and diameter of 4.8×10^{3} km. The acceleration due to gravity on its surface is

   (A) $3.8\ \mathrm{m\,s^{-2}}$
   (B) $15.2\ \mathrm{m\,s^{-2}}$
   (C) $0.95\ \mathrm{m\,s^{-2}}$
   (D) $7.6\ \mathrm{m\,s^{-2}}$

4. What is the role of a transformer at an electrical power station?

   (A) To reduce heating in the transmission lines by stepping up the voltage.
   (B) To reduce heating in the transmission lines by stepping up the current.
   (C) To increase heating in the transmission lines by stepping up the voltage.
   (D) To increase heating in the transmission lines by stepping up the current.

5. The orbital period and orbital radius of some planets are shown below.

Planet	Orbital Period (days)	Orbital Radius (10^6 km)
P	88	58
Q	687	228
R	59,800	4495
S	80,560	5906

Which of these planets orbit a different star to the others?

(A) P
(B) Q
(C) R
(D) S

6. A car is turning on a banked track at a constant speed. Which of the following statements is true?

(A) All the forces acting on the car are balanced, allowing it to travel at a constant speed.
(B) There is no frictional force from the road acting on the car.
(C) The force acting on the car parallel to the track is equal to the centripetal force.
(D) The net force on the car creates a centripetal force.

7. Unpolarised light of intensity I_0 is incident on two polarising sheets. At what angle should the second sheet be rotated relative to the first sheet so that the exiting light has intensity $0.25I_0$?

(A) 30°
(B) 45°
(C) 60°
(D) 90°

8. What change to the atomic model did the results of the Geiger-Marsden gold foil experiment lead to?

(A) The atom is mostly empty space.
(B) The nucleus consists of neutrons and protons.
(C) Electrons orbit the nucleus in discrete energy levels.
(D) All atoms contain positive and negative charge.

9. Which of the following is an inertial frame of reference?

(A) A lift slowing down as it reaches the bottom floor.
(B) A cyclist riding downhill without braking.
(C) A ball when it reaches its maximum height after being thrown vertically.
(D) A sky diver falling at their terminal velocity.

10. Carbon-14 has a half-life of 5730 years. How many grams of a 4.0 g sample of carbon-14 are left after 3.5 half-lives?

(A) 0.125 g
(B) 0.250 g
(C) 0.354 g
(D) 0.375 g

11. Which of the following statements regarding nuclear reactions is true?

(A) If the binding energy of the reactants is greater than that of the products, the reaction absorbs energy.
(B) If the mass of the products is greater than that of the reactants, the reaction releases energy.
(C) If the reaction is a fission reaction, the reaction releases energy because the products weigh less.
(D) If the reaction is a fusion reaction, the reaction absorbs energy because the products are more stable.

12. A new type of motor has no back EMF induced when it is running. This new motor is compared to a similar motor that does have normal back EMF. The new type of motor without back EMF would

(A) Have less torque than the normal motor.
(B) Start up faster than a normal motor.
(C) Likely burn out.
(D) Spin slower than a normal motor.

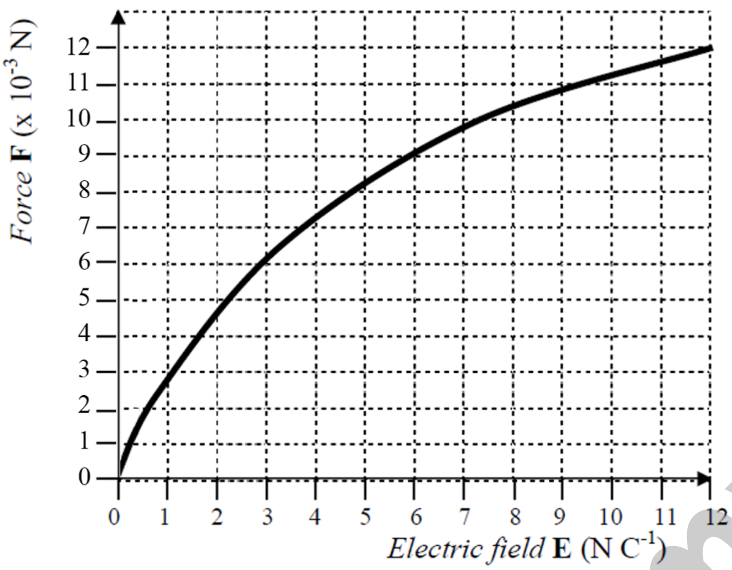
13. The principle of the conservation of energy is the reason why

(A) Transformers produce the same current in the secondary coil.
(B) Step-up transformers have a larger current in the secondary coil.
(C) Step-down transformers have a larger current in the secondary coil.
(D) Transformers are not very efficient.

