2025/4738
Web version of 2024/75500

Government of **Western Australia**
School Curriculum and Standards Authority

ATAR course examination, 2024

Question/Answer booklet

PHYSICS

Place one of your candidate identification labels in this box.

Ensure the label is straight and within the lines of this box.

WA student number: In figures

In words

Time allowed for this paper

Reading time before commencing work: ten minutes
Working time: three hours

Number of additional answer booklets used (if applicable):

Materials required/recommended for this paper

To be provided by the supervisor

This Question/Answer booklet
Formulae and Data booklet

To be provided by the candidate

Standard items: pens (blue/black preferred), pencils (including coloured), sharpener, correction fluid/tape, eraser, ruler, highlighters

Special items: up to three calculators, which do not have the capacity to create or store programmes or text, are permitted in this ATAR course examination, drawing templates, drawing compass and a protractor

Important note to candidates

No other items may be taken into the examination room. It is **your** responsibility to ensure that you do not have any unauthorised material. If you have any unauthorised material with you, hand it to the supervisor **before** reading any further.

Ref: 24-070

PHY

Structure of this paper

Section	Number of questions available	Number of questions to be answered	Suggested working time (minutes)	Marks available	Percentage of examination
Section One Short response	11	11	50	55	30
Section Two Problem-solving	6	6	90	96	50
Section Three Comprehension	2	2	40	39	20
				Total	100

Instructions to candidates

1. The rules for the conduct of the Western Australian external examinations are detailed in the *Year 12 Information Handbook 2024: Part II Examinations*. Sitting this examination implies that you agree to abide by these rules.

2. Write your answers in this Question/Answer booklet preferably using a blue/black pen. Do not use erasable or gel pens.

3. You must be careful to confine your answers to the specific questions asked and to follow any instructions that are specific to a particular question.

4. When calculating numerical answers, show your working or reasoning clearly. Unless otherwise instructed, give final answers to three significant figures and include appropriate units where applicable.

   When estimating numerical answers, show your working or reasoning clearly. Give final answers to a maximum of two significant figures and include appropriate units where applicable.

5. Supplementary pages for planning/continuing your answers to questions are provided at the end of this Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, i.e. give the page number.

6. The Formulae and Data booklet is not to be handed in with your Question/Answer booklet.

Section One: Short response **30% (55 Marks)**

This section has **11** questions. Answer **all** questions. Write your answers in the spaces provided.

When calculating numerical answers, show your working or reasoning clearly. Unless otherwise instructed give final answers to **three** significant figures and include appropriate units where applicable.

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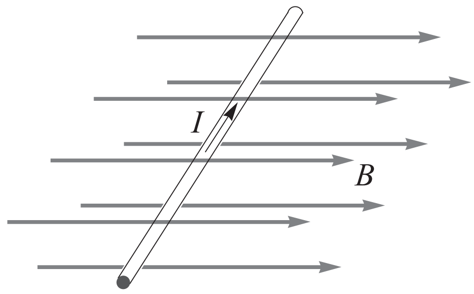
Suggested working time: 50 minutes.

Question 1 **(4 marks)**



A 25.0 cm long segment of horizontal wire is perpendicular to a 3.78 mT magnetic field as shown in the diagram above. A current of 2.54 A is running through the wire.

(a) In what direction is the force on the wire acting? Circle your answer. (1 mark)

A. Upward

B. Downward

C. To the left

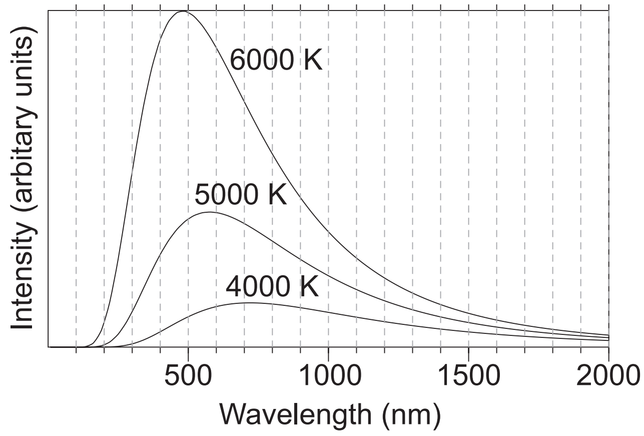
D. To the right

(b) Calculate the magnitude of the force on the wire. (3 marks)

Answer: ______________ N

Question 2 **(5 marks)**

Stars can be classified as black body radiators. The temperature of distant stars can be estimated by observing their colour.



(a) Define the term 'black body'. (2 marks)

(b) With reference to the graph above, explain how a star's colour indicates their surface temperature. (3 marks)

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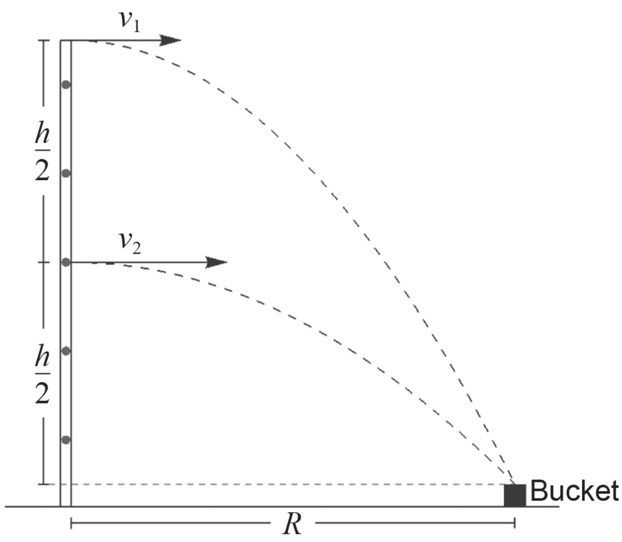
Question 3 **(7 marks)**



A window cleaner on a vertical ladder is at a height h from the ground. He throws a used sponge into a bucket on the ground at a distance R from the base of the ladder. He throws it horizontally at a velocity v_1. When he is halfway down the ladder, he has to throw the sponge at a different velocity v_2 in order for it to land in the bucket. He still throws the sponge horizontally.

Express v_2 in terms of v_1. Assume there is no air resistance and the sponge lands in the middle of the bucket. Show all working.

Answer: v_2 = ______________________ v_1

Question 4 **(3 marks)**

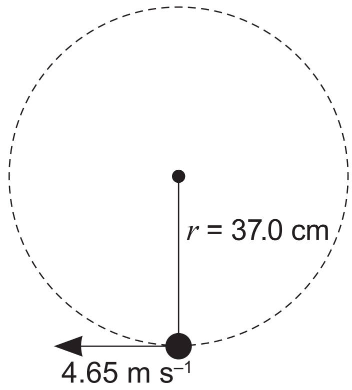
According to the Big Bang theory, the strong nuclear force separated from the electromagnetic and weak forces around 10^{-36} s after the expansion of the universe began.

Explain how this separation enabled the formation of hadrons.

Question 5 **(4 marks)**

Arianna is swinging her keys attached to a string in a vertical circle of radius 37.0 cm. The keys have a mass of 1.20×10^2 g.

Calculate the maximum tension in the string if the maximum speed the keys reach is 4.65 m s^{-1}.



