Examiners' Report
June 2016

GCE Physics 6PH04 01

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Introduction

Section A of the paper contains 10 multiple choice questions while section B contains questions of increasing length and usually of increasing demand. This A2 paper builds on the work in the AS units and some questions require some AS knowledge such as the application of Newton's law and equilibrium of forces.This paper enabled candidates of all abilities to apply their knowledge to a variety of styles of examination questions. Many candidates showed a good progression from AS to A2 level, with prior knowledge extended and new concepts understood well.

While the contexts used in the examination were not any more challenging than in previous examination series, the consideration by candidates as to all the factors involved was not always thorough enough and answers given sometimes lacked the precision required to score the marks. However, candidates from across all ability ranges always managed to score some marks within these questions and all marks were awarded to some candidates. There were a number of question parts that were more challenging and these provided good discrimination across the paper.

In calculation questions, sometimes the layout of the work was poor with just a series of numbers multiplied and divided. There are missing subjects on the left hand side of the equation, missing equal signs and lines of working not following on correctly. Some calculations require the use of a previously calculated value. Some candidates write their answer to an appropriate number of significant figures but do not clear their calculators. This means that in the next calculation, their answer is not consistent with the values they have written down. This can result in the final mark not being awarded.

Multiple choice questions
These were generally well answered with questions 1, 2 6 & 8 being correctly answered by over 90% or more of the candidates.

Question 3 This required candiates to identify which of the given units was not a unit of mass. Many scored the mark but given that the amount of work on particle physics in this unit, it is surprising that some candidates did not choose MeV but instead went for N m^{-1} s^2 perhaps because it looked the most different.

Question 4 Candidates need to appreciate that in a calculation multiple choice question, the distractors will be the answers given by common wrong errors. They are not random numbers so if a candidate's answer is one of the given answers, they still need to check if their method is correct. In this question the distractors are based around missing the ½ from the equation and getting the powers of ten wrong for the picocoulomb.

Question 5 The confusion in this type of question is in the wording. Have they been asked for the time for the charge to fall by an amount or the time for the charge to fall to an amount?

Question 7 Candidates would benefit by practise in finding the physical quantity represented by the area of many different graphs. In this question the area is force x time and since force is rate of change of momentum the area is change in momentum. The more candidates practise this type of question, the easier they will find it.

Question 9 Conceptually this is quite difficult. Distractor A should be eliminated since it is the wrong definition of the charge separation. Both B and C would have reduced the force to a quarter of its value. It was pleasing to see how many candidates (80%) chose the correct answer.

Question 10 This was the multiple choice that achieved the lowest number of correct answers, 56%. It required the candidates to write down and use the equation: $p^2 = E_k\, 2m$ as a ratio for the two particles. The confusion occured because the equation has a factor of 2 which the more able candidates realised could be cancelled as well as a 3m and a 2E_k. Candidates need to realise that some multiple choice questions can be answered very quickly without having to write anything down while a few take a bit longer and do need to have some working out.

Question 11

(a) This question was generally well answered with many candidates scoring full marks. If candidates went wrong, it was sometimes an arithmetic error so still able to score the 2 method marks. Less able candidates used *E=eV* correctly to find the electron energy, but only part of MP1, and then used this energy in the photon equation *E* = *hf* , demonstrating a lack of understanding of the equations.

(b) Some candidates identified the similarity between the wavelength and atomic spacing but did not state whether or not a diffraction pattern would be produced. Some candidates did not appreciate that the difference between the values was insignificant in terms of producing a diffraction pattern and said that one would not be produced because the values were different. We did allow candidates whose wavelength calculation was wrong to score this mark if they made a correct statement. However a number of candidates who had a wavelength a power of ten different did tell us that they were similar.

In a particular investigation the atomic spacing of the crystal is 2.3×10^{-11} m and the electrons are accelerated through 3000 V.

(a) Calculate the wavelength of these electrons.

(3)

$\lambda = \frac{h}{p}$ $\quad ke = \frac{p^2}{2m} \Rightarrow p = \sqrt{2mke}$

$E = VQ = 3000 \times 1.6 \times 10^{-19} = 4.8 \times 10^{-16}$ J

$p = \sqrt{2 \times 9.11 \times 10^{-31} \times 4.8 \times 10^{-16}} = 2.95 \times 10^{-23}$ kgms^{-1}

$\therefore \lambda = \frac{6.63 \times 10^{-34}}{2.95 \times 10^{-23}} = 2.24 \times 10^{-11}$ m

Wavelength = 2.2×10^{-11} m

(b) State with a reason whether these electrons will produce a suitable diffraction pattern.

(1)

Yes, because ~~their~~ the electron's wavelength is similar to the atomic spacing of the crystal

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Examiner Comments

A well laid out answer that scores full marks. The candidate's working can be clearly followed, so if an arithmetic error had been made in the last calculation, the method marks could easily have been awarded. In (b) the candidate makes a clear link between the calculated wavelength and the atomic spacing.

An answer that scores no marks. MP1 required the use of E=eV and another calculation to determine velocity of momentum. This candidate has used the electron's energy in the photon energy equation as a route to finding a velocity.

In (b) their answer is a power of ten different to the atomic spacing, so in order to be awarded the mark, the candidate needed to say that diffraction would not happen because the wavelength was much bigger than the atomic spacing.

In a particular investigation the atomic spacing of the crystal is 2.3×10^{-11} m and the electrons are accelerated through 3000 V.

(a) Calculate the wavelength of these electrons.

(3)

$E = eV \quad = (1.6\times10^{-19}) \times 3000$

$E = hf \qquad\qquad = 4.8\times10^{-16}$ J $\qquad \lambda = \frac{h}{mv}$

$v = \lambda f \qquad \frac{4.8\times10^{-16}}{6.63\times10^{-34}} = 7.24\times10^{17}$ Hz.

$\lambda = \frac{v}{f} \qquad \frac{3\times10^{8}}{7.24\times10^{17}} = \underline{\underline{4.14\times10^{-10}\text{ m}}}$

Wavelength = 4.14×10^{-10} m

(b) State with a reason whether these electrons will produce a suitable diffraction pattern.

(1)

Yes, as their wavelength is (smaller) similar to the size of the nucleus, diffraction would be suitable

(Total for Question 11 = 4 marks)

ResultsPlus
Examiner Comments

E =hf is an equation that gives the energy of a photon related to the photon's frequency. It cannot be used with electrons.

In a particular investigation the atomic spacing of the crystal is 2.3×10^{-11} m and the electrons are accelerated through 3000 V.

(a) Calculate the wavelength of these electrons.

(3)

~~λ~~ $\frac{h}{p}$, ~~ ~~ $E_K = 3000 \times 1.6 \times 10^{-19} = 4.8 \times 10^{-16}$

$\Rightarrow \frac{1}{2} m v^2 = 4.8 \times 10^{-16} \Rightarrow v^2 = \frac{2 \times 4.8 \times 10^{-16}}{9.11 \times 10^{-31}}$

$\Rightarrow v = 3.25 \times 10^7$

$\lambda = \frac{h}{p} = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 3.25 \times 10^7} = 2.88 \times 10^{-6}$ m

Wavelength = 2.88×10^{-6} m ..... m

(b) State with a reason whether these electrons will produce a suitable diffraction pattern.

(1)

The wavelength is too long and so they will not produce a suitable difraction pattern, 2.88×10^{-6} m $\gg 2.3 \times 10^{-11}$ m

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Examiner Comments

(a) This candidate makes an arithmetic error in the final calculation so scores 2 marks for the correct method.

(b) The marker has awarded the response because it is consistent with the calculated wavelength.

Question 12 (a)

This question was about tracks in a bubble chamber where the tracks are produced by ionisation. So the only answer we accepted was where the candidate identified that ionisation did not occur. It was not sufficient to just say that the photon is uncharged. A large number of candidates did say that because the photon was uncharged, it could not cause ionisation which explained why there is no track and why ionisation does not occur.

Question 12 (b)

The stem of the question stated that the electron moves at high speed so there was no credit for stating that. Candidates needed to refer to $r = mv/BQ$ to identify that the radius of the electron was bigger so it had a higher velocity or a higher momentum. Comparative statements were needed in order to score the marks.

(b) Explain why the ejected electron undergoes less deflection than the electron-positron pair.

(2)

It is ejected at a high speed. As ~~...~~ $r = \frac{p}{BQ}$ ~~...~~ so as the ~~speed~~ velocity of the electron is higher the radius of its deflection is greater than the electron - positron pairs

ResultsPlus
Examiner Comments

The candidate does refer to the equation and that the radius of its path is greater than that of the electron-positron pair but twice the candidate says it has high speed and does not compare it to the speed of the electron-positron pair. Scores 1 mark.

(b) Explain why the ejected electron undergoes less deflection than the electron-positron pair.

(2)

It has gained more energy than the electron pair due to the conservation of momentum. The momentum is equal to that of the ~~hydrogen~~ photon which hit it. It therefore has greater speed as so it's deflection is less

ResultsPlus
Examiner Comments

The marks are independent so this scores 1 mark for a greater speed.

(b) Explain why the ejected electron undergoes less deflection than the electron-positron pair.

(2)

~~It travels faster~~ Conservation of momentum explains how they curve in opposite directions, there is slight deflection because charged particles attract and repel but momentum wouldn't be conserved if electron deflected a lot.

ResultsPlus
Examiner Comments

Quite a few candidates attempted to answer in terms of momentum which was not possible since they didn't know anything about the direction of the intial momentum. This scored 0.

Question 12 (c)

Whenever candidates are asked to show that a conservation law applies they must refer to each particle. A number of candidates said that an electron-positron pair has no charge but this is insuffucient, they must state that the electron is negative and the positron is positive. Candidates who did this were unable to score the second mark. Often particles were omitted or even if written down, no charge was assigned to them.

(c) Show that charge is conserved in the interaction.