14. Which of the following is a correct consequence of the speed of light in a vacuum being the same for all observers?

(A) The frame of reference of the observer is always the real frame of reference.
(B) Observations of events in distant galaxies are observations of events that occurred in the past.
(C) When measured by a stationary observer, the length of a moving object is longer than the length of the object when it is measured in its own frame of reference.
(D) A clock that is at rest in the observer's own frame of reference will tick faster than a clock that is moving relative to an observer.

15. An investigation was performed to measure the force F on a charged object as the electric field E was varied. The results were plotted on a graph of F versus E which is shown below.



Using the graph, which of the following statements is true?

(A) The magnitude of the charge was 1.0×10^{-3} C.

(B) The force was proportional to the electric field.

(C) The particle was losing charge as the electric field was strengthened.

(D) The particle was gaining charge as the electric field was strengthened.

16. Magnetic flux is most closely associated with the

(A) Number of lines of magnetic force.

(B) Density of the lines of magnetic force.

(C) Direction of the lines of magnetic force.

(D) Size of the area that the magnetic lines of force pass through.

17. A satellite of mass 845 kg moves from a low Earth orbit of altitude 2000 km to a medium Earth orbit of altitude 5000 km. Its total change in energy is:

(A) 5.07×10^{10} J

(B) -5.07×10^{10} J

(C) 5.33×10^{9} J

(D) -5.33×10^{9} J

18. Which of the four fundamental forces is not described by the Standard Model of matter?

(A) Gravitational

(B) Electromagnetic

(C) Strong

(D) Weak

19. Students are conducting a photoelectric effect experiment. They shine light of known frequency onto a metal and measure the maximum kinetic energy of the emitted photoelectrons.

    The students increase the intensity of the incident light. The effect of this increase would most likely be

    (A) Lower maximum kinetic energy of the emitted photoelectrons.
    (B) Higher maximum kinetic energy of the emitted photoelectrons.
    (C) Fewer emitted photoelectrons but of higher maximum kinetic energy.
    (D) More emitted photoelectrons but of the same maximum kinetic energy.

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

    (A) Random errors can be reduced by repeated readings.
    (B) Both random and systematic errors can be reduced by repeated readings.
    (C) Systematic errors can be reduced by repeated readings.
    (D) Neither systematic nor random errors can be reduced by repeated readings.

Part B: Short Answer Questions (40 marks)
Attempt Questions 11 – 18
Allow about 1 hour and 13 minutes for this part

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.

Question 21 (5 marks)

(a) Describe the evidence for time dilation and and length contraction. **3**

The Hafele-Keating experiment involved 3 atomic clocks; the control clock was kept on Earth, another was flown east (with direction of Earth's rotation, so it was moving faster) and the last flown west (against Earth's rotation, so moving slower). When the clocks were later compared, less time had passed on the east-bound clock than the Earth clock, while more time had passed on the west-bound clock than the Earth clock. This is supports time dilation, showing that the faster moving clocks experienced time passing more slowly.

1 mark – Identifies an experiment supporint time dilation.

1 mark – Describes the experimental method.

1 mark – Explains how the results support time dilation.

(b) Alice is on a spherical spaceship travelling at 200 000 km/s past Earth. Describe the shape of the spaceship to an observer on Earth, including relevant calculations. **2**

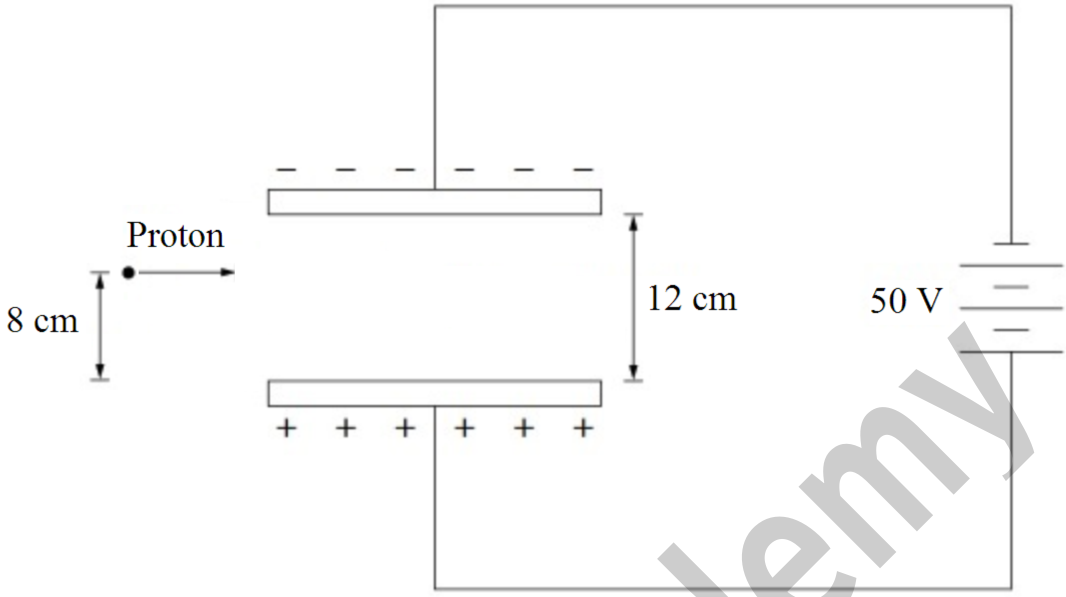
$$
\begin{aligned}
l_v &= l_0\sqrt{1-\frac{v^2}{c^2}} \\
&= D\sqrt{1-\left(\frac{2}{3}\right)^2} \\
&= 0.75D
\end{aligned}
$$