Answer: ______________ N

Question 6 **(5 marks)**

A new hadron consisting of three quarks is discovered in a particle accelerator experiment. Two of the quarks, an up and a bottom, have been identified. The overall charge on the hadron is determined to be +1 e.

(a) Identify a possible third quark. (1 mark)

(b) Determine the quark composition of the hadron's anti-particle and its charge. (2 marks)

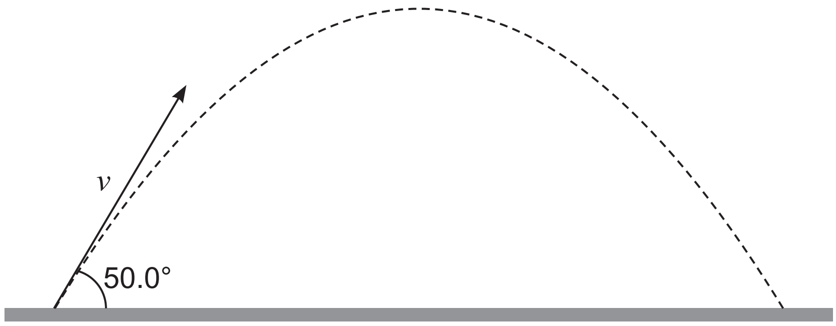
Composition: ____________________

Charge: ____________________

(c) The up quark in the hadron decays by the weak interaction into a down quark, a positron and a neutrino. Show that both charge and lepton number are conserved in this reaction. (2 marks)

$$u \rightarrow d + e^{+} + \nu_e$$

Question 7 **(4 marks)**



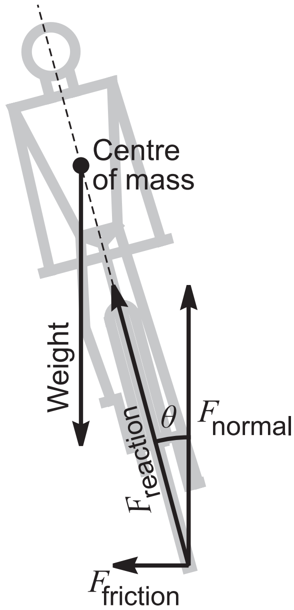
A golfer plays a high chip shot by hitting the ball at an angle of 50.0° to the horizontal, as shown in the diagram. The ball reaches a maximum height of 21.5 m above the ground.

Calculate the initial speed of the ball when hit.

Answer: ______________________ $m\ s^{-1}$

Question 8 **(6 marks)**

When a cyclist goes around a corner, they lean into the curve so that the resulting friction from the road on their tyres provides the centripetal force to push them around the corner. The road also pushes upward with a normal force to balance their weight. The normal and friction forces add together to form the overall reaction force of the road, which acts through the centre of mass of the cyclist, leaning at angle θ to the vertical.



(a) Derive the following expression that relates the angle of lean θ, to the speed v of the cyclist, the radius r of the circular path of the cyclist's centre of mass and the acceleration due to gravity g. (3 marks)

$$\tan\theta = \frac{v^2}{rg}$$

(b) With reference to the expression given in part (a), explain how the cyclist could go around the same corner at a greater speed. (3 marks)

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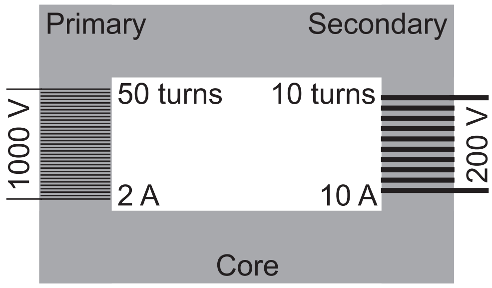
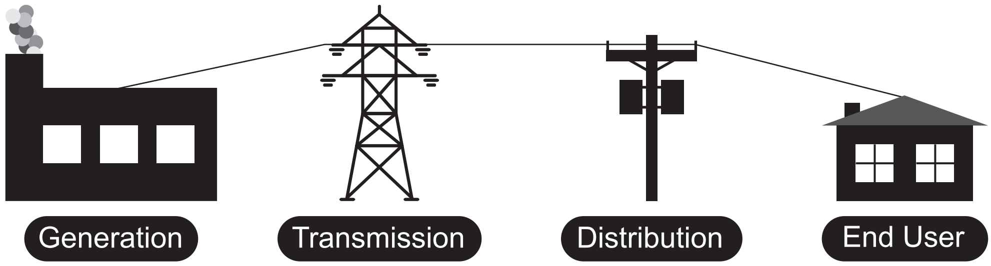
Question 9 **(6 marks)**



Transformers are an important element of electricity transmission.

(a) Is the transformer in the diagram above a step-up or step-down transformer? Circle your answer. (1 mark)

A. Step-up   B. Step-down



(b) Where would be the **most** likely placement of such a transformer in the electricity transmission process? Circle your answer. (1 mark)

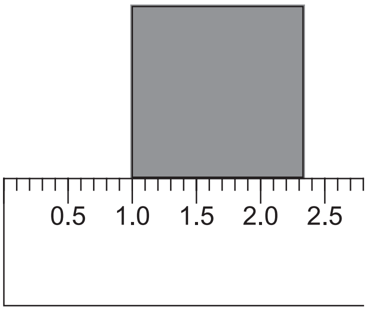
A. After generation   B. After transmission   C. After distribution

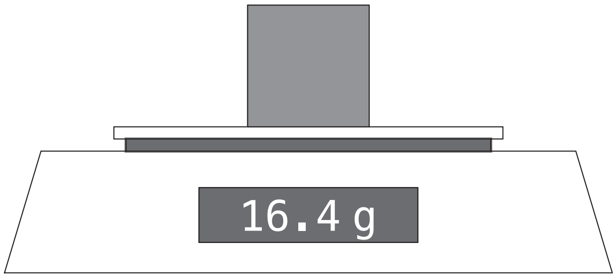
(c) Use a calculation to show how the transformer is 100% efficient. (2 marks)

(d) In real life, 100% efficiency is impossible to achieve. Describe **one** way transformers lose efficiency. (2 marks)

Question 10 **(7 marks)**

A group of students was set the task of calculating the density of a cube made from an unknown material. They measured the length of each side using a ruler with millimetre intervals and found each side was exactly the same length. That length is shown below.