(2)

$$\underset{\text{photon}}{0} + \underset{\text{He}}{0} \rightarrow \underset{e^-}{-1} + \underset{\bar{e}}{1} \underset{e^-}{-1} \underset{He^+}{+1}$$

$$0 \Rightarrow 0$$

ResultsPlus
Examiner Comments

A good answer, where all of the particles and all of the charges are given, scores 2 marks.

(c) Show that charge is conserved in the interaction.

(2)

~~A~~ ~~hydrogen~~ The electron-positron pair produce no charge as they cancel out, the ejected electron is neutralised by the positive hydrogen ion, so charge = 0.

ResultsPlus

Examiner Comments

An example of a general statement about the electron positron pair. There is no indication of the charge before the interaction so this scores 0.

ResultsPlus

Examiner Tip

In any interaction, list all of the particles individually and write down their charge. Saying the electron is neutralised by the positive hydrogen ion is not good enough. It should be stated the electron is negative.

(c) Show that charge is conserved in the interaction. mass/ which are both neutral

(2)

Initially there was a photon and H atom so ~~0~~ total charge = 0+0 = 0 (initial charge was 0e).

ResultsPlus

Examiner Comments

This candidate correctly identifes that the charge before the interaction was zero but says nothing about after. Scores 1 mark.

ResultsPlus

Examiner Tip

Any interaction has particles before and after. To justify any conservation law, you must refer to all of the particles.

Question 12 (d)

This is the part of the question where conservation of momentum should have been considered but was rarely mentioned. Many candidates were able to identify that the speed of the ionised hydrogen atom was zero or negligible but hardly anyone referred to the relative mass of the atom. Some candidates were clearly confused by the phrase 'ionised hydrogen atom' and said that it could not leave a track because it was ionised.

(d) Explain why there is no track from the ionised hydrogen atom after the collision.

(2)

~~It does not move so does not interact~~

~~It's~~ The hydrogen atom ~~gains~~ and the electron it loses have the same, (but opposite) momentum. as the atom (or an ion) is so massive, its speed increase is negligible, so it does not move

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Examiner Comments

A rare example of an answer that scores 2 marks.

(d) Explain why there is no track from the ionised hydrogen atom after the collision.

(2)

because it has no momentum, therefore it is stationary inorder to conserve momentum.

ResultsPlus

Examiner Comments

Common answer scores 1 mark.

(d) Explain why there is no track from the ionised hydrogen atom after the collision.

(2)

Because it has no charge and it can't Ionise

ResultsPlus

Examiner Comments

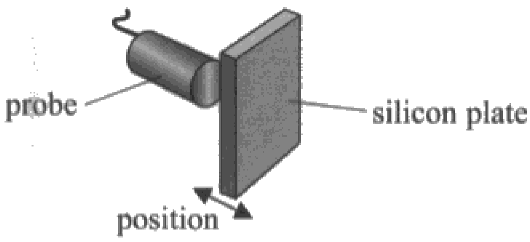
This answer was seen quite often. Candidates clearly do not know that an ionised atom is charged.

Question 13 (a)

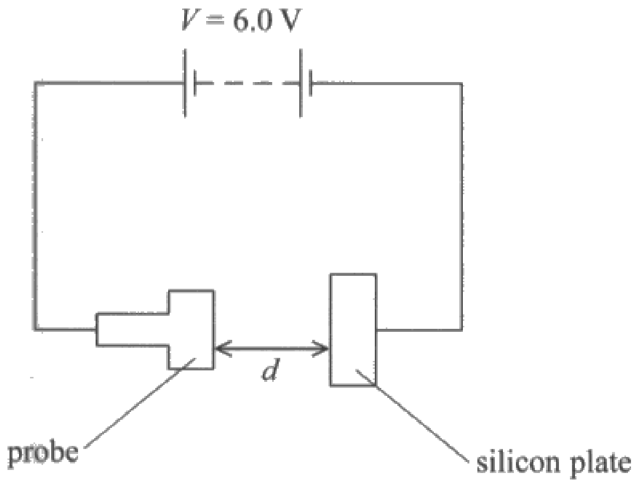
This was generally well answered since it only required an understanding of an inversely proportional relationship and using the equation $C = Q/V$. This was an explain question so after establishing that the capacitance would decrease, some justification as to why the charge would decrease was also needed. The ideal answer would have been to state that because $C = Q/V$ *and* V was constant, that Q would decrease. However we accepted either the reference to the equation or the statement that V was constant. Some candidates did not make one of these statements and less able candidates made the error of confusing symbols. Despite the question telling them that C was capacitance, they assumed that it was charge. 25% of candidates scored zero for this item.

13 During the manufacture of some computer components it is necessary to monitor the position of pieces of silicon.

Capacitors can be used to detect a change in the position of a piece of silicon. The piece of silicon forms one plate of a capacitor whilst a probe acts as the other plate as shown in the diagram.



The capacitor is charged by connecting it to a 6.0 V battery as shown in the diagram below.



The relationship between the capacitance C and the distance d between the silicon plate and the probe is

$$C = k/d$$

where k is a constant.

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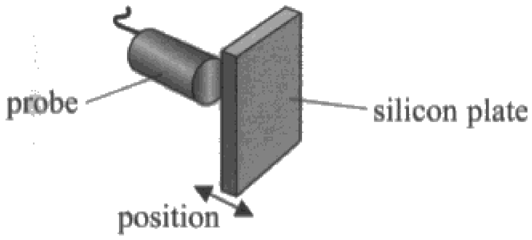
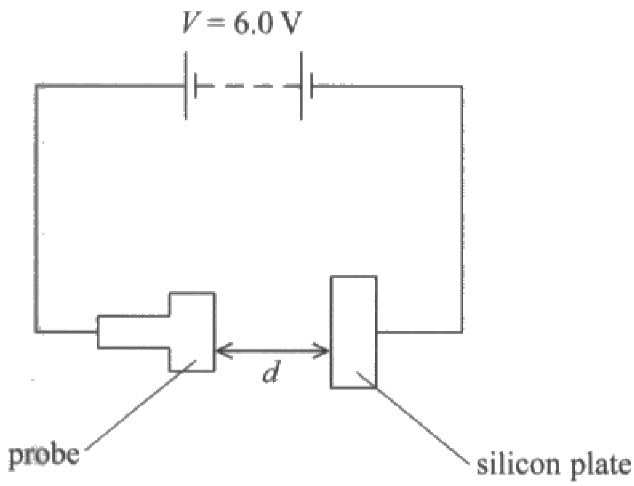


The capacitor is charged by connecting it to a 6.0 V battery as shown in the diagram below.



The relationship between the capacitance C and the distance d between the silicon plate and the probe is

$$C = k/d$$

where k is a constant.

(a) Explain qualitatively how the charge on the capacitor will vary if the silicon plate moves away from the probe.

(2)

As $C = \frac{k}{d}$, as the distance d increases, the capacitance C will decrease. $C = \frac{Q}{V}$, as $V = 6.0$ and is constant, Q must decrease as C decreases.

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Examiner Comments
Model answer that quotes the equation and that V is constant.

13 During the manufacture of some computer components it is necessary to monitor the position of pieces of silicon.

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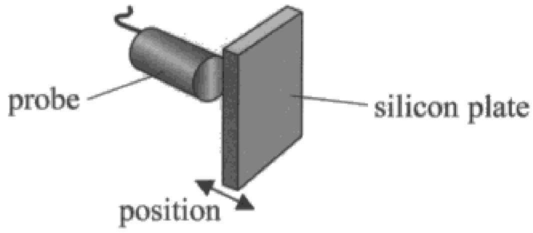

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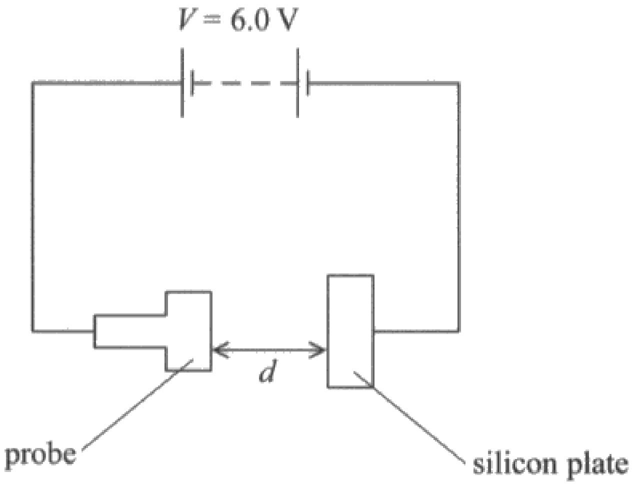


The relationship between the capacitance C and the distance d between the silicon plate and the probe is

$$C = k/d$$

where k is a constant.

(a) Explain qualitatively how the charge on the capacitor will vary if the silicon plate moves away from the probe.

(2)

Charge will decrease if distance is increased

$C = k/d$ $\quad$ $k =$ constant

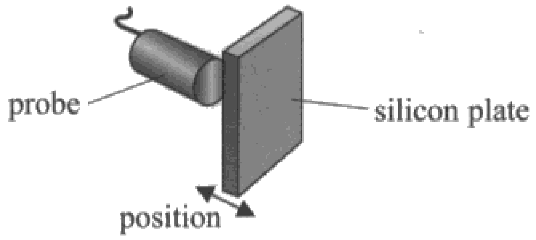
$\frac{1}{2}C = k/2d$

ResultsPlus
Examiner Comments

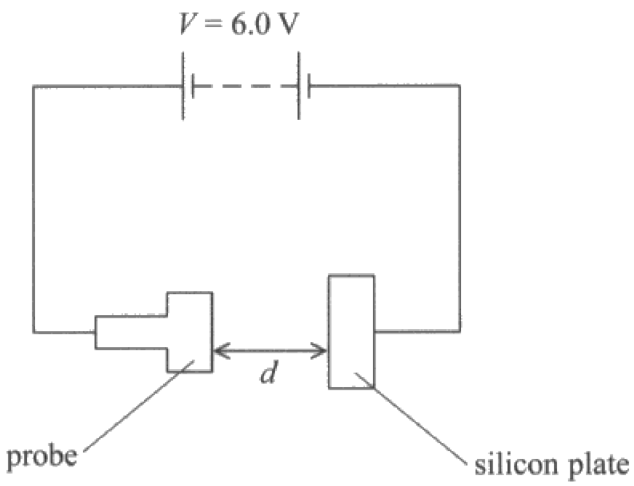
An example where the candidate thinks that the C is for charge.