The sphere will appear contracted in the direction of motion to around 75% of its original diameter, but its height will remain the same. Hence the ship appears elliptical to the observer.

1 mark – Describe the sphere as having contracted in one direction, but not the other.

1 mark – Calculates the degree of contraction.

Question 22 (5 marks)
A proton is projected horizontally between a pair of parallel plates as shown in the diagram below. The proton enters the electric field at a speed of 2×10^4 ms^{-1} and later hits one of the plates.



(a) Calculate the work done on the proton by the electric field. **2**

$$
\begin{aligned}
E &= \frac{V}{d} \\
&= \frac{50\text{ V}}{0.12\text{ m}} \\
&= 416.7\text{ N m}^{-1} \\
W &= qEd \\
&= 1.602 \times 10^{-19}\text{ C} \times 416.7\text{ N m}^{-1} \times 0.04\text{ m} \\
&= 2.67 \times 10^{-18}\text{ J}
\end{aligned}
$$

1 mark – Calculates the electric field strength or equivalent

1 mark – Calculates the work done

(b) Calculate the final velocity of the proton. **3**

$$
\begin{aligned}
\mathit{\Delta} K &= W \\
\frac{1}{2}mv^2 - \frac{1}{2}mv_x^2 &= W \\
\frac{1}{2}mv^2 &= W + \frac{1}{2}mv_x^2 \\
v^2 &= \frac{2W}{m} + v_x^2 \\
v &= \sqrt{\frac{2W}{m} + v_x^2} \\
&= \sqrt{\frac{2 \times 2.67 \times 10^{-18}}{1.673 \times 10^{-27}} + \left(2 \times 10^4\right)^2} \\
&= 6.0 \times 10^4\ \mathrm{m\,s^{-1}}
\end{aligned}
$$

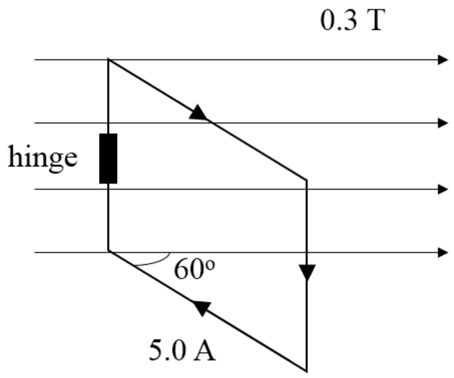
$$
\begin{aligned}
\cos(\theta) &= \frac{v_x}{v} \\
\theta &= \cos^{-1}\left(\frac{2}{6}\right) \\
&= 70.5^\circ
\end{aligned}
$$

The final velocity is $6.0 \times 10^4\ \mathrm{m\,s^{-1}}$ at an angle of 70.5° to the plate.

2 marks – Calculates the final speed. Students may also have calculated $v_y = 5.65 \times 10^4\ \mathrm{m\,s^{-1}}$ separately.

1 mark – Calculates the direction

Question 23 (4 marks)
A 20 x 20 cm square loop of wire is immersed in a magnetic field of strength 0.3 T to the right. The loop is hinged on its left side and carries a current of 5.0 A. The angle between the plane of the loop and the magnetic field is 60°.



(a) Calculate the torque acting on the loop. **2**

$$\begin{aligned} F &= BIl\sin\theta \\ &= 0.3 \times 5.0 \times 0.2 \\ &= 0.3 \text{ N out of the page} \\ \tau &= rF \\ &= 0.2 \times 0.3 \\ &= 0.06 \text{ Nm downwards} \end{aligned}$$

1 mark – Calculates the force.

1 mark – Calculates the torque. Students also could have used $\tau = nBIA\cos\theta$

(b) The current in the loop is turned off. The loop is now rotated about its hinge by 90° anticlockwise from a top view. If this rotation occurs over 0.4 seconds, what is the average emf induced in the loop? **2**

$$\begin{aligned} \varepsilon &= n\frac{\Delta\phi}{\Delta t} \\ &= \frac{0.3 \times 0.2^2(\sin 60 - \cos 30)}{0.4} \\ &= 0.011 \text{ V} \end{aligned}$$

1 mark – Calculates the change in flux correctly.