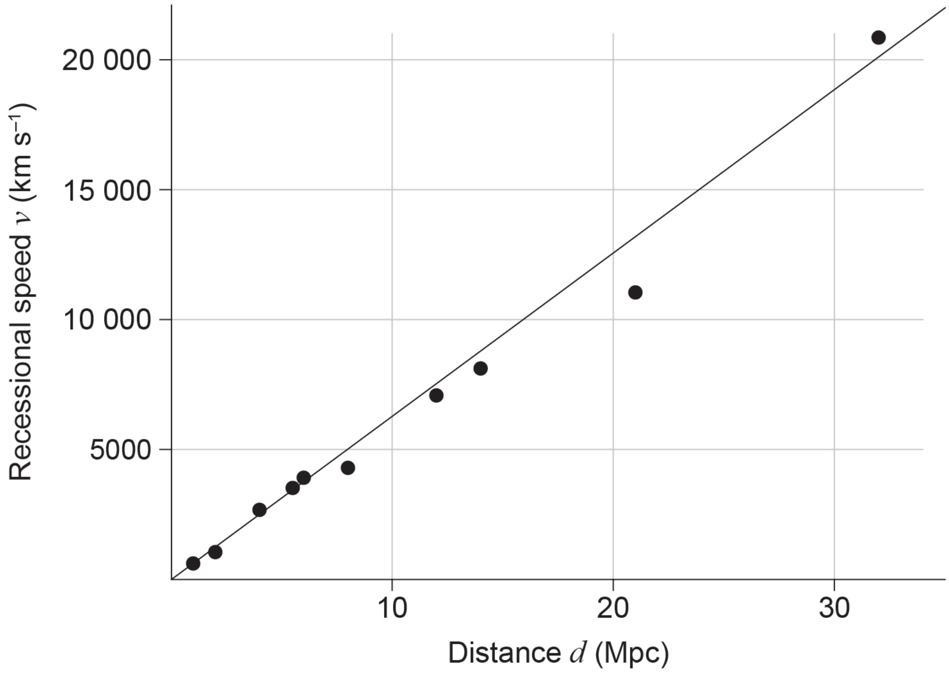
They then placed the cube on a set of scales. The reading is shown in the diagram above. They recorded their measurements in the following table.

Side length (cm)	Mass (g)
1.33 ± 0.05	16.4 ± 0.1

Given density = $\frac{\text{mass}}{\text{volume}}$, calculate the density of the cube in g cm^{-3}. Include the absolute uncertainty in your answer.

Answer: ______________ g cm^{-3} ± ______________ g cm^{-3}

Question 11 **(4 marks)**



Edwin Hubble needed two key sets of data to deduce that the universe was expanding. One was that the properties of some stars allowed their distance from Earth to be calculated, and therefore, the distance to nearby galaxies determined.

(a) Describe the other key observation, detailing the nature of the measurements made. (2 marks)

(b) Describe the interpretation of these observations and how they show that the universe is expanding. (2 marks)

End of Section One

Section Two: Problem-solving 50% (96 Marks)

This section has **six** questions. Answer **all** questions. Write your answers in the spaces provided.

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Suggested working time: 90 minutes.

Question 12 (17 marks)

Mass spectrometry can be used to analyse the isotope composition of an element. Chlorine has two isotopes, Cℓ-35 and Cℓ-37. The mass of each is shown in the table below.

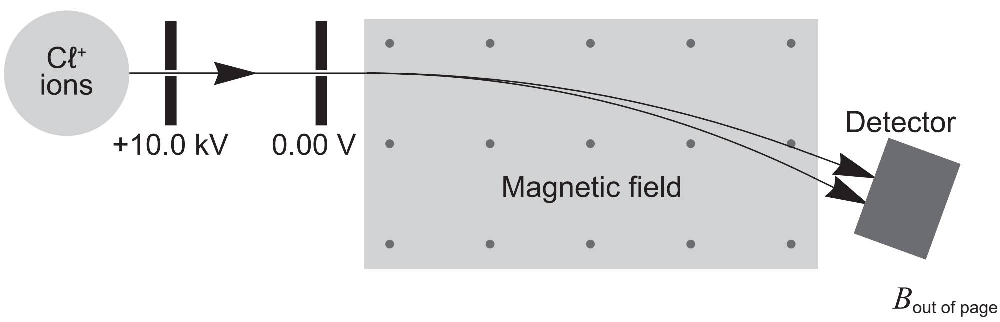
Isotope	Mass (amu)
Cℓ-35	34.97
Cℓ-37	36.97

1 amu = 1.6605×10^{-27} kg.

The atoms in the gaseous chlorine sample are ionised by being bombarded with electrons of energy 15.0 eV. The minimum energy required to ionise a chlorine atom is 12.9676 eV. The chlorine ions now have a charge of +1 e.

The moving ions are accelerated across a potential difference of 1.00×10^4 V, and then enter a 0.930 T magnetic field with their velocity perpendicular to the flux lines. Here they are separated by their momentum.

This process is illustrated below.



Schematic of a mass spectrometer

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Question 12 (continued)

(a) Describe **two** reasons why the ions would take different paths in the magnetic field given that $r = \frac{mv}{qB}$. (4 marks)

One:

Two:

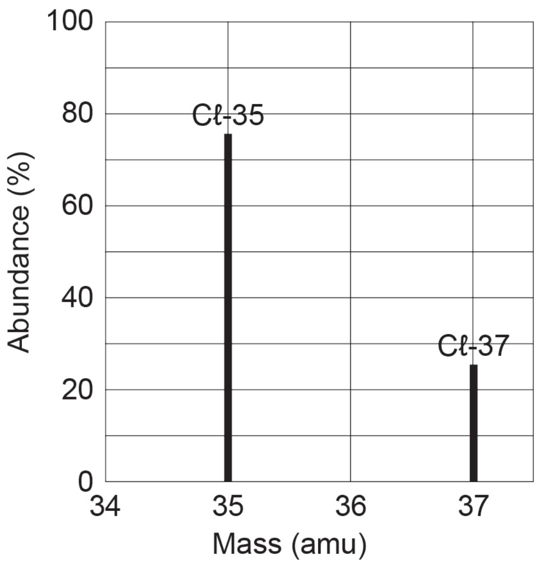
(b) Calculate the velocity of a Cℓ-35 ion when it leaves the electric field if it entered with a velocity of 4.51×10^4 m s^{-1}. Ignore relativistic effects. (7 marks)

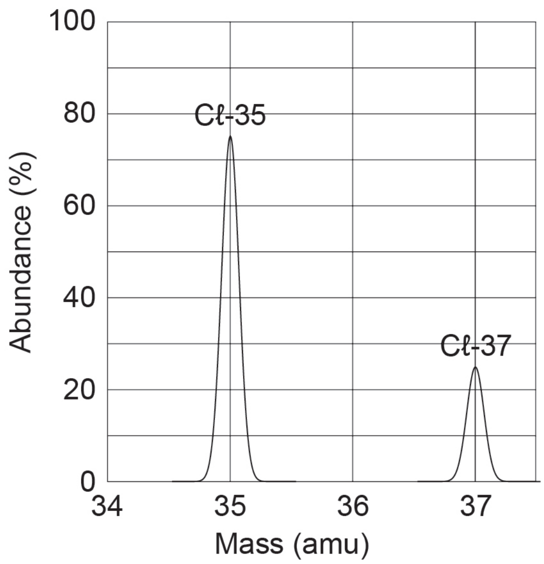
Answer: ______________ m s^{-1}

(c) Calculate the radius of the circular path taken by this Cℓ-35 isotope in the magnetic field. If you could not obtain an answer to part (b) on page 14, use 3.72×10^5 m s^{-1}. (3 marks)

Answer: ______________________ m

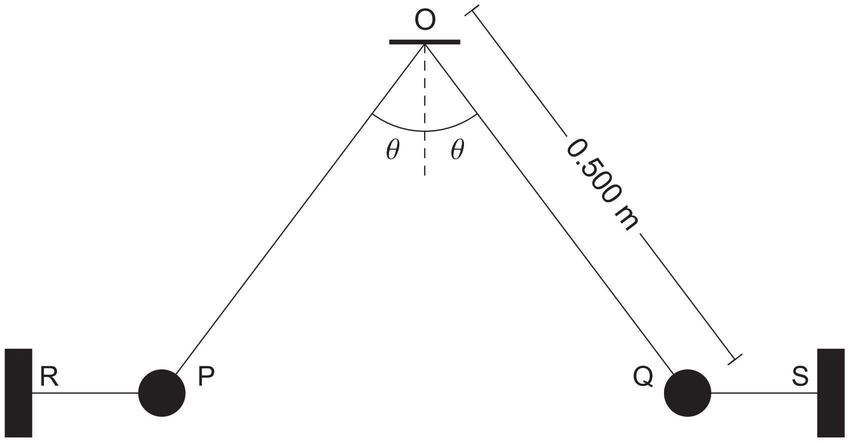
The graph of the actual relative abundance of the two isotopes is shown in the diagram below left. The graph below right is what is produced in the mass spectrometer printout.