13 During the manufacture of some computer components it is necessary to monitor the position of pieces of silicon.

Capacitors can be used to detect a change in the position of a piece of silicon. The piece of silicon forms one plate of a capacitor whilst a probe acts as the other plate as shown in the diagram.



The capacitor is charged by connecting it to a 6.0 V battery as shown in the diagram below.



$C = Q/V$

The relationship between the capacitance C and the distance d between the silicon plate and the probe is

$$C = k/d$$

where k is a constant.

(a) Explain qualitatively how the charge on the capacitor will vary if the silicon plate moves away from the probe.

(2)

The capacitance falls as d increases, this causes charge to fall as less electrons pass between the plates.

ResultsPlus

Examiner Comments

This scored 1 mark for the capacitance decrease but there is no justification for why the charge decreases.

Question 13 (b)

This question gave a specific position for the silicon with respect to the probe and the distance by which the silicon could move from this position. The question asked candidates to determine the maximum percentage decrease in the charge on the capacitor. Candidates needed to realise that this meant the silicon was moving away from the probe and so using the distances 3.5 mm amd 4.2 mm. Some candidates ignored where the probe was starting and did not use the initial position of the silicon. Some candidates just calculated the capacitance at each position which gives the same percentage difference since charge and capacitance are proportional. Having found two values of charge candidates then had to work out a percentage difference. Since for both of the errors mentioned, candidates were still demonstrating some good physics, it was decided that both of these candidates could score 3 of the 4 possible marks. A few candidates did state that *Q* was proportional to *C* before just calculating values for *C* and these candidates were given full credit.70% of candidates scored 3 or 4 marks. The less able candidates usually struggled with finding a percentage difference.

(b) When the silicon is in a certain position, the probe is 3.5 mm from it. The silicon must remain within 0.70 mm of this position.

Determine the maximum allowable percentage decrease in the charge on the capacitor.

$k = 2.8 \times 10^{-15}$ F m

(4)

$\frac{Q}{V} = \frac{k}{d}$ $\quad Q = \frac{k}{d} V$ $\quad Q = \frac{2.8\times10^{-15}}{3.5\times10^{-3}} \times 6$

$= 4.8\times10^{-12}$ C $\quad Q = \frac{2.8\times10^{-15}}{2.8\times10^{-3}} \times 6 = 6\times10^{-12}$ C

$\frac{4.8\times10^{-12}}{6\times10^{-12}} = 0.8 \quad 1 - 0.8 = 0.2$

Maximum allowable percentage decrease = 20 %

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Examiner Comments

This candidate goes the wrong way and uses the starting position and decreases it so is finding the percentage increase in charge.This scored 2 marks for finding charge and using $\Delta Q/Q$.

(b) When the silicon is in a certain position, the probe is 3.5 mm from it. The silicon must remain within 0.70 mm of this position.

Determine the maximum allowable percentage decrease in the charge on the capacitor.

$k = 2.8 \times 10^{-15}$ F m

(4)

$\frac{Q}{V} = \frac{k}{d}$

$Q = \frac{6 \times 2.8 \times 10^{-15}}{2.8 \times 10^{-3}} = 6 \times 10^{-12}$ $Q = \frac{6 \times 2.8 \times 10^{-15}}{4.2 \times 10^{-3}} = 4 \times 10^{-12}$

$\frac{6 \times 10^{-12} - 4 \times 10^{-12}}{6 \times 10^{-12}} \times 100 = 33.3\%$

Maximum allowable percentage decrease = 33%.

ResultsPlus
Examiner Comments

An example where the initial position was ignored getting 33%. This scored 3 marks.

(b) When the silicon is in a certain position, the probe is 3.5 mm from it. The silicon must remain within 0.70 mm of this position.

Determine the maximum allowable percentage decrease in the charge on the capacitor.

$k = 2.8 \times 10^{-15}$ F m

(4)

$3.5 + 0.7 = 4.2$mm

$\frac{2.8 \times 10^{-15}}{4.2 \times 10^{-3}} = 6.7 \times 10^{-13}$

$\frac{2.8 \times 10^{-15}}{3.5 \times 10^{-3}} = 8 \times 10^{-13}$

$\frac{8 \times 10^{-13} - 6.7 \times 10^{-13}}{8 \times 10^{-13}} \times 100 = 16.25\%$

Maximum allowable percentage decrease = 16.25%

ResultsPlus
Examiner Comments

An example that just finds capacitance, again scoring 3 marks.

However there is a lack of symbols and units which is not good practice.

(b) When the silicon is in a certain position, the probe is 3.5 mm from it. The silicon must remain within 0.70 mm of this position.

Determine the maximum allowable percentage decrease in the charge on the capacitor.

$k = 2.8 \times 10^{-15}$ F m

(4)

~~3.5+0.~~ $d = 3.5 + 0.7 = 4.2\,\text{mm} = 4.2\times10^{-3}\,\text{m}$ $\quad d_0 = 3.5\times10^{-3}\,\text{m}$

$C_0 = \frac{k}{d_0} = \frac{k}{3.5\times10^{-3}} = 8\times10^{-13}\,\text{F}$

$Q_0 = C_0 V = 4.8\times10^{-12}\,\text{C}$

$C = \frac{k}{d} = \frac{k}{4.2\times10^{-3}} = 6.67\times10^{-13}\,\text{F}$

$Q = CV = 4\times10^{-12}\,\text{C}$

$100 \times \frac{(4.8\times10^{-12} - 4\times10^{-12})}{4.8\times10^{-12}} = 16.7\%$

Maximum allowable percentage decrease = 16.7%

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Examiner Comments

An answer that scores 4 marks with symbols used so that the working can be followed clearly. This is a good example of how work should be set out.

Question 13 (c)

Over 50% of the candidates scored zero. They did not appreciate that rapid changes in position meant that there were rapid changes in charge or that it needed a shorter time to charge or discharge and that this could be monitored by having a small time constant.

(c) In order to detect rapid changes in the position of the silicon, it is necessary to use a capacitor with a small capacitance.

Explain why.

(2)

has a smaller time constant RC, so discharges at a faster rate ~~and~~ when the probe moves away from the silicon and detects change.

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Examiner Comments

An example that scores 2 marks which was only achieved by 17% of the candidates.

(c) In order to detect rapid changes in the position of the silicon, it is necessary to use a capacitor with a small capacitance.

Explain why.

(2)

Small time constant, so the capacitor can discharge before the plate begins to move again.

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Examiner Comments

This scored 1 mark for realising that the time constant was involved but does not say that the capacitor needs to discharge quickly.

(c) In order to detect rapid changes in the position of the silicon, it is necessary to use a capacitor with a small capacitance.

Explain why.

(2)

Because a smaller capacitance will mean slight changes will have a bigger/faster effect which can be detected easier.

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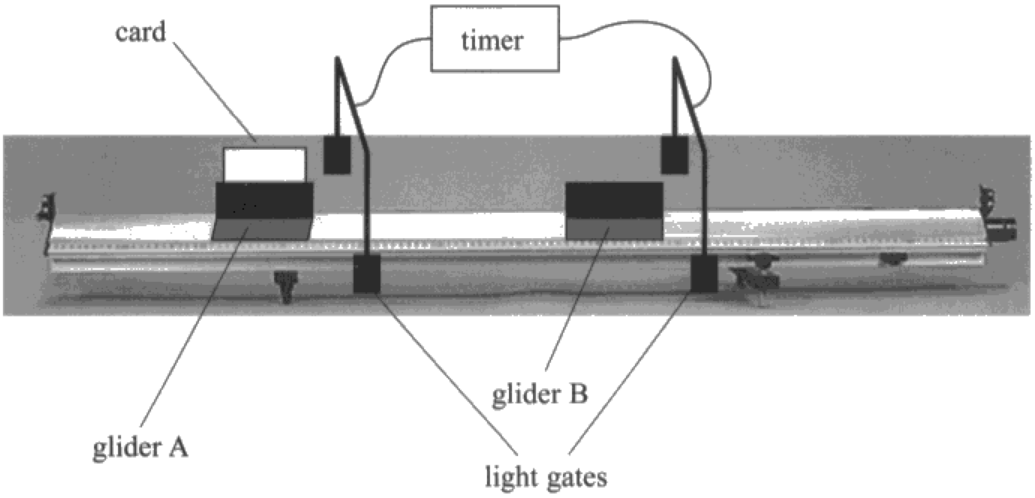
Examiner Comments

This candidate does not say what the effect is so scores no marks. This was a typical response.

Question 14 (a) (i)

This was a practical description and so detail such as measuring the masses of the gliders and measuring the length of the card were required. Candidates were expected to use the apparatus shown in the diagram which were light gates. There was no data logger so there was no means of the apparatus giving the velocities. Candidates were expected to measure the length of the card and the time for which the light was interrupted by the card. Most answers did not have this detail. The most common mark awarded was 2.

14 The law of conservation of momentum can be investigated using a low-friction track with two gliders. Glider B is stationary. Glider A is given a gentle push towards glider B. The gliders collide, stick together and move off.



(a)*(i) Describe how you would use the apparatus shown to verify the law of conservation of momentum.