1 mark – Calculates the torque.

Question 24 (5 marks)

"One of the most significant discoveries in physics was Maxwell's discovery of the laws of electromagnetism." **5**

Evaluate this statement with reference to Maxwell's contribution to the classical theory of electromagnetism.

Maxwell's equations were undoubtedly one of the most important discoveries in physics. They signified the unification of electricity and magnetism, which we can now consider together as one fundamental interaction.

From his laws, he was also able to predict the existence of electromagnetic waves and explain their propagation. He predicted the velocity of these waves to be $\frac{1}{\sqrt{\mu_0 \varepsilon_0}}$ which was close to the known speed of light. Because of this, he proposed that light was a portion of the electromagnetic spectrum with a visible wavelength, and that there other wavelengths of electromagnetic radiation invisible to the naked eye. These other electromagnetic waves were subsequently discovered in later years by other scientists (for example, Heinrich Hertz's discovery of radio waves).

The implications of Maxwell's laws also later paved the way for other scientific work, such as Einstein's theory of special relativity.

Hence the far reaching effects of Maxwell's laws make it one of the most significant discoveries in physics.

2 marks – Describes the unification of electricity and magnetism and and its relationship with light.

2 marks – Describes Maxwell's predictions.

1 mark – Provides a judgement evaluating the statement.

Question 25 (4 marks)
A scientist is investigating the escape velocity of an electron from a proton. It is known that the potential energy of a charge q in the presence of another charge Q a distance r away is given by

$$U_E = \frac{1}{4\pi\epsilon_0}\frac{qQ}{r}$$

(a) Calculate the minimum velocity required for an electron orbiting a proton at a radial distance of 9×10^{-15} m to escape from the proton. **2**

The electron can escape if its kinetic energy can overcome its potential energy.

$$\begin{aligned}
K + U_E &= 0 \\
\frac{1}{2}mv^2 + \frac{1}{4\pi\epsilon_0}\frac{qQ}{r} &= 0 \\
\frac{1}{2}mv^2 &= -\frac{1}{4\pi\epsilon_0}\frac{qQ}{r} \\
v &= \sqrt{\frac{-2qQ}{m \times 4\pi\epsilon_0 \times r}} \\
&= \sqrt{\frac{2(1.602 \times 10^{-19})^2}{9.109 \times 10^{-31} \times 4\pi \times 8.854 \times 10^{-12} \times 9 \times 10^{-15}}} \\
&= 2.37 \times 10^8 \text{ m s}^{-1}
\end{aligned}$$

1 mark – Equates $K + U_E$ or equivalent.

1 mark – Calculates the escape velocity.

(b) Explain why an electron orbiting a proton at a radial distance of 5×10^{-15} m can never escape from the proton. **2**

Using the expression for the escape velocity from part (a), the escape velocity at this new radius is

$$\begin{aligned}
v &= \sqrt{\frac{2(1.602 \times 10^{-19})^2}{9.109 \times 10^{-31} \times 4\pi \times 8.854 \times 10^{-12} \times 5 \times 10^{-15}}} \\
&= 3.18 \times 10^8 \text{ m s}^{-1} \\
&> c
\end{aligned}$$

No object can travel faster than the speed of light, hence the electron will never be able to reach its required escape velocity and cannot escape from the proton.

1 mark – Equates $K + U_E$ or equivalent.

1 mark – Calculates the escape velocity.

Question 26 (4 marks)
An astronomer observes the spectra of two stars in the sky, star X and star Y. It is known that X travels toward the Earth while Y travels away from Earth. It is also known that the rotational velocity of star X is significantly greater than that of star Y.

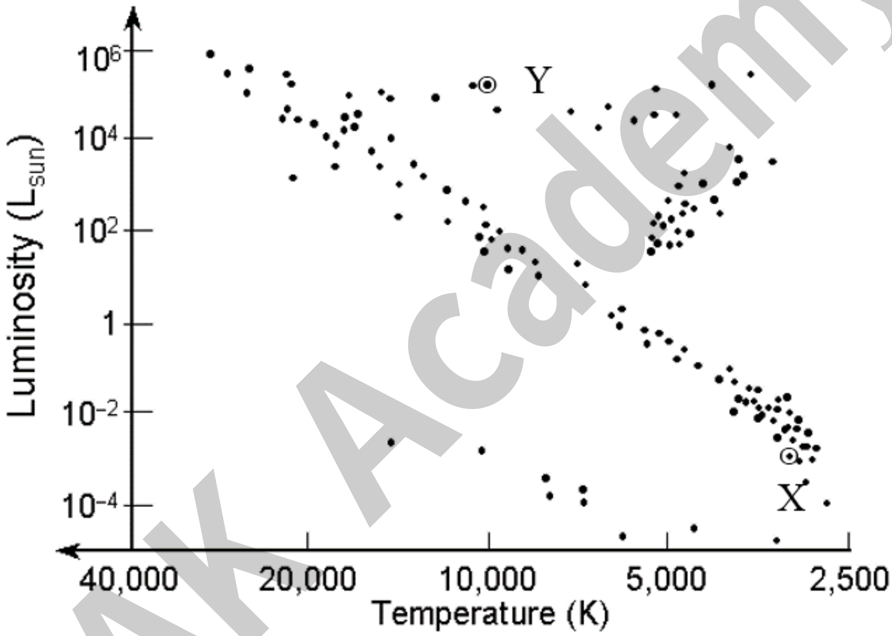
(a) Compare the expected spectral lines of stars X and Y. **2**