(d) Explain why there is a range of masses in the printout instead of clearly-defined lines, as in the graph above left. (3 marks)

Question 13 **(16 marks)**



Two 0.650 kg metal spheres, P and Q, are each held in place by two strings, as shown in the diagram above. The strings OP and OQ are 0.500 m long. The strings RP and QS are horizontal. The angle θ is equal to 37.0°.

(a) Calculate the tension in either of the strings OP or OQ. (3 marks)

Answer: ______________ N

The metal balls are now charged. P is given a charge of -3.51×10^{-5} C and Q a charge of $+2.03 \times 10^{-5}$ C.

(b) (i) Explain why the tension in strings OP and OQ does not change despite the tensions in RP and QS changing. RP and QS remain horizontal and θ remains constant. (3 marks)

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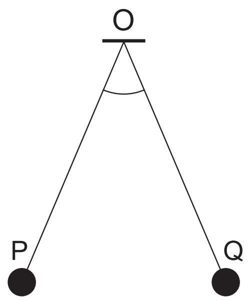
See next page

(ii) Calculate the tension in either RP or QS after the balls have been charged. The tensions are equal in magnitude. (6 marks)

Answer: ______________ N

(c) The strings RP and QS are now loosened slowly and the two spheres P and Q are allowed to touch gently. After touching, they are observed to be in the position shown in the diagram below.



(i) Calculate the charge on each ball after they have touched. (2 marks)

Answer: ______________ C

(ii) Describe why the balls come to rest in the position shown in the diagram above. (2 marks)

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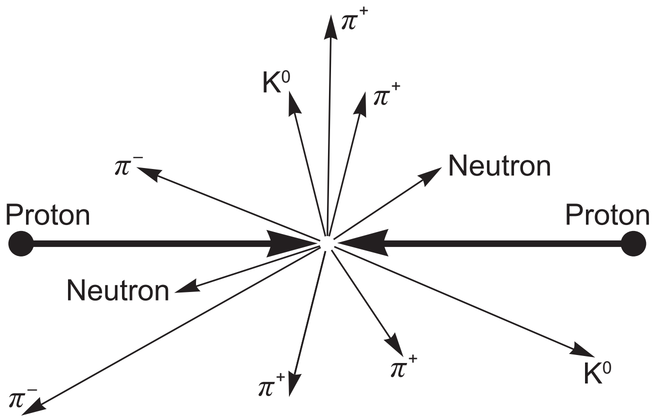
Question 14 **(14 marks)**



Two protons, travelling at 0.9500 c in opposite directions relative to an observer in the laboratory, collide. A possible outcome of the collision is depicted in the diagram above. The two protons are annihilated and two neutrons, six π mesons and two K mesons are produced.

(a) Calculate the momentum of either proton in the laboratory's frame of reference. (3 marks)

Answer: ______________________ kg m s^{-1}

(b) Determine the total momentum of the two protons as measured in the laboratory frame of reference. (1 mark)

Answer: ______________________ kg m s^{-1}

(c) Calculate the momentum of one proton in the other proton's frame of reference. Give your answer to **four** significant figures. (6 marks)

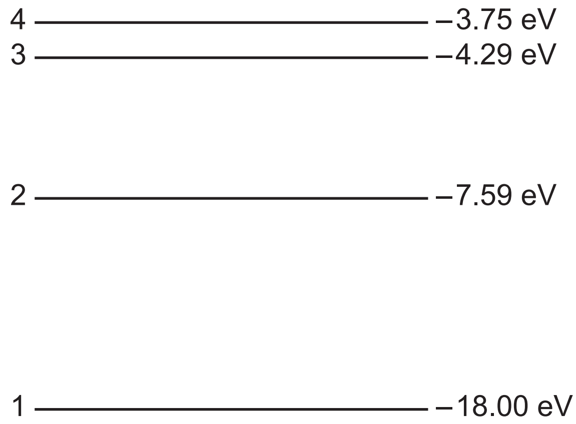
Answer: ______________________ kg m s^{-1}

(d) Calculate the total energy of the particles produced in the collision, as measured by the observer in the laboratory. Give your answer to **three** significant figures. (4 marks)

Answer: ______________________ J

Question 15 **(18 marks)**

Below are some of the energy levels of an element used to produce light, which is then shone onto a sodium cathode in a photoelectric cell.



The light produced by the downward transition from level 3 to 2 is shone onto the sodium plate. Sodium has a work function of 2.28 eV.

(a) Calculate the wavelength of the light produced by the downward transition from level 3 to level 2. (4 marks)

Answer: ____________________ m

(b) Calculate the maximum speed of a liberated electron when this wavelength of light is incident on the sodium plate in the photoelectric cell. (4 marks)

Answer: ____________________ $m\ s^{-1}$

The stopping voltage is the minimum reverse voltage required to stop photocurrent.

(c) Calculate the stopping voltage for the electron produced in part (b) on page 20. (2 marks)

Answer: ____________________ V

(d) Explain why increasing the brightness of the incident light will not affect the stopping voltage. (4 marks)

(e) (i) Identify which transition would require the stopping voltage to be the largest. (1 mark)

Transition: from ______________ to ______________

(ii) Explain your answer to part (e)(i). (3 marks)

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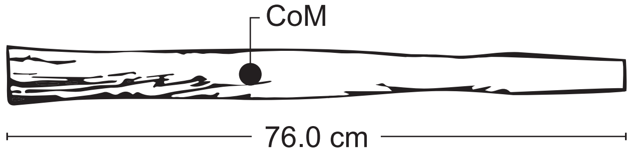
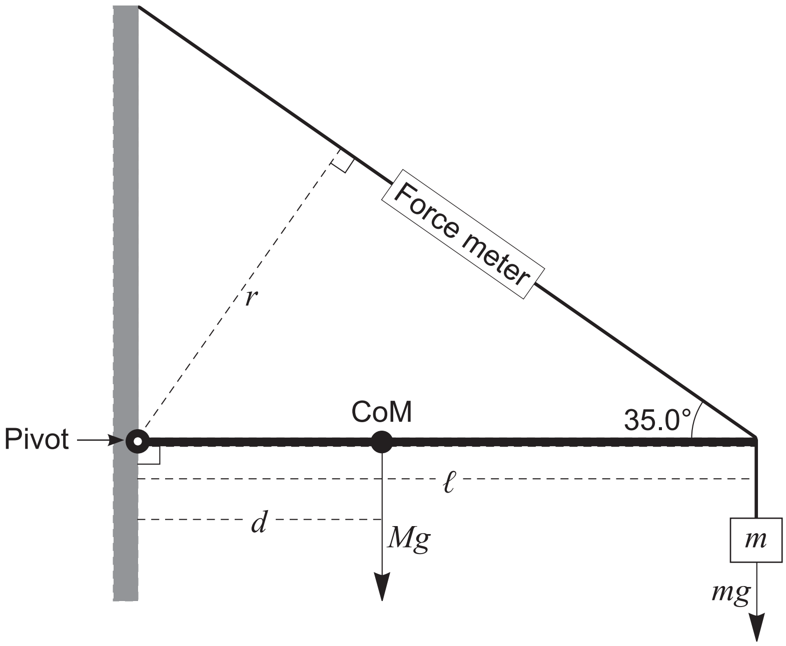
Question 16 **(19 marks)**