(5)

The mass of both gliders would be measured. ~~before the~~ Glider A would then be pushed through the first light gate which would measure the velocity of the glider. This velocity can then be multiplied by the mass of the glider to calculate the initial momentum of the system. After glider A hits B they will both pass through the second light gate which records the ~~speed~~ velocity they are moving at. This can then be multiplied by the combined mass of both gliders to calculate the final momentum of the system after a collision. This value of final momentum can then be compared to the value for initial momentum; they should be equal.

ResultsPlus
Examiner Comments

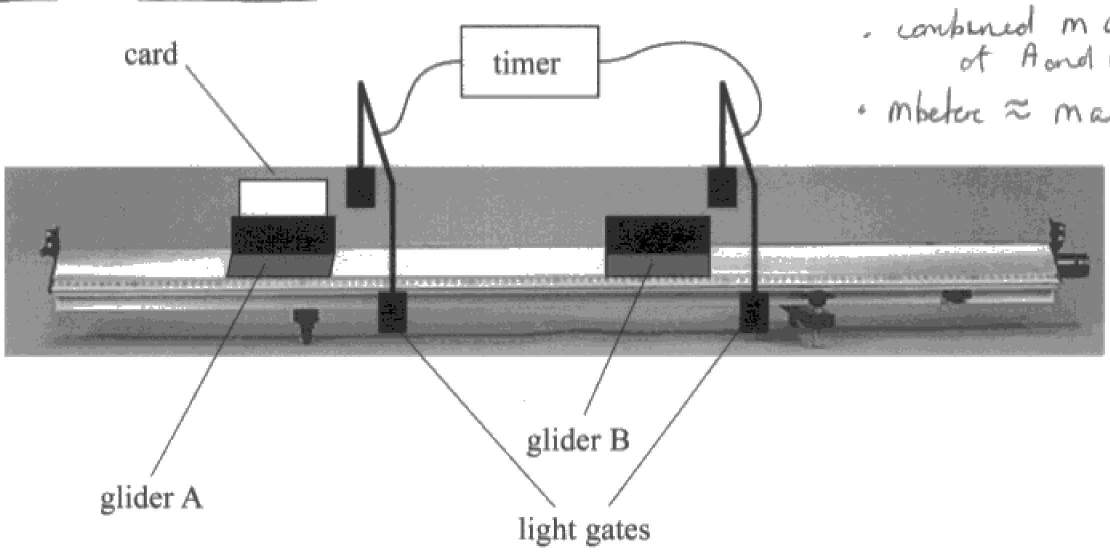
A typical answer that scored 2 marks, one for measuring the mass of the gliders and one for explaining how the masses and velocities would be used to demonstrate the conservation of momentum.

ResultsPlus
Examiner Tip

Whenever a question asks you to describe how you would do a practical, remember to state all of the meaurements needed and how you would use them.

14 The law of conservation of momentum can be investigated using a low-friction track with two gliders. Glider B is stationary. Glider A is given a gentle push towards glider B. The gliders collide, stick together and move off.

- m and v of A
- combined m and v of A and B.
- $m_{before} \approx m_{after}$.



(a)*(i) Describe how you would use the apparatus shown to verify the law of conservation of momentum.

(5)

Measure the length of the card.

Measure the masses of glider A and glider B. The light gates would record the velocity of glider A (the time taken for the card of known length to cut the light then they would use speed = distance over time). Then after the glider collide and stick together The light gates would record the velocity of the two combined gliders. Momentum is equal to mass x velocity. Calculate the momentum of glider A before the collision and calculate the momentum of the two combined gliders after the collision using their combined mass. The two calculated values of momentum should be ~~roughly~~ the same as ~~if there was no friction~~ momentum before would equal momentum after.

ResultsPlus
Examiner Comments
An example of an answer that scores all the marks.

Question 14 (a) (ii)

Candidates needed to state that momentum is only conserved if no external forces act and that friction is an external force. There was no credit for just referring to closed systems without saying that this meant there was no external force. For the second marking point, instead of saying that friction was an external force, candidates could tell us the effect of friction in altering the velocities in the experiment. Hardly anyone commented on the fact that in the experiment you are finding an average velocity over a period of time and you cannot measure the velocities immediately before and after collision. Since this was part of a question about demonstrating the law of conservation of momentum and therefore needing mass and velocity values, a surprisingly large number of candidates talked about the effect of friction on energy and not velocity. This is the main reason why the most common mark was 1.

(c) In order to detect rapid changes in the position of the silicon, it is necessary to use a capacitor with a small capacitance.

Explain why.

(2)

Small time constant, so the capacitor can discharge before the plate begins to move again.

ResultsPlus

Examiner Comments

Model answer, the first two lines scores both marks.

(ii) Explain why it is necessary to use a low-friction track to verify the law of conservation of momentum.

(2)

Because momentum is only conserved if no external forces act on the particles colliding, therefore low friction is needed so that friction does not affect the results.

ResultsPlus

Examiner Comments

1 mark for the need for no external forces but the comment about it that 'it doesn't affect the results' is too vague.

(ii) Explain why it is necessary to use a low-friction track to verify the law of conservation of momentum.

(2)

- So there is no energy lost due to friction and all energy is converted to kinetic energy

ResultsPlus
Examiner Comments
A zero mark answer, there is no mention of external forces or velocity.

Question 14 (b)

Generally very well answered with nearly 80% of candidates scoring full marks. Where candidates did go wrong was in calculating the kinetic energy after the collision. Some did not realise that you needed to do two separate calculations and add them. They tried to do a single calculation with an average mass.

(b) In a different investigation a glider of mass 0.50 kg travelling at 0.90 m s^{-1} collides head-on with a stationary glider of mass 0.70 kg. The 0.50 kg glider continues moving in the same direction at a velocity of 0.20 m s^{-1}. The gliders do not stick together.

(i) Calculate the velocity of the 0.70 kg glider after the collision.

(2)

0.5 0.9 → 0 0.7

→ 0.2 →

$0.5 \times 0.9 = 0.5 \times 0.2 + 0.7 \times V$

Velocity = 0.5 ms^{-1}

(ii) By doing further calculations, determine whether the collision is elastic.

(2)

Kinetic energy before $= \frac{1}{2}mv^2 = 0.20\text{J}$

after $= \frac{1}{2}(0.5)(0.2)^2 + \frac{1}{2}(0.7)(0.5)^2$

$= 0.0975 \approx 0.1\text{J}$

$\therefore$ Kinetic energy is not conserved so it is not elastic → inelastic

ResultsPlus
Examiner Comments
Model answer

(b) In a different investigation a glider of mass 0.50 kg travelling at 0.90 m s^{-1} collides head-on with a stationary glider of mass 0.70 kg. The 0.50 kg glider continues moving in the same direction at a velocity of 0.20 m s^{-1}. The gliders do not stick together.

(i) Calculate the velocity of the 0.70 kg glider after the collision.

(2)

$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$

$0.5 \times 0.9 + 0 = 0.5 \times 0.2 + 0.7v$

$0.45 = 0.1 + 0.7v$

$0.5 = v$

Velocity = $0.5\ ms^{-1}$

(ii) By doing further calculations, determine whether the collision is elastic.

(2)

$E = \frac{p^2}{2m} = \frac{0.5 \times 0.9^2}{2 \times 0.5}$ $\quad$ $E = \frac{(0.5 \times 0.2 + 0.7 \times 0.5)^2}{2 \times 1.2}$

$= 0.203\ J$ $\quad$ $= 0.084\ J$

$\Rightarrow$ Inelastic as kinetic energy isn't conserved.

ResultsPlus
Examiner Comments

Use of this enery equation is fine but it cannot be done as a single calculation.

Question 15 (a) (i)

Although nearly 60% of candidates scored both marks, this is an example of recall of a straightforward definition and unit which most candidates are capable of learning. Some candidates just identified N as the number of turns and Φ as flux without mentioning linkage. The unit is the Weber and we accepted T m^2. However there is no unit called the Weber-turn so this was not credited. Some candidates wrote Weber w which meant the mark could not be awarded since w is the unit for watts.

15 Faraday's and Lenz's laws of electromagnetic induction state that

$$\varepsilon = -\frac{d(N\Phi)}{dt}$$

(a) (i) State the meaning of the term $N\Phi$ and give its unit.

(2)

Flux linkage, measured in Webers (Wb)

ResultsPlus
Examiner Comments

Model answer scores both marks

15 Faraday's and Lenz's laws of electromagnetic induction state that

$$\varepsilon = -\frac{d(N\Phi)}{dt}$$

(a) (i) State the meaning of the term $N\Phi$ and give its unit.

(2)

It is the quantity of electromagnetic flux that is 'contained' within a coil of wire unit: weber-turns

ResultsPlus
Examiner Comments

The reference to electromagnetic is incorrect and the phrase electromagnetic flux linkage would not have been awarded the mark.

This scored zero.

15 Faraday's and Lenz's laws of electromagnetic induction state that

$$\varepsilon = -\frac{d(N\Phi)}{dt}$$

(a) (i) State the meaning of the term $N\Phi$ and give its unit.

(2)

The change in flux of a coil of wire with N being the amount of turns. Given in Weber (wb).

ResultsPlus
Examiner Comments

This answer scored 1 mark for the unit.

Question 15 (a) (ii)

The examiners were looking for the idea that the induced e.m.f. was in such a direction as to oppose the change causing it. Since it was only one mark, we did not insist on induced e.m.f. but accepted just e.m.f. Some candidates wanted to talk about the direction of current, presumably because it is that direction which determines the direction of the magnetic field produced. However the direction of the current is determined by the direction of the e.m.f. and the question was asking about a minus sign in an equation which links e.m.f. and rate of change of flux linkage. The other common error was to say that the direction of the e.m.f. was opposite to the change which shows a lack of understanding of the physics.

(ii) State the significance of the negative sign.

(1)

The induced emf is in a direction that opposes the change that caused it.

ResultsPlus
Examiner Comments

An example that scored the mark.