Because of their radial velocities, the spectral lines of X will be blue-shifted while the spectral lines of Y will be red-shifted. The spectral lines of star X will also appear thicker than those in star Y since X has a greater rotational velocity.

1 mark – Correctly identifies the blue/red shift of each.

1 mark – Correctly identifies the relative thickness of each.

(b) The location of stars X and Y on the Hertzsprung-Russell diagram are shown below. **2**



Identify the possible nuclear reactions occurring in stars X and Y.

X is a main sequence star so it will have hydrogen fusion occuring in its core. Y is a supergiant, so it could have the fusion of helium and heavier elements up to iron in its core.

2 marks – Correctly identifies the possible elements fused in each star (1 mark each).

Question 27 (8 marks)

(a) Describe how Millikan's oil drop experiment and ONE other experiment advanced scientific understanding of the electron. **4**

J.J. Thomson deflected cathode rays (electrons) with magnetic and electric fields to calculate their charge to mass ratio. He obtained the same charge to mass ratio regardless of electrode material, suggesting the electrons were present in all atoms. The ratio was also quite small, leading Thomson to believe that the electrons were light subatomic particles.

Millikan was later able to determine the charge of a single electron in his oil drop experiment. His results showed that charge was quantised and he suggested that the base value of -1.6×10^{-19} C was the charge of an electron.

With the charge of an electron and its charge to mass ratio known, the mass of an electron could also then be theoretically calculated.

2 marks – Describes how Millikan's oil drop experiment advanced our understanding of the electron.

2 marks – Describes how one other experiment advanced our understanding of the electron.

(b) An oil droplet suspended between a pair of vertical parallel plates has a diameter and density of 0.24 mm and 886 kg/m^3 respectively. The plates are supplied with 220 V and are separated by 4 mm. Calculate the net charge of the oil droplet. **4**

$$\begin{aligned} m &= \rho V \\ &= 886 \text{ kg m}^{-3} \times \frac{4}{3}\pi \left(\frac{0.24 \times 10^{-3} \text{ m}}{2}\right)^3 \\ &= 6.41 \times 10^{-9} \text{ kg} \end{aligned}$$

$$\begin{aligned} E &= \frac{V}{d} \\ &= \frac{220 \text{ V}}{0.004 \text{ m}} \\ &= 55000 \text{ V m}^{-1} \end{aligned}$$

$$\begin{aligned} F_g &= F_E \\ mg &= Eq \\ q &= \frac{mg}{E} \\ &= \frac{6.41 \times 10^{-9} \times 9.8}{55000} \\ &= 1.14 \times 10^{-12} \text{ C} \end{aligned}$$

4 marks – Equates F_g and F_E, calculates the mass, electric field strength and charge on the droplet (1 mark each).

Question 28 (5 marks)

Various methods have been used in the past to measure the speed of light.

(a) Describe one historical and one contemporary method that has been used to measure the speed of light. **4**

Historical method: Roemer realised that Io's orbital period around Jupiter as observed from Earth varied depending on the time of year. This was due to light travelling a greater/less distance when Earth moved away from/towards Jupiter. From the time difference of Io's period and the difference in distance travelled, Roemer calculated the speed of light to be near 2×10^8 ms^{-1}.

Contemporary method: Fizeau shone light through the teeth of a rotating toothed wheel. A mirror 8 km away reflected the light back through the same slot. If the wheel rotates quickly enough, it will block the returning light and make the wheel appear opaque. The required rotational speed along with the other experimental parameters could then be used to calculate the speed of light.

2 marks – Describes a historical method used to measure the speed of light. Other methods include Galileo's (timing and observing 2 lamps) and Bradley's (change in stellar abberation).

2 marks – Describes a contemporary method used to measure the speed of light. Other methods include the rotating mirror (Foucault).

(b) Today, the speed of light has been declared to be 299 792 458 m/s. Explain how this has been used to define units of measurement. **1**

Since the speed of light is a precisely known standard, a metre has been defined as the distance travelled by light in $\frac{1}{299792458}$ seconds.

1 mark – States the definition of the metre using the speed of light.