A group of students designed an experiment to estimate the value of g (the acceleration due to gravity at ground level), and to locate the centre of mass (CoM) of a non-uniform piece of wood, as shown in the diagram below.



They drilled a small hole in one end of the piece of wood to make a pivot, then attached a strong wire with a force meter to the other end, as shown in the diagram below. They hung different masses m from the end of the piece of wood and measured the tension T in the wire.



The length ℓ of the piece of wood was 76.0 cm and it had a mass M of 257 g. The distance d was from the pivot to the centre of mass of the piece of wood. The angle between the piece of wood and the wire was kept constant at 35.0°.

The results are in the table below.

Mass m (kg)	0.200	0.300	0.400	0.500	0.600	0.700
Tension T (N)	5.30	6.50	8.10	10.4	11.9	13.2

Taking moments around the pivot, they established the following relationship:

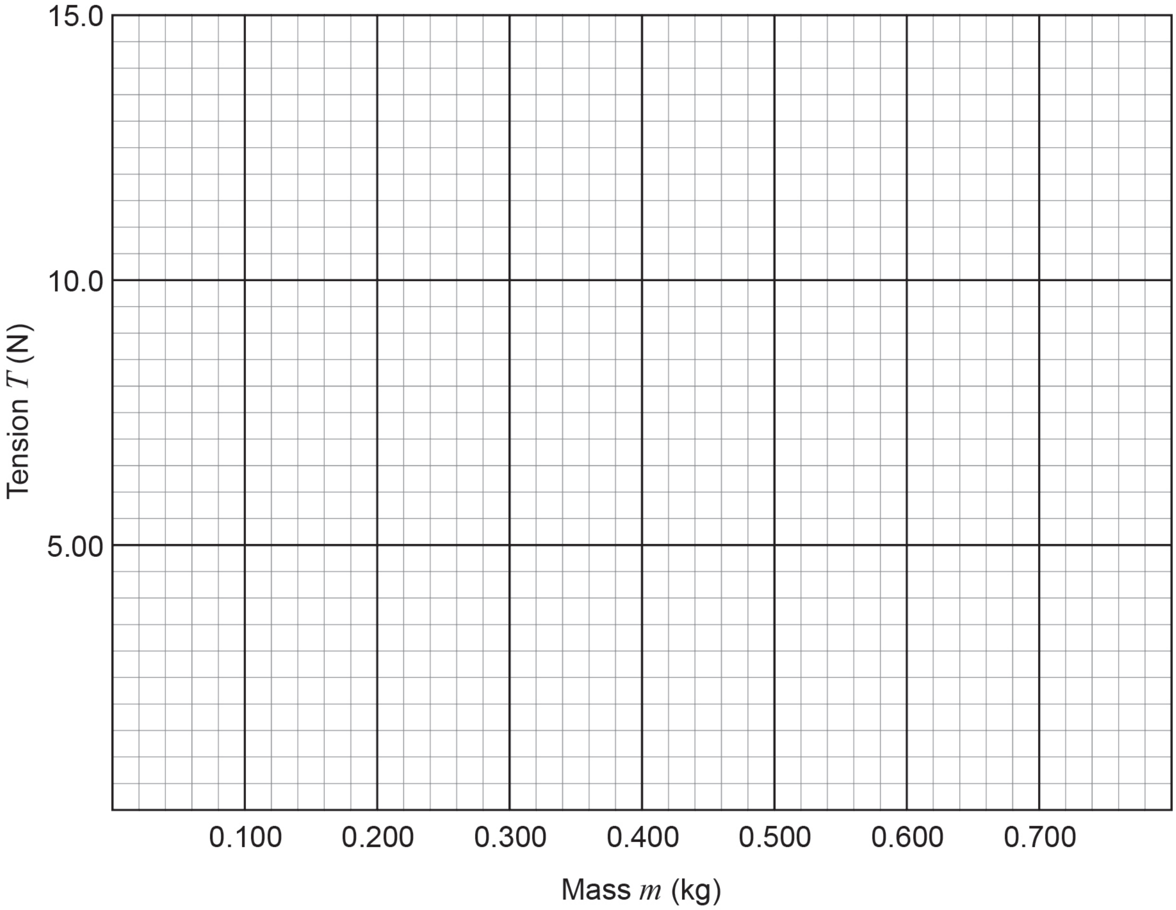
$$\Sigma\, acm = \Sigma\, cm \quad \Rightarrow \quad T \times r = (mg \times \ell) + (Mg \times d) \quad \Rightarrow \quad T = \frac{mg\ell}{r} + \frac{Mgd}{r}$$

This allowed the students to graph tension T against the hanging mass m and use their graph to estimate the acceleration due to gravity g and to locate the centre of mass of the piece of wood.

(a) Calculate the distance r from the pivot to the wire. (2 marks)

Answer: ______________________ m

(b) Graph T versus m on the grid below. Include a line of best fit. (3 marks)



A spare grid is provided at the end of this Question/Answer booklet. If you need to use it, cross out this attempt and indicate that you have redrawn it on the spare grid.

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Question 16 (continued)

(c) Calculate the gradient of your line of best fit from part (b) on page 23. Indicate clearly on the graph the **two** points used in your calculation. Express the gradient to **three** significant figures and include the unit for the gradient. (5 marks)

Answer: ____________________ Unit ____________________

(d) Use the calculated gradient from part (c) to estimate the students' experimental value for g. Give your answer to **two** significant figures. (4 marks)

Answer: ____________________ $m\ s^{-2}$

(e) Use the line of best fit from part (b) on page 23 and the value of g found in part (d) to calculate the distance d from the pivot to the centre of mass of the piece of wood. Give your answer to **two** significant figures. (5 marks)