(ii) State the significance of the negative sign.

(1)

shows that there is an induced current which opposes the change in the rate of change of the magnetic field.

ResultsPlus
Examiner Comments

An example of an answer that refers to current and not e.m.f. Scores zero.

(ii) State the significance of the negative sign.

(1)

Because it's in the opposite direction

ResultsPlus
Examiner Comments

There is no mention of opposing the change and 'it' is not defined, could be any quantity so no credit.

Question 15 (b) (i)

The most commonly awarded mark was 2 with over 70% of candidates scoring 2 or 3 marks. The least awarded mark was MP3 which required candidates to refer to the closed circuit. Some candidates referred to induced current or providing an e.m.f. Ideally we would like candidates to talk about a changing flux but we did accept magnetic field lines being cut providing this was linked to the coil. So a statement that was just 'magnetic field lines are cut' was not credited.

*(i) With reference to the laws of electromagnetic induction explain why a current is produced in the coil as the magnet moves upwards.

(3)

The coil cuts the lines of flux from the magnet which produces a rate of change of magnetic flux linkage. This, in accordance to Faraday's law induces an emf, and therefore a current, as it is a closed circuit

ResultsPlus
Examiner Comments

An answer that scores all three marks.

ResultsPlus
Examiner Tip

Remember when answering questions on electromagnetic induction, it is an e.m.f. that is induced and a current is only induced if there is a closed circuit.

*(i) With reference to the laws of electromagnetic induction explain why a current is produced in the coil as the magnet moves upwards.

(3)

the moving magnet ~~caused~~ causes a changing magnetic field and when it accelerates upwards the flux lines created are cut which ~~induced~~ induces a current in the coil proportional to the rate of flux lines cut.

ResultsPlus
Examiner Comments

The first two lines of this answer are not sufficient since it is referring to field lines with no mention of the coil. There is an induced current but then at the end there is enough for 1 mark to be awarded.

*(i) With reference to the laws of electromagnetic induction explain why a current is produced in the coil as the magnet moves upwards.

(3)

The magnetic field from the magnet will have magnetic flux linkage with the coil. As the magnet accelerates away there is a change in this flux linkage, inducing an emf in the coil ($\varepsilon = -\frac{d(N\phi)}{dt}$), the emf will drive a current around the coil.

ResultsPlus
Examiner Comments

An example of the most common score of 2. Saying the e.m.f. will drive a current around the coil is not the same as saying it is a closed/complete circuit.

Question 15 (b) (ii)

The magnitude of the current is determined by the magnitude of the induced e.m.f. so the key bit of physics was to refer to the rate of change of flux. This is affected by both the speed of the magnet and the magnetic flux density that the magnet is moving through. Since the question told the candidates that the magnet was moving, it was too easy for candidates to say the speed was changing. Because of this it was decided to make the second marking point dependent on scoring the first marking point. Conceptually candidates find it difficult to talk about the rate of change changing, so it is not surprising this was a discriminating question.

(ii) Explain why the magnitude of the current varies as the magnet moves upwards.

(2)

As the magnet moves upwards, the speed of the magnet changes.
So the rate of change of flux ~~linkage~~ linkage changes.
The magnitude of induced e.m.f depends on the rate of change of flux linkage.
So, the magnitude of the current produced varies.

ResultsPlus
Examiner Comments

An answer that scores both marks.

(ii) Explain why the magnitude of the current varies as the magnet moves upwards.

(2)

As the magnet is further away there are less flux lines per unit area so the magnet won't cut as many so a smaller emf is produced

ResultsPlus
Examiner Comments

Although this statement is correct, there is no mention of the rate of change of flux so it scores zero.

Question 15 (b) (iii)

This item was specific to the set-up of this question and so the only possible answers were in terms of an increased sampling rate. Candidates should not assume that a data logger is more precise or accurate. Automatic plotting of a graph is never an advantage.

Question 16 (a) (i)

This was a straightforward calculation aimed to get the candidates thinking about circular motion. It was pleasing to see 90% of candidates scored both marks.

(i) The radius of the bicycle wheel including the inflated tyre is 0.40 m.
Calculate the speed of the bicycle if the magnet passes through the sensor once every 1.2 s.

(2)

$F = \frac{mv^2}{r} = mr\omega^2$

$0.4 \div 1.2 = 0.3\dot{3}\ ms^{-1}$

Speed = 0.33 ms^{-1}

ResultsPlus
Examiner Comments

This candidate just decided to divide the two pieces of data given, so scores zero.

(i) The radius of the bicycle wheel including the inflated tyre is 0.40 m.
Calculate the speed of the bicycle if the magnet passes through the sensor once every 1.2 s.

(2)

$v = r\omega \qquad \omega = \frac{2\pi}{T}$

$v = r\frac{2\pi}{T} = \frac{0.4 \times 2\pi}{1.2} = \underline{2.09\ ms^{-1}}$

Speed = 2.1 ms^{-1}.

ResultsPlus
Examiner Comments

A model answer using the simplest method.

(ii) State the significance of the negative sign.

(1)

The induced emf is in a direction that opposes the change that caused it.

ResultsPlus

Examiner Comments

This candidate also scores both marks but does it as a two stage calculation.

ResultsPlus

Examiner Tip

Try to think of the simplest method. Speed is asked for so distance is one circumference $2\pi r$ and the time is given.

Question 16 (a) (ii)

This two mark question provided discrimination since conceptually it is quite difficult. It was relatively easy to say that the radius was reduced, but working out the effect this would have on the speedometer was more difficult. Quite a large number of candidates identified that the speed of the bike would be less but they did not mention the speedometer.

(ii) Explain how the reading on the speedometer is affected if the tyre is **not** fully inflated.

(2)

If the tyre is not fully inflated then the circumference of the wheel will be reduced, so for each revolution the wheel will travel less distance, meaning the speedometer will give an erroneously high reading

ResultsPlus
Examiner Comments

An example that scores both marks.

(ii) Explain how the reading on the speedometer is affected if the tyre is **not** fully inflated.

(2)

the radius would be smaller so it would say you are traveling slower

ResultsPlus
Examiner Comments

This candidate scores 1 mark for the radius being smaller. Since the question asks about the speedometer we assume that the 'it' is referring to the speedometer but the statement is wrong.

(ii) Explain how the reading on the speedometer is affected if the tyre is **not** fully inflated.

(2)

If the tyre is not fully inflated its radius would be lower and ∴ the speed of the bike would also be lower as $V = \omega r$ ∴ $V \propto r$ so if r decreases so does V.

ResultsPlus

Examiner Comments

The common wrong answer where everything written is correct but it is not linked to the speedometer. Scores 1 mark.

Question 16 (a) (iii)

A very straightforward calculation that most candidates could do.

(iii) In normal use there is a small current in the sensor. When the magnet passes the sensor the magnetic field is perpendicular to the velocity of the electrons. There is a magnetic force on the electrons.

Calculate the magnitude of the magnetic force on an electron moving at 7.4×10^{-4} m s^{-1}.

magnetic flux density = 0.050 T

(2)

$F = Bqv \sin 90 = Bqv$

$B = 0.050$ $q = 1.60 \times 10^{-19}$ $v = 7.4 \times 10^{-4}$ m s^{-1}

$0.050 \times 1.60 \times 10^{-19} \times 7.4 \times 10^{-4}$

$= 5.92 \times 10^{-24}$

Magnetic force = 5.9×10^{-24}

ResultsPlus

Examiner Comments

Scores 1 mark, no units.

ResultsPlus

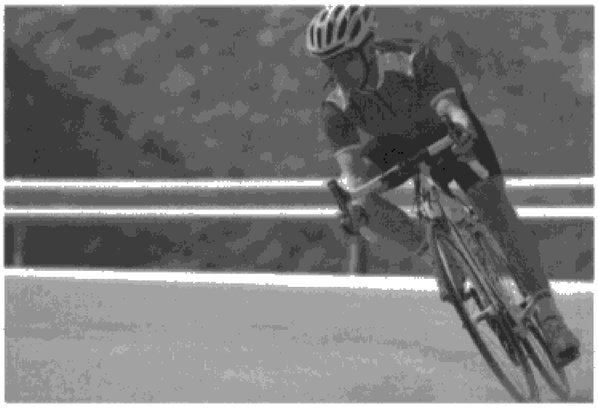
Examiner Tip

Remember units. All that work to then forget to add the unit N.

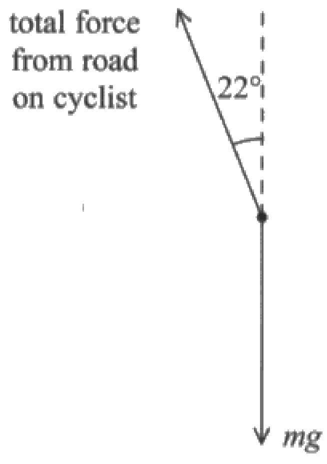
Question 16 (b)

This calculation was not so well done with only 50% of candidates arriving at the correct answer. The difficulty was in realising that the vertical force from the road was equal to the weight which allowed this force to be calculated. Then the horizontal component of this force acted as the centripetal force. Some candidates were able to do the calculation of the horizontal force in one step using the tan relationship.The most commonly wrong method was to resolve forces along the line of action of the force from the road, that is, mg cosθ = R and then to use this as the centripetal force. These candidates were allowed to score 1 mark for the use of this force as a centripetal force.

(b) A cyclist leans to one side as he travels around a bend as shown.



The cyclist is travelling at 9.0 m s^{-1} and leans at an angle of 22° to the vertical.
A simplified free-body force diagram for the cyclist and the bicycle is shown below.