Question 29 (3 marks)

Explain how elements can be identified by spectroscopy, making reference to Bohr's model of the atom. **3**

In Bohr's atomic model, electrons orbit the nucleus in discrete, quantised energy levels. When electrons move between these levels, they will absorb/emit a quantised amount of energy equal to the energy difference in the form of a photon. Since a photon's energy is related to its frequency (E = hf), this results in specific frequencies being absorbed/emitted, creating a discrete absorption or emission spectrum. Different elements will have unique electron energy levels and produce unique spectra, hence allowing for their identification by spectroscopy.

1 mark – Describes the quantised electron energy levels from Bohr's atomic model.

1 mark – Explains how spectral lines arise.

1 mark – Explains how elements are identified by their unique spectral lines.

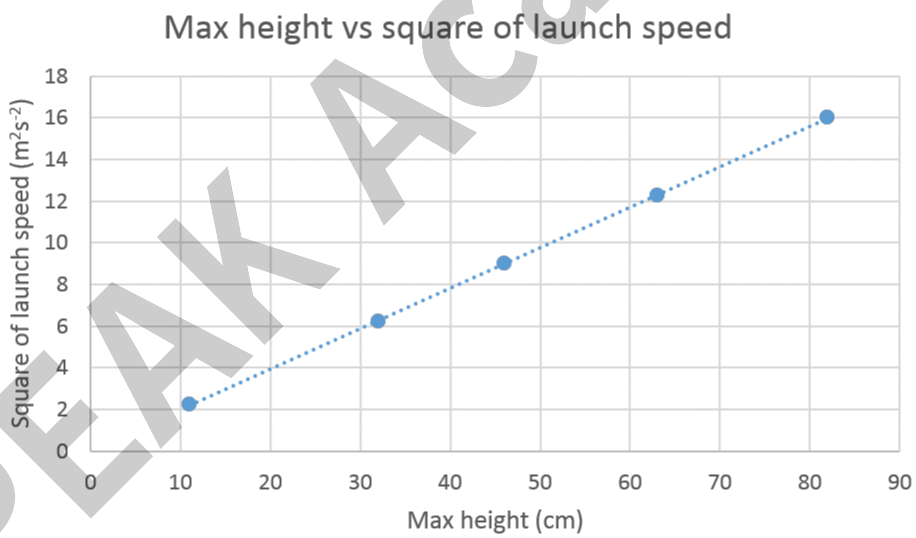
Question 30 (9 marks)
A student conducted an experiment where they measured the maximum height achieved by launching an object upwards at different speeds. Their results are shown below.

Launch speed (ms^{-1})	Height (cm)
1.5	11
2.5	32
3.0	46
3.5	63
4.0	82

(a) On the grid below, plot the data so that the acceleration due to gravity can be obtained from the gradient. **3**

$$v^2 = u^2 + 2as$$
$$0 = u^2 - 2gh$$
$$u^2 = 2gh$$

Graphing the square of the launch speed against maximum height will give $2g$ as the gradient.



1 mark – Plots either height against the square of launch speed, or square root of height against launch speed.

2 marks – Draws an appropriate graph including a title, axes titles with units, line of best fit, correct plots, etc.

(b) From the graph, calculate the acceleration due to gravity. **2**

$$m = \frac{y_2 - y_1}{x_2 - x_1}$$
$$2g = \frac{15.6 - 4 \text{ m}^2 \text{ s}^{-2}}{(80 - 20) \times 10^{-2} \text{ m}}$$
$$= 19.3 \text{ m s}^{-2}$$
$$g = 9.7 \text{ m s}^{-2}$$

1 mark – Calculates the gradient from the line of best fit.

1 mark – Uses the gradient to find g.

(c) The student wishes to launch a projectile with a maximum height of 3.5 m and a range of 5 m. What is the required launch speed? **4**

$$u_y^2 = 2gh$$
$$u_y = \sqrt{2 \times 9.8 \times 3.5}$$
$$= 8.28 \text{ m s}^{-1}$$

$$v_y = u_y + a_y t$$
$$t_{\frac{1}{2}} = \frac{v_y - u_y}{a_y}$$
$$= \frac{0 - 8.28}{-9.8}$$
$$= 0.845 \text{ s}$$
$$t = 2 \times 0.845$$
$$= 1.69 \text{ s}$$

$$s_x = u_x t$$
$$u_x = \frac{s_x}{t}$$
$$= \frac{5}{1.69}$$
$$= 2.96 \text{ m s}^{-1}$$

$$u = \sqrt{u_y^2 + u_x^2}$$
$$= \sqrt{8.28^2 + 2.96^2}$$
$$= 8.79 \text{ m s}^{-1}$$

1 mark – Finds the time of flight.

2 marks – Finds the horizontal and vertical velocity.

1 mark – Finds the launch speed.

Question 31 (4 marks)
In his doctoral thesis, Louis de Broiglie proposed an unconventional view of the nature of electrons and particles.