Answer: ____________________ m

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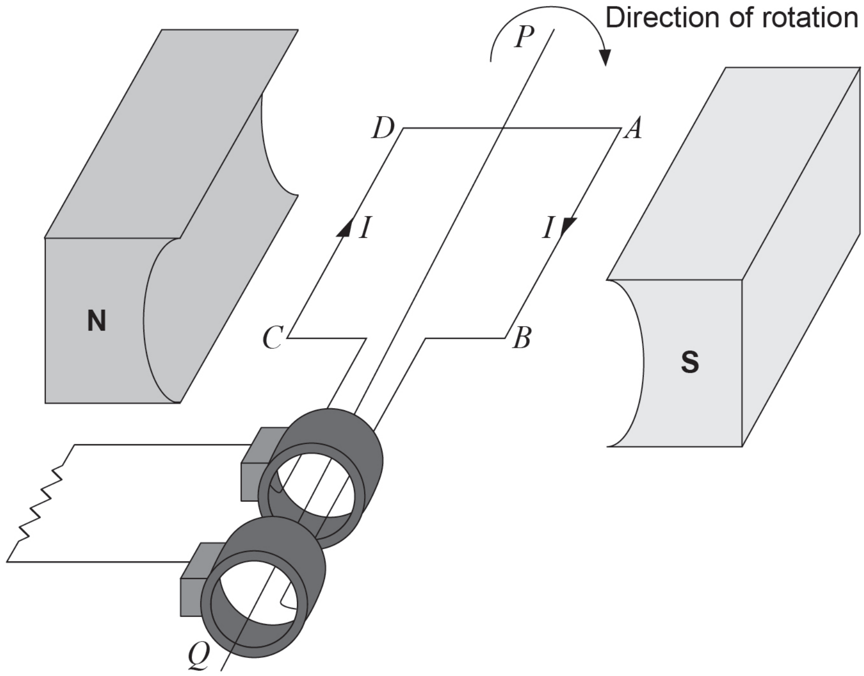
Question 17 **(12 marks)**

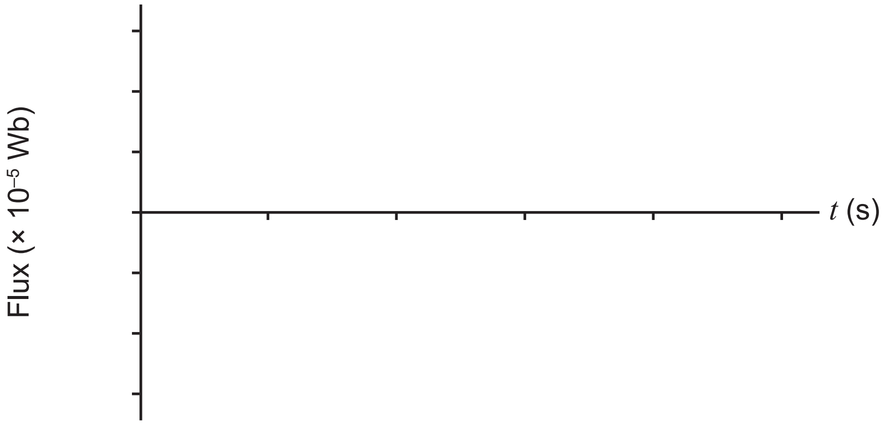


A single rectangular loop alternating current (AC) generator has dimensions 13.0 cm × 8.50 cm. It sits in a magnetic field of strength 2.37 mT and is rotated at a frequency of 10.0 Hz.

(a) Calculate the maximum amount of flux passing through the coil at any time in a complete rotation. (3 marks)

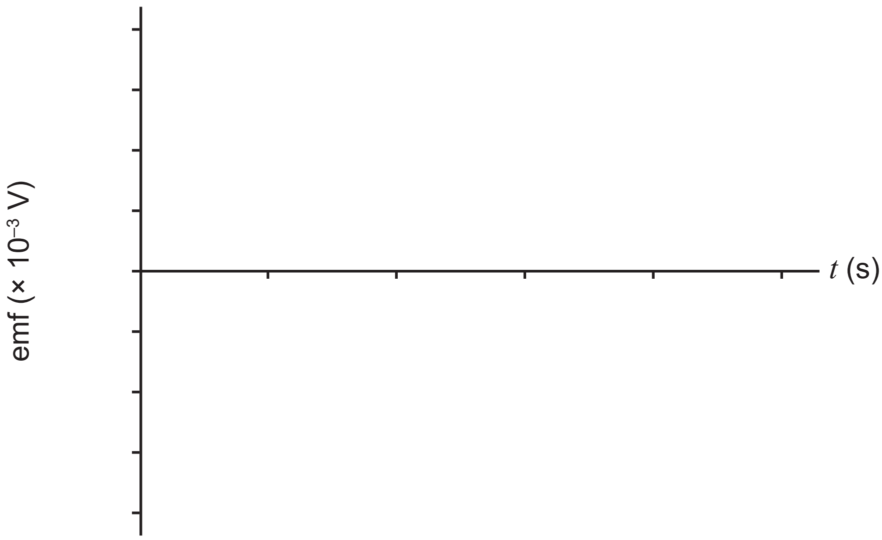
Answer: ______________________ Wb

(b) On the axes below, graph the flux passing through the coil during one complete rotation. Take the starting position shown in the diagram on page 26. Include your value from part (a) on the y-axis and place actual time values on the x-axis. (4 marks)



A spare grid is provided at the end of this Question/Answer booklet. If you need to use it, cross out this attempt and indicate that you have redrawn it on the spare grid.

(c) On the axes below, graph the emf induced in the coil as it goes through one complete rotation. Take the starting position shown in the diagram on page 26. Include values on both axes. (5 marks)



A spare grid is provided at the end of this Question/Answer booklet. If you need to use it, cross out this attempt and indicate that you have redrawn it on the spare grid.

End of Section Two

Section Three: Comprehension **20% (39 Marks)**

This section has **two** questions. You must answer **both** questions. Write your answers in the spaces provided.

When calculating numerical answers, show your working or reasoning clearly. Unless otherwise stated, give final answers to **three** significant figures and include appropriate units where applicable.

When estimating numerical answers, show your working or reasoning clearly. Give final answers to a maximum of **two** significant figures and include appropriate units where applicable.

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Suggested working time: 40 minutes.

Question 18 **(21 marks)**

Cooling with lasers

When we think of lasers, we think of extreme heat being generated. We imagine lasers cutting through metals. However, lasers can actually be used to cool things like monatomic low-density gases. They do this by lowering the average kinetic energy (KE) of the gas atoms.

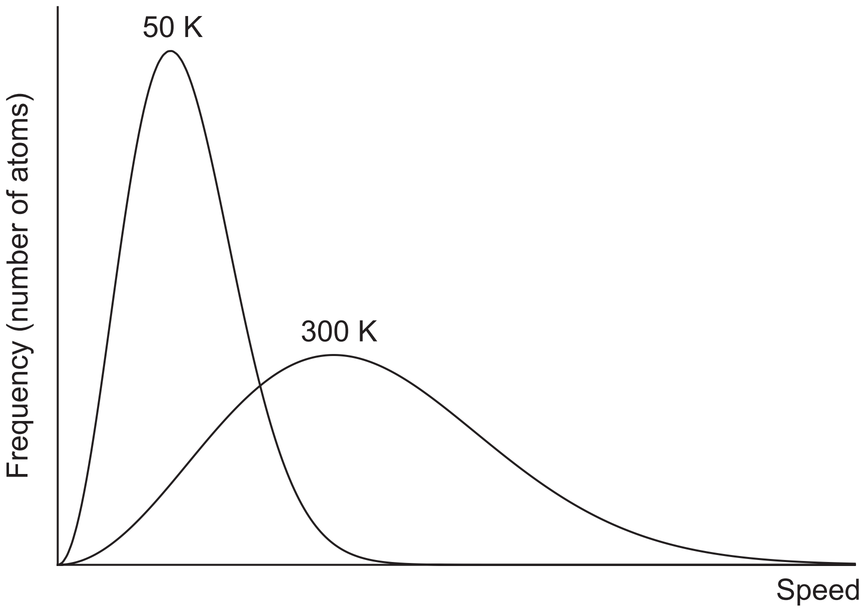


Figure 1: Number of atoms versus speed for a fixed sample of gas

In a sample of gas, the atoms are in constant random motion and possess a range of kinetic energies and speeds. Figure 1 above shows how the temperature of a sample of gas increases with the average KE of the atoms.