Determine the radius of the bend.

combined mass of cyclist and bicycle = 80 kg

(3)

F_v: $T\cos 22 = 80 \times 9.81$

$T = 846\,N$

F_H: $846 \times \sin 22 = \frac{mv^2}{r} = \frac{80 \times 9^2}{r}$

$r = \frac{80 \times 9^2}{846 \times \sin 22} = 20.4\,m$

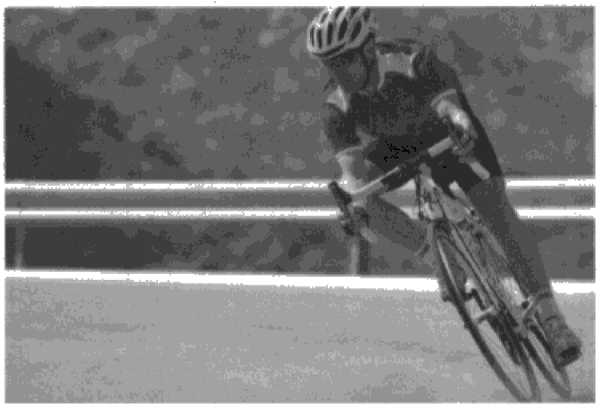
Radius = 20m

ResultsPlus

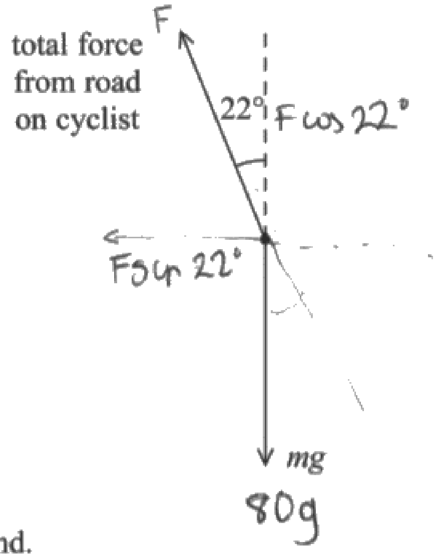
Examiner Comments

Model answer scoring all 3 marks.

(b) A cyclist leans to one side as he travels around a bend as shown.



The cyclist is travelling at 9.0 m s^{-1} and leans at an angle of 22° to the vertical.
A simplified free-body force diagram for the cyclist and the bicycle is shown below.



Determine the radius of the bend.

combined mass of cyclist and bicycle = 80 kg

(3)

$F\cos 22° = mg \quad F\cos 22° = 80g \quad F = \dfrac{80g}{\cos 22} = 846.4\,\text{N}$

$F = \dfrac{mv^2}{r} = \dfrac{80 \times 9^2}{r}$

$r = \dfrac{80 \times 9^2}{846.4} = 6.85\,\text{m}$

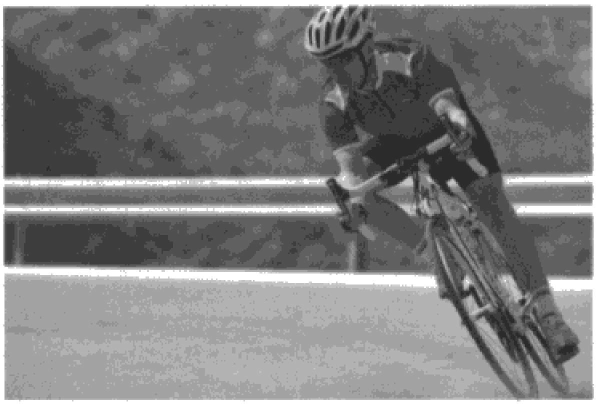
Radius = 6.85 m

ResultsPlus

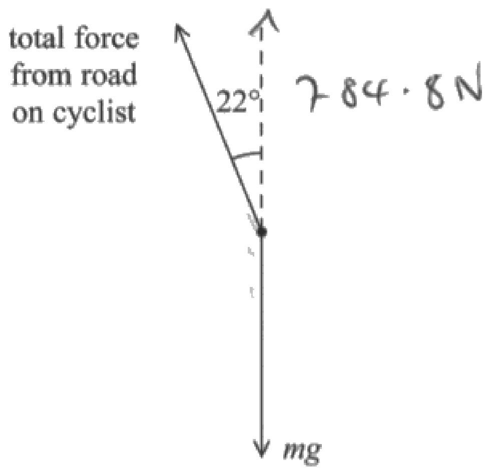
Examiner Comments

This candidate correctly resolves vertically and determines the force from the road but does not find a horizontal component. This scores 1 mark.

(b) A cyclist leans to one side as he travels around a bend as shown.



The cyclist is travelling at 9.0 m s^{-1} and leans at an angle of 22° to the vertical.
A simplified free-body force diagram for the cyclist and the bicycle is shown below.



Determine the radius of the bend.

combined mass of cyclist and bicycle = 80 kg

(3)

$80 \times 9.81 = mg = W = 784.8\,N$ $\qquad m = 80$

$v = 9.0\,ms^{-1}$

$\cancel{784.8} \; 784.8 \cos 22 = 727.6539\,N$ $\qquad \theta = 22°$

horizontal

$F = \frac{mv^2}{r}$ $\qquad \frac{(80)(9^2)}{727.6539} = r = 8.905$

$\frac{mv^2}{F} = r$ $\qquad = 8.91\,m$

Radius = 8.91m

ResultsPlus
Examiner Comments

This candidate determines the weight and then does weight x cos θ. Also scores 1 mark.

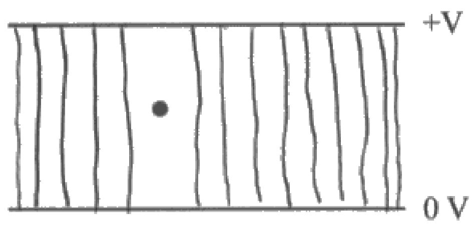
Question 17 (a)

Most candidates knew that the field pattern was vertical lines pointing downwards. A mark was often lost due to the quality of the drawings. The use of rulers would help some candidates. The most common error was that the lines were not equally spaced, the issue being that many wanted to avoid the position of the drop. This is a case of less is more. A minimum of three lines was required and it was usually the candidates who drew many more than three lines that lost the equispacing mark.

(a) The diagram shows one oil drop falling between the plates.

Add lines to the diagram to show the electric field between the plates.

(2)



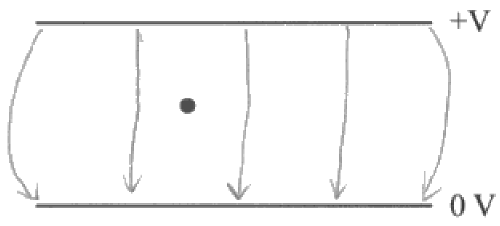
ResultsPlus
Examiner Comments

Arrows missing and an enormous gap around the oil drop. Scores zero.

(a) The diagram shows one oil drop falling between the plates.

Add lines to the diagram to show the electric field between the plates.

(2)



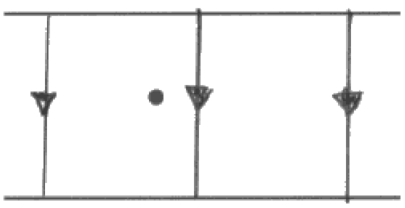
ResultsPlus
Examiner Comments

This was just acceptable for the central lines being straight and equispaced but none of the lines touch the bottom plate so scores one mark only for arrow direction.

(a) The diagram shows one oil drop falling between the plates.

Add lines to the diagram to show the electric field between the plates.

(2)



ResultsPlus
Examiner Comments

Model answer

ResultsPlus
Examiner Tip

A minimum of three lines is required for a uniform field and four lines for a radial field.

Question 17 (b)

This is AS work and was not as well answered as expected. Quite a few candidates missed the clue about stops falling and becomes stationary between the plates and so did not explain the forces. Many were unclear with their language and did not describe the upwards force as electric or electrostatic. Several candidates talked about attraction and repulsion rather than electrical force or upwards force. Many realised that the weight balanced the electrostatic force. Many incorrectly described the electrostatic force as equal to the weight rather than equal and opposite.

(b) V is gradually increased. At a particular value of V, the oil drop stops falling and remains stationary between the plates.

Explain this observation.

(2)

This occurs when the upwards force on the drop ~~is equal~~ from the electric field is equal to the weight of the drop.

ResultsPlus
Examiner Comments

An answer that scores both marks.

(b) V is gradually increased. At a particular value of V, the oil drop stops falling and remains stationary between the plates.

Explain this observation.

(2)

As $E = \frac{V}{d}$ and d is constant, increasing V will cause an increase in the electric field strength. As $E = \frac{F}{Q}$ and Q stays the same, the force increases as E increases, until the force is large enough to stop the drop falling.

ResultsPlus

Examiner Comments

This candidate eventually identifies an electric force but omits to say in which direction it acts. The question stated that the drop stops falling so there is no credit for rewording the stem. This scored zero.

ResultsPlus

Examiner Tip

Remember not to just quote what is given in the stem of the question.

Question 17 (c) (d)

These calcualtions were well done with over 60% of candidates scoring all six marks. Some candidates struggled with (c) because of the algebraic nature of the question but since this was a 'show that' they could use the 'show that' value in (d) and gain some credit here. The most common error in (d) was to either forget to square the separation *d* or to halve it since they assume the *r* in Faraday's equation is a radius and *d* is a diameter.

(c) The oil drop has mass m and charge Q and stops falling when $V = 5000$ V.

Show that $\frac{Q}{m}$ for this oil drop is about 50 μC kg^{-1}.

(3)

$d = 2.5$ cm

$E = \frac{V}{d} = \frac{5000}{0.025} = 20 \times 10^4 \ Vm^{-1}$ ~~$E = \frac{F}{Q}$~~

$E = \frac{F}{Q}$ $\quad EQ = ma \quad 20 \times 10^4 Q = ma$

$a = g$

$\frac{Q}{m} = \frac{a}{20 \times 10^4} \quad \frac{9.81}{20 \times 10^4} = 49.1 \times 10^{-6}$

$= 49.1 \mu C kg^{-1}$

(d) The oil drop is close to another oil drop that has the same charge and mass. The oil drops can be considered to act as point charges 2.2 mm apart.