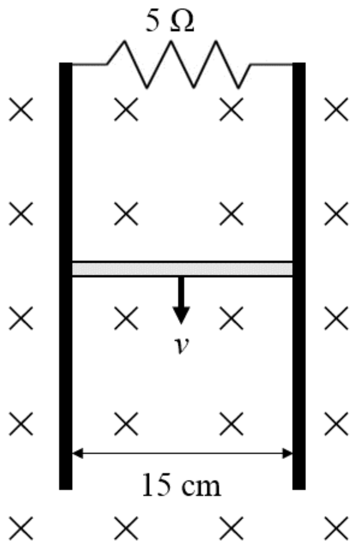
(a) State de Broglie's proposal. **1**

> De Broglie proposed that all particles have a wave nature as well as a particle nature, with wavelength related to their wavelength by $\lambda = \frac{h}{mv}$.
>
> 1 mark – State de Broglie's proposal.

(b) Describe the experimental evidence for de Broglie's proposal. **3**

> De Broglie suggested it should be possible to observe the wave nature of a beam of electrons. Davisson and Germer were able to show this in an experiment where they directed electrons onto a nickel crystal, which acted as diffraction slits. They observed a pattern from the scattered electrons similar to the diffraction pattern of X-rays. From this, they were able to calculate the wavelength of the electrons and found this to be close to de Broglie's predicted value using his formula.
>
> 3 marks – Describe and experiment and relates the experimental results to de Broglie's proposal.

Question 32 (6 marks)
A horizontal rod of length 15 cm and mass 100 g falls from rest along a pair of long vertical conductive rails. The rails are joined by a 5 Ω resistor as shown in the diagram below. A magnetic field of 2.0 T points into the page.



Assume that air resistance is negligible.

(a) When the rod is released, it speeds up with decreasing acceleration until it reaches a constant velocity. Explain this observation, making reference to any relevant physics principles. **3**

When the rod falls under gravity, the loop formed by the rod, rails and resistor increases in area and experienes an increase in magnetic flux. By Faraday's law, this will induce an emf and current that by Lenz's law, will oppose the change in flux. Hence, current will flow counterclockwise to reduce the change in flux and produce an upwards force on the rod. This partially counteracts the rod's weight force and decreases its downwards acceleration.

The faster the rod falls, the greater the resistive force from the induced current. Eventually, the rod is falling fast enough that the resistive force balances the weight force and the net force on the rod is zero. It has reached a constant velocity.

2 marks – Explains the decreasing acceleration of the rod with reference to Faraday's and Lenz's law.

1 mark – Explains that the rod reaches a constant velocity with the resistive and weight forces are balanced.

(b) Determine the final speed of the rod. **3**

Let $l = 0.15$ m and y be the distance fallen by the rod.

$$\begin{aligned}\varepsilon &= n\frac{\Delta BA}{\Delta t}\\ &= \frac{\Delta B(ly)}{\Delta t}\\ &= Bl\frac{\Delta y}{\Delta t}\\ &= Blv\end{aligned}$$

$$\begin{aligned}I &= \frac{\varepsilon}{R}\\ &= \frac{Blv}{R}\end{aligned}$$

$$\begin{aligned}BIl &= mg\\ Bl \times \frac{Blv}{R} &= mg\\ v &= \frac{mgR}{(Bl)^2}\\ &= \frac{0.1 \times 9.8 \times 5}{(2.0 \times 0.15)^2}\\ &= 54.4 \text{ m s}^{-1}\end{aligned}$$

1 mark – Relates emf to the velocity of the rod.

1 mark – Equates $BIl = mg$

1 mark – Calculates the terminal speed.

Question 33 (8 marks)

(a) Describe the relationship between quarks, hadrons and atomic nuclei and their formation in the early universe. **2**

After the big bang, the universe expanded rapidly and cooled, allowing matter to form. Quarks formed first and once the universe had cooled further, the quarks could combine to form hadrons, including protons and neutrons. Further cooling of the universe allowed the protons and neutrons to combine into atomic nuclei of light elements like hydrogen and helium.

1 mark – Describes the physical relationship between quarks, hadrons and atomic nuclei.

1 mark – Identifies that the cooling universe allowed quarks, then hadrons then nuclei to form.

(b) Assess the importance of particle accelerators in testing and/or validating theories. Refer to specific examples in your answer. **6**

Using particles accelerators, evidence has been obtained to support theories such as the Standard Model of matter and Einstein's Special Relativity.

Particle accelerators bombard a target with a particle, inducing artificial transmutation and/or breaking the target up. This has allowed us to investigate the composition of particles, discover new particles and compare these findings with predictions made by the Standard Model. For example, experiments at the Stanford Linear Accelerator Centre (SLAC) provided evidence that protons consist of smaller subatomic particles, indicating that protons are not fundamental particles. These smaller subatomic particles are identified as quarks in the Standard Model. A second example is the discovery of the Higgs boson decades after it was first theorised.