A laser produces photons that all have precisely the same energy. The frequency of the laser can be finely adjusted to suit the purpose. The number of photons produced can be altered by varying the power of the laser.

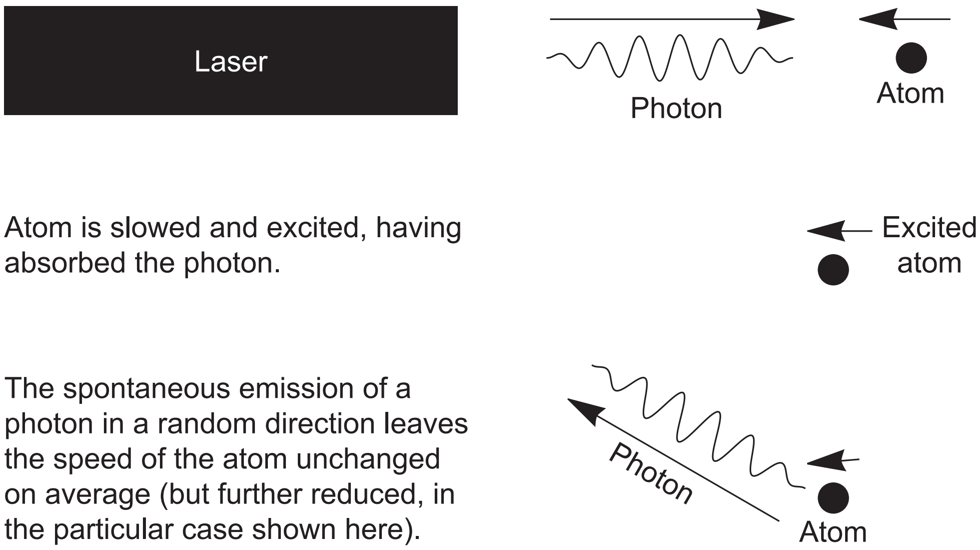


Figure 2: Front-on collisions between a laser photon and a gas atom

The laser is shone through the sample of gas. An atom of gas moving directly toward the source of the photons will have the light blue-shifted. Therefore, the frequency of the photon is increased. If the frequency of the light has been set just below the corresponding transition energy for the atom (the amount of energy required to promote an electron to a higher level), the photon will be absorbed along with its momentum. This slows the atom down. As the momentum of the atom is now reduced, so is its KE and, therefore, the temperature of the sample.

When the electron transitions back to its original level, it will emit the same frequency as the original photon. However, the direction in which the photon is emitted is random and, therefore, on average, has no effect on the atom's momentum and the temperature of the sample.

Further cooling can only be achieved if the photon energy is set closer to the atom's transition energy, but not equal to it. The average speed of the gas atoms and their transition energy must be known in order to set the frequency of the laser appropriately.

This process is used in modern quantum systems such as atomic clocks, which only work at temperatures close to absolute zero.

(a) (i) Calculate the momentum of a photon of frequency of 5.12×10^{16} Hz. (4 marks)

Answer: ______________ kg m s^{-1}

Question 18 (continued)

(ii) Calculate how many photons with the same frequency as in part (a)(i) on page 29 would be produced per second by a 10.0 W laser. (3 marks)

Answer: ____________________ s^{-1}

(b) An atom with a mass of 6.80×10^{-27} kg is travelling with a speed of 5.70×10^{2} m s^{-1} in the opposite direction to an incoming photon of the same wavelength as in part (a)(i) on page 29.

Calculate the percentage of speed it loses when it absorbs the incoming photon. (5 marks)

Answer: ____________________ %

See next page

(c) Explain the mechanism required for cooling to occur. (5 marks)

(d) The frequency of the laser is now set slightly higher than the corresponding transition energy of the gaseous atoms.

(i) What effect would this have on the temperature of the gaseous sample? Circle your answer. (1 mark)

A. Increase B. Decrease C. No effect

(ii) Explain your answer to part (d)(i). (3 marks)

Question 19 **(18 marks)**

de Broglie and Bohr

The 1913 Bohr model of the hydrogen atom was replaced by Schrödinger's wave mechanical model in 1926. However, Bohr's model is still taught today because of its conceptual and mathematical simplicity, and because it introduced a number of key quantum mechanical ideas such as the quantum number.

In 1924, de Broglie postulated wave-particle duality for the electron, which removed some of the arbitrary nature of Bohr's model. For example, an electron possessing wave properties is subject to constructive and destructive interference. If we assumed circular electron orbits around the nucleus, this meant that only certain whole numbers of a particular wavelength could 'fit' into the circumference of the orbit.

$$n\lambda = 2\pi r \qquad \text{Equation 1}$$

This introduces the quantum number n, which can have values of 1,2,3, ...

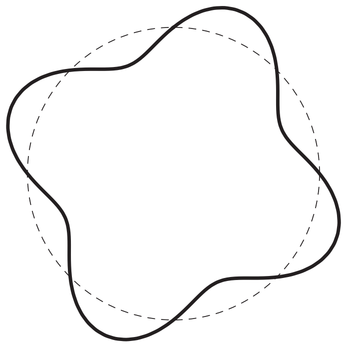


Figure 3: The $n = 4$ state of an electron

If we combine Equation 1 with the de Broglie equation, $\lambda = \frac{h}{p} = \frac{h}{m_e v}$, we get

$$m_e v = \frac{nh}{2\pi r} \qquad \text{Equation 2}$$

where m_e is the mass of an electron.

This equation holds for non-relativistic speeds. Relativistic momentum must be considered with speeds above 0.50 c.

If we then combine Equation 2 with the equation for kinetic energy, $KE = \frac{m_e v^2}{2}$, we get

$$KE = \frac{n^2 h^2}{8 m_e \pi^2 r^2} \qquad \text{Equation 3}$$

This shows that the kinetic energy of electrons bound to nuclei is quantised and the total energy of these electrons is quantised. This explains why electrons can be found in different orbits but not in-between. Therefore, when electrons de-excite and jump down from one orbit to another, photons with specific energies are emitted. This is supported by observing emission spectra of elements in which only certain wavelengths appear.