Calculate the electrostatic force between the two drops.

mass of each drop = 1.0×10^{-13} kg

(3)

$F = \frac{k Q_1 Q_2}{r^2} \quad F = \frac{k Q^2}{r^2} \quad \frac{Q}{m} = 49.1 \times 10^{-6}$

$Q = 49.1 \times 10^{-6} \times 1 \times 10^{-13} = 4.91 \times 10^{-18}$

$F = \frac{8.99 \times 10^9 \times (4.9 \times 10^{-18})^2}{(2.2 \times 10^{-3})^2}$

$= 4.46 \times 10^{-20}$

Force between oil drops = 4.46×10^{-20} N

ResultsPlus
Examiner Comments

Model answer scoring all six marks.

(c) The oil drop has mass m and charge Q and stops falling when $V = 5000$ V.

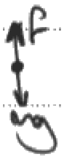
Show that $\frac{Q}{m}$ for this oil drop is about 50 μC kg^{-1}. **(3)**

$d = 2.5$ cm

$F = QE$ $E = \frac{V}{d}$ $F = \frac{QV}{d}$ $F = \frac{Q(5000)}{2.5} = $ ~~RA~~

$F = Q2000$

$F = EQ$

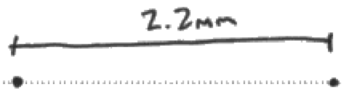


$E = \frac{V}{d} = \frac{5000}{2.5} = 2000$

(d) The oil drop is close to another oil drop that has the same charge and mass. The oil drops can be considered to act as point charges 2.2 mm apart.

Calculate the electrostatic force between the two drops.

mass of each drop = 1.0×10^{-13} kg **(3)**



$\frac{Q}{M} = 50 \times 10^{-6}$

$Q = (50\times10^{-6})(1\times10^{-13}) = 5\times10^{-18}$

$\frac{kQ_1Q_2}{r^2} = F$ $F = \frac{(5\times10^{-18})(5\times10^{-18})(8.99\times10^9)}{(2.2\times10^{-3})}$

$F = \frac{(5\times10^{-18})^2(8.99\times10^9)}{(2.2\times10^{-3})^2} = 4.64\times10^{-20}$ N

Force between oil drops = 4.64×10^{-20}

ResultsPlus
Examiner Comments

This candidate derives *F=VQ/d* but despite the lead from the earlier question parts does not equate this to weight. Scores 1 mark for (c) but successfully scores 3 marks in (d). Although the until is missing on the answer line, it is clearly written just above so all the marks can be awarded.

(c) The oil drop has mass m and charge Q and stops falling when $V = 5000$ V.

Show that $\frac{Q}{m}$ for this oil drop is about 50 μC kg⁻¹. $= 4.905 \times 10^{-5}$

$E = \frac{V}{d} = \frac{F}{Q}$ **(3)** $F = EQ$ $E = \frac{V}{d}$

$d = 2.5$ cm

$\frac{F}{Q} = \frac{5000}{0.025} = 200000$ $\frac{Q}{F} = 5 \times 10^{-6}$

$F = mg$ $\frac{Q}{m} = 5 \times 10^{-6} \times 9.81 = 4.905 \times 10^{-5} = 49.05\ \mu C kg^{-1}$

$\approx 50\ \mu C kg^{-1}$

(d) The oil drop is close to another oil drop that has the same charge and mass. The oil drops can be considered to act as point charges 2.2 mm apart.

$0.22 cm = 0.0022$

Calculate the electrostatic force between the two drops.

$0.22 cm = 0.0022$

mass of each drop = 1.0×10^{-13} kg

$2 cm = 0.002$

(3)

$F = k\frac{Q_1 Q_2}{r^2} = 8.99 \times 10^9 \times \frac{Q^2}{0.0022} = \frac{8.99 \times 10^9 \times (4.905 \times 10^{-5} \times 1 \times 10^{-13})^2}{0.0022}$

$= 9.8314 \times 10^{-23}$

Force between oil drops = 9.831×10^{-23} N

ResultsPlus
Examiner Comments

This is not so well laid out and takes a bit of working out but it is correct so scores 3 marks for (c). In (d) Q is correctly found but the 0.022 is not squared despite the equation being written correctly, so 1 mark only.

Question 17 (e)

There were four marking outcomes, 0, 1, 2 or 3 and each outcome was more or less equally achieved. Those who scored 2 usually lost a mark through lack of detail. The weaker candidates did not realise that the force between the oil drops was independent of the potential difference between the plates and answered in terms of the drops moving upwards and outwards. These candidates sometimes scored one mark if they identified that the vertical force increased.

(e) With reference to the forces acting on the drops, explain what would happen to the oil drops if V is increased above 5000 V.

(3)

The attractive forces from the positive charged plate ~~would overcome~~ acting upwards would overcome the force of the weight of the oil drop acting downwards and cause it to rise towards the positive plate.

ResultsPlus

Examiner Comments

There is no merit in saying that one force will overcome another force and 'rise upwards' could have been at a constant speed so there is no credit in this answer.

(e) With reference to the forces acting on the drops, explain what would happen to the oil drops if V is increased above 5000 V.

(3)

Increase in V → increase in E as $E = \frac{V}{d}$.
→ increase in F as $E = \frac{F}{Q}$. Force on both would increase. As $F = \frac{kQ^2}{r^2}$,
r would decrease as force increased, so they would get closer together.

ResultsPlus

Examiner Comments

In the first line the candidate identifies, by referring to $E=V/d$, that the electric force increases so scores one mark. However this candidate thinks that this is also the force between the drops so there is no more credit.

Question 18 (a)

Another straightforward calculation where 72% of the candidates scored both marks. All that was needed was to divide the energy given by the value of *e.*

18 In his theory of special relativity, Einstein proposed that it is impossible for particles to travel faster than the speed of light.

In 1964 the physicist William Bertozzi performed an experiment to test Einstein's theory. Electrons were accelerated from rest through a potential difference (p.d.) and their kinetic energy was determined.

The electrons then travelled through a tube 8.4 m long and the time taken to travel this distance was measured. The speed of the electrons in the tube was then calculated.

The table shows results based on Bertozzi's experiment.

Kinetic energy of electron / 10^{-13} J	Speed of electron / 10^{8} m s^{-1}
0.8	2.60
1.6	2.73
2.8	2.89
4.8	2.95
7.2	2.96

(a) Calculate the p.d. needed to accelerate an electron from rest if it gains a kinetic energy of 7.2×10^{-13} J.

(2)

$Vq = 7.2 \times 10^{-13}$

$V = \dfrac{7.2 \times 10^{-13}}{1.6 \times 10^{-19}} = 4500000$

p.d. = 4.5×10^{6} V

ResultsPlus

Examiner Comments

Model answer

18 In his theory of special relativity, Einstein proposed that it is impossible for particles to travel faster than the speed of light.

In 1964 the physicist William Bertozzi performed an experiment to test Einstein's theory. Electrons were accelerated from rest through a potential difference (p.d.) and their kinetic energy was determined.

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4.8	2.95
7.2	2.96

(a) Calculate the p.d. needed to accelerate an electron from rest if it gains a kinetic energy of 7.2×10^{-13} J.

(2)

$E = QV \qquad 7.2 \times 10^{-13} = 1.6 \times 10^{-19} \times V$

$V = 4500000$

p.d. = 4.5×10^{6}

ResultsPlus
Examiner Comments

This answer scored 1 not gaining the 2nd mark because the unit is missing.

ResultsPlus
Examiner Tip

Remember units.

18 In his theory of special relativity, Einstein proposed that it is impossible for particles to travel faster than the speed of light.

In 1964 the physicist William Bertozzi performed an experiment to test Einstein's theory. Electrons were accelerated from rest through a potential difference (p.d.) and their kinetic energy was determined.

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(a) Calculate the p.d. needed to accelerate an electron from rest if it gains a kinetic energy of 7.2×10^{-13} J.

(2)

$E = V/d$

$7.2 \times 10^{-13} = V/d$

$V = 7.2 \times 10^{-13} \times 8.4$

$= 6.05 \times 10^{-12}$ V (3sf)

p.d. = 6.05×10^{-12} V

ResultsPlus
Examiner Comments

Not all of the data has to be used. This candidate thinks that the 8.4 m length has to be used.

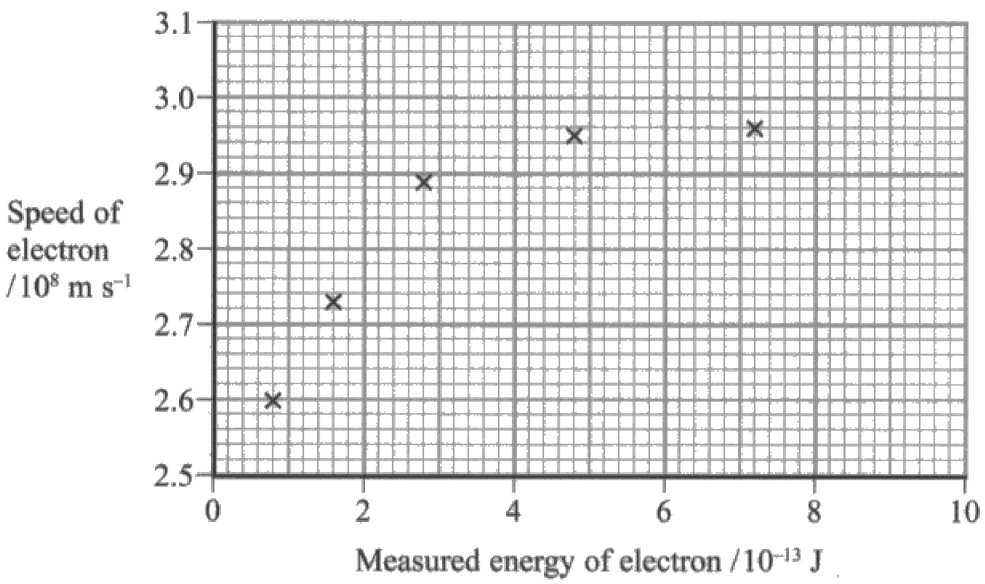
ResultsPlus
Examiner Tip

At this level sometimes a decison has to be made about what data to use.

Question 18 (b)

The common error here was not to draw the graph. The data points were plotted for the candidates but they needed to complete the graph in order to comment on it. MP2 was for commenting on the graph and not just referring to the data. For example saying that the speed never reaches *c* could be stated for the data table and does not refer to the graph so no credit was given.

(b) The results are plotted on the graph below.



Use the graph to verify that Bertozzi's experiment supports Einstein's theory.

(2)

As the energy of the electrons increase, the speed of the electron increases at a decreasing rate.

∴ As the speed of the electron goes towards the speed of light, the rate at which the speed increases, decreases. ∴ the speed of light is never reached.

1

ResultsPlus

Examiner Comments

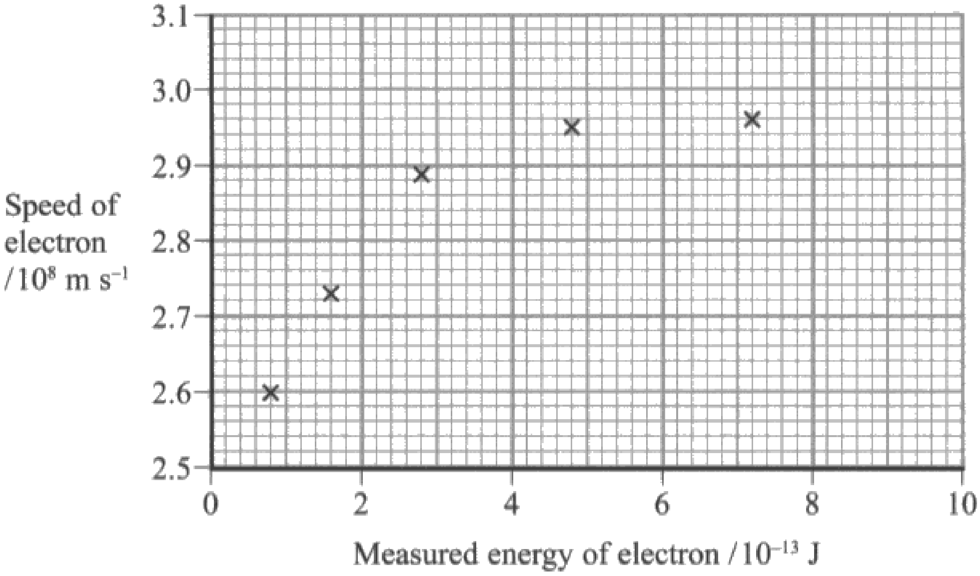
No line added and no comment about the line so no marks.

ResultsPlus

Examiner Tip

It is difficult to comment on a graph if a line of best fit hasn't been added.

(b) The results are plotted on the graph below.



Use the graph to verify that Bertozzi's experiment supports Einstein's theory.

(2)

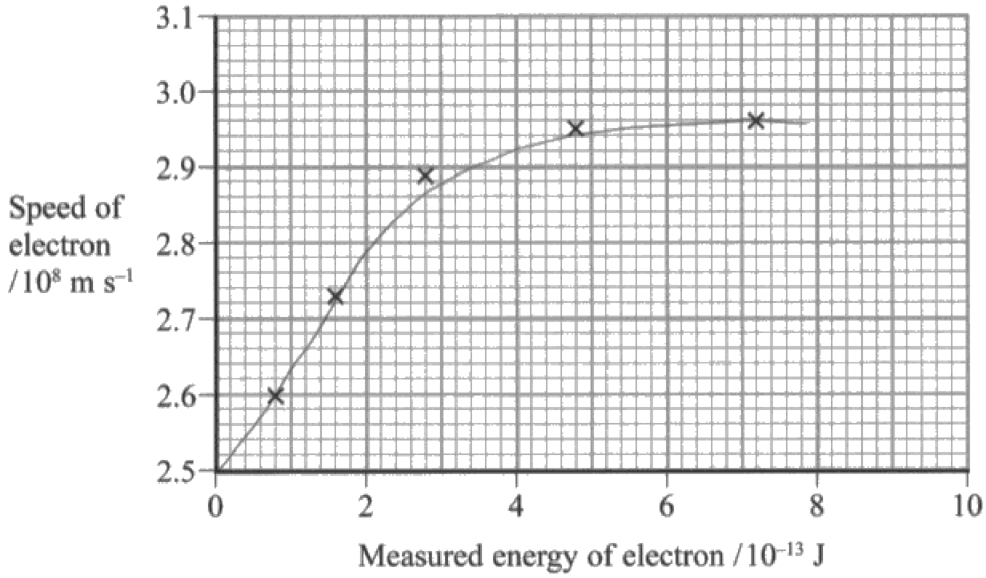
The speed steadily increases until it comes to just under the speed of light 3×10^8 and it then starts to flatten to a horizontal line.

ResultsPlus

Examiner Comments

Although the line hasn't been drawn the comment refers to flatten to a horizontal line so this scored 1 mark.

(b) The results are plotted on the graph below.



Use the graph to verify that Bertozzi's experiment supports Einstein's theory.

(2)

The graph plateus off before the speed of electrons reaches 3×10^8 ms^{-1} even though the electrons are being given more kinetic energy.

ResultsPlus
Examiner Comments

An answer that scores both marks.

Question 18 (c)

Most candidates were able to state that as the speed approached the speed of light the mass of the electrons increased. *Quoting* $E = mc^2$ was not sufficient for MP1. For MP2 we were looking for a statement that the Newtonian equation ½m v^2 could not be used or that realistic equations should be used. Since these equations are beyond the scope of the specification, MP2 was allowed when some candidates knew them, even though they were not strictly accurate saying $E = mc^2$ should be used.

(c) A student uses the equation $E_k = \frac{1}{2}mv^2$ and information from the data at the back of this paper to calculate values for the kinetic energy of the electrons in this experiment. When he compares his correctly calculated values with the measured values in the table, they are **not** the same. Explain why.

(2)

When particles ~~experience~~ travel close to the speed of light they experience relativistic effect which are explained by $E=mc^2$. The particles begin to gain energy in the form of mass rather than speed. So ~~even~~ even though E is increasing ~~and would~~ the particle will never go beyond the speed of light, instead it would gain mass.

ResultsPlus
Examiner Comments

MP1 only for the increase in mass.

(c) A student uses the equation $E_k = \frac{1}{2}mv^2$ and information from the data at the back of this paper to calculate values for the kinetic energy of the electrons in this experiment. When he compares his correctly calculated values with the measured values in the table, they are **not** the same. Explain why.

(2)

The electrons gain mass as the speed approaches the speed of light, so the measured values are greater than the calculated values

ResultsPlus
Examiner Tip

Another example that scores 1 mark.

(c) A student uses the equation $E_k = \frac{1}{2}mv^2$ and information from the data at the back of this paper to calculate values for the kinetic energy of the electrons in this experiment. When he compares his correctly calculated values with the measured values in the table, they are **not** the same. Explain why.

(2)

At speeds ~~close~~ close to the speed of light relativistic effects occur, which means the electrons gain mass rather than kinetic energy so their usual mass cannot be used in $\frac{1}{2}mv^2$. $E=mc^2$ must be used instead.

ResultsPlus
Examiner Comments

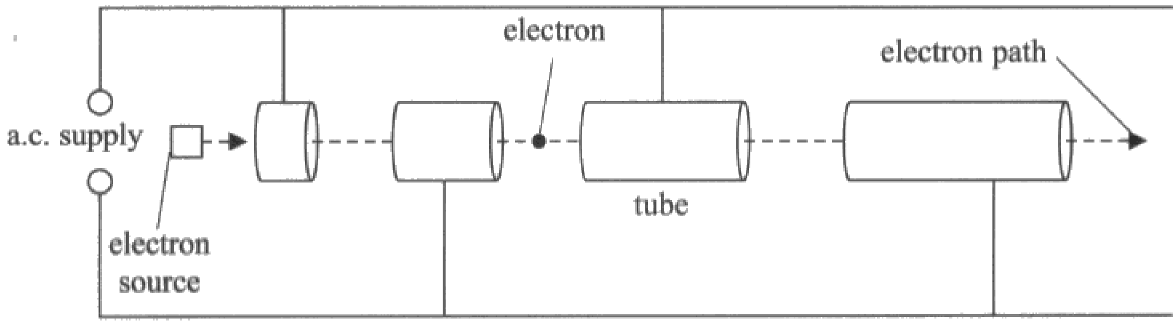
This scores 2 marks. MP2 could have been awarded for either not using the KE equation or for saying the mass energy equation should be used.

Question 18 (d)

(i) Most candidates were able to explain why the tubes increased in length scoring one mark. This was usually accompanied by a statement that this allowed the frequency to be constant which was insufficient since it is the constant frequency that means the tubes have to become longer. Very few were able to explain that the increase in length was to allow the polarity of the tubes to switch at constant time intervals.

(ii) Most candidates appreciated that the speed was now constant though many said that the particles were no longer accelerating. This did not get across the point of why the tubes needed to be the same length and so was not given any credit.

(d) Bertozzi used an early type of linac to accelerate the electrons in his experiment. The diagram shows the essential structure of a modern linac.



In the first part of the accelerator the drift tubes gradually increase in length, but at the end of the accelerator, the tubes are of the same length.

(i) Explain why the tubes gradually increase in length in the first part of the accelerator. **(2)**

This is so that as the electron speeds up it will still spend the same amount of