Experimental evidence for time dilation has also been obtained by using particle accelerators. In these experiments, scientists have been able to verify that time passes more slowly for high speed particles, providing validation for time dilation as predicted by Special Relativity.

Clearly, particle accelerators have been highly important in investigating and providing evidence to validate and test theories such as the Standard Model and Special Relativity.

1 marks – Identifies specific examples of theories validated or tested by evidence from particle accelerators.

2 marks – Describes how particle accelerators have tested/validated the Standard Model.

2 marks – Describes how particle accelerators have tested/validated one other theory (e.g. Special Relativity).

1 mark – Provides a judgement.

Question 34 (6 marks)

Light with wavelength 300 nm is incident on a metal plate with a work function of 3.5 eV.

(a) Calculate the maximum kinetic energy of the ejected photoelectrons. **2**

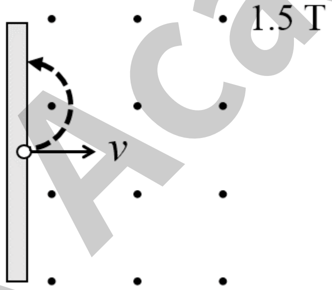
$$\begin{aligned} K_{max} &= \frac{hc}{\lambda} - \phi \\ &= \frac{6.626 \times 10^{-34} \times 3 \times 10^{8}}{300 \times 10^{-9}} - 3.5 \times 1.602 \times 10^{-19} \\ &= 1.019 \times 10^{-19} \text{ J} \end{aligned}$$

1 mark – Correctly calculates the energy of the photon.

1 mark – Calculates the maximum kinetic energy.

(b) The photoelectrons are ejected into a magnetic field of strength 1.5 T pointing out of the page. The photoelectrons strike the metal plate again at a maximum distance d away from the point of ejection. **1**

On the diagram below, sketch the path of the ejected photoelectron (shown as a white circle).



1 mark – Draws a circular arc curving upwards.

(c) Calculate d. **3**

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

$$v = \sqrt{\frac{2K}{m}}$$

$$= \sqrt{\frac{2 \times 1.019 \times 10^{-19}}{9.109 \times 10^{-31}}}$$

$$= 4.73 \times 10^5 \text{ m s}^{-1}$$

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

$$r = \frac{mv}{qB}$$

$$= \frac{9.109 \times 10^{-31} \times 4.73 \times 10^5}{1.602 \times 10^{-19} \times 1.5}$$

$$= 1.79 \times 10^{-6} \text{ m}$$

$$d = 2r$$

$$= 2 \times 1.79 \times 10^{-6}$$

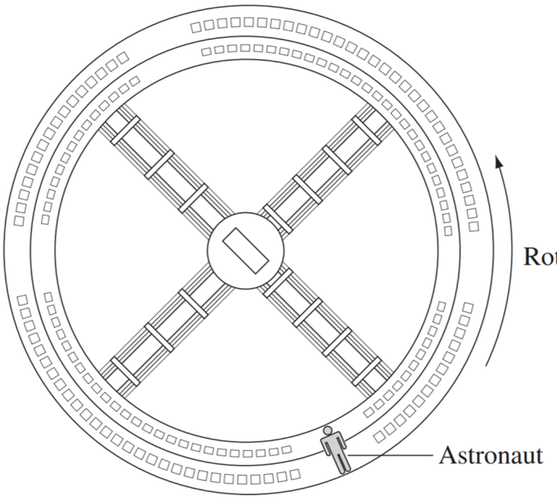
$$= 3.59 \times 10^{-6} \text{ m}$$

1 mark – Calculates the velocity of the electron.

1 mark – Calculates the radius of the electron's path.

1 mark – Correctly calculates d.

Question 35 (4 marks)
The diagram shows a futuristic space station designed to simulate gravity in a weightless environment.



(a) Explain how rotating the space station simulates gravity for the astronaut. **2**

The rotating wheel provides a centripetal (normal) force towards the centre. The astronaut reacts against this force according to Newton's 3rd Law, thus providing a simulated gravity.

1 mark – Identifies centripetal force towards centre and relates this force to simulation of gravity.

1 mark – Provides a correct explanation.

(b) Calculate the angular velocity that a space station with a diameter of 550 m would need for astronauts to experience 1 g of acceleration. **2**

$$\frac{mv^2}{r} = mg$$
$$\frac{r^2\omega^2}{r} = g$$
$$\omega = \sqrt{\frac{g}{r}}$$
$$= \sqrt{\frac{9.8}{\frac{550}{2}}}$$
$$= 0.189 \text{ rad s}^{-1}$$

1 mark – Equates centripetal force/acceleration with mg or g.

1 mark – Calculates the angular velocity.

End of paper