(a) Explain why de Broglie’s theory that electrons can be treated as waves led to the introduction of quantum numbers. (3 marks)

(b) Derive Equation 3 from Equation 2 and the equation for kinetic energy. (5 marks)

Question 19 (continued)

(c) With the use of a diagram, describe the experimental evidence stated in the text on page 32 that supports the quantisation of electron energy. (5 marks)

(d) Calculate the wavelength of an electron travelling at 0.750 c. (5 marks)

Answer: ______________ m

End of questions

Supplementary page

Question number: ____________

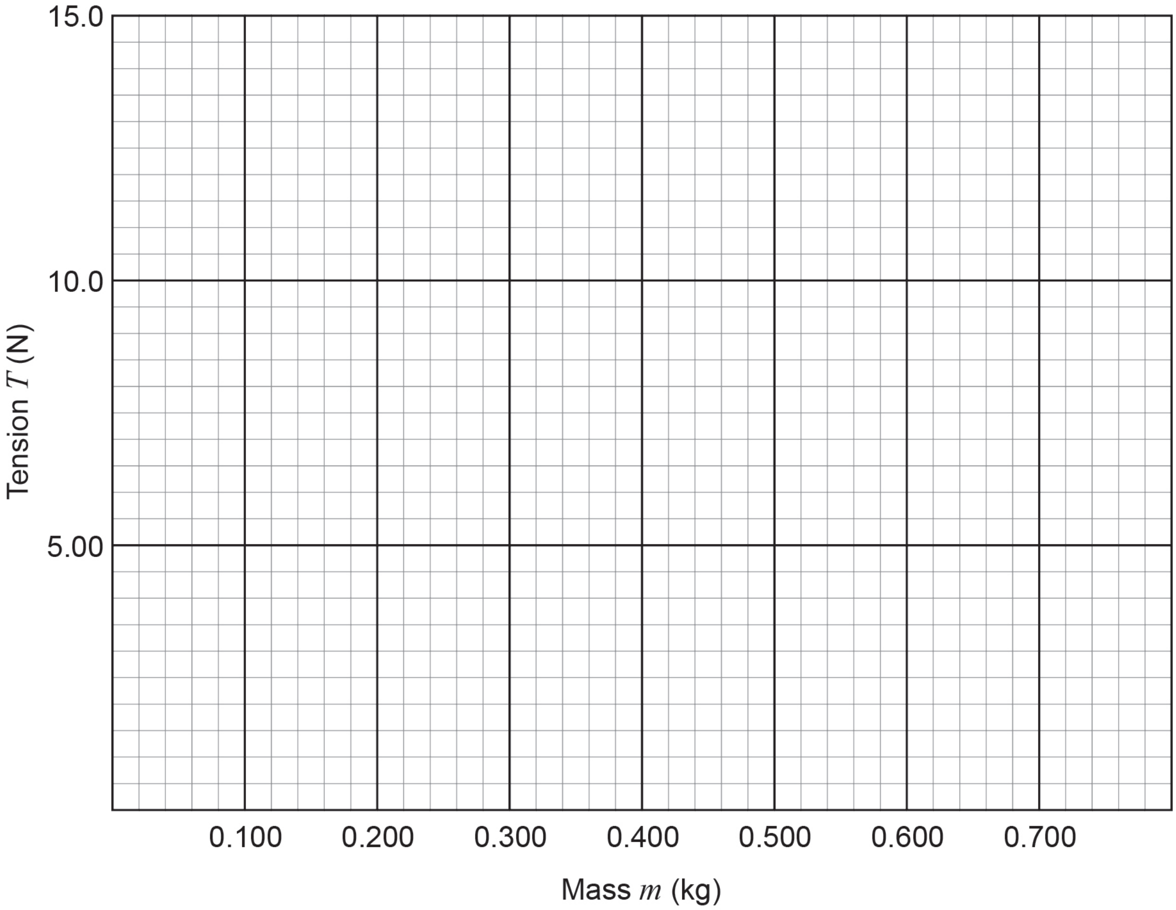
Supplementary page

Question number: ____________

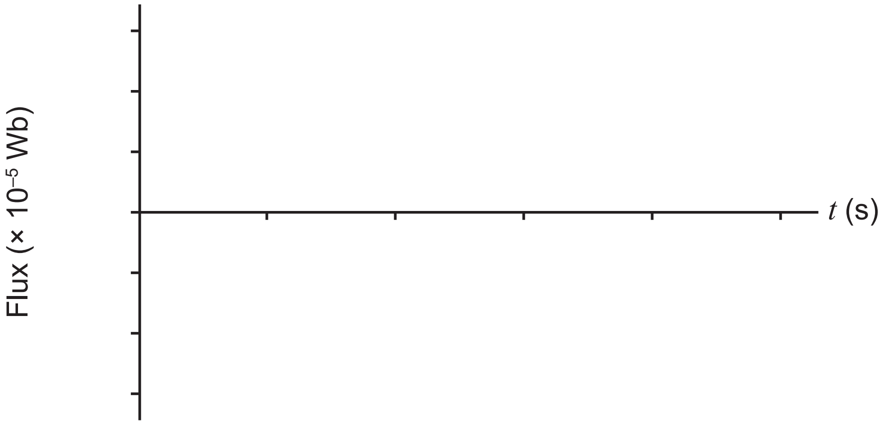
Supplementary page

Question number: ____________________

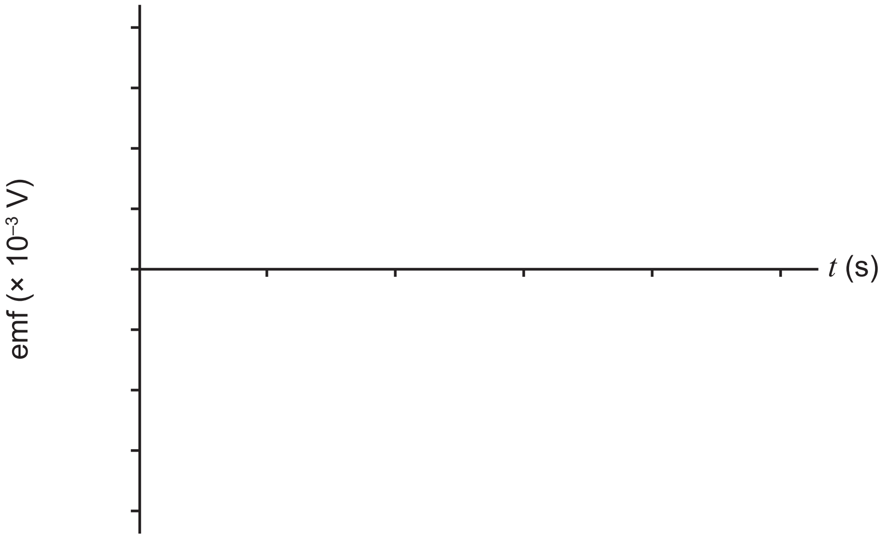
Spare grid for Question 16(b)



Spare graph for Question 17(b)



Spare graph for Question 17(c)



ACKNOWLEDGEMENTS

Question 19 Adapted from: Rioux, F. (n.d.). 2.5: A de Broglie-Bohr Model for the Hydrogen Atom - Version 4. *Quantum Tutorials.* Retrieved April, 2024, from https://chem.libretexts.org/Bookshelves/Physical_and_Theoretical_Chemistry_Textbook_Maps/Quantum_Tutorials_(Rioux)/02%3A_Atomic_Structure/2.05%3A_The_de_Broglie-Bohr_Model_for_the_Hydrogen_Atom_-_Version_4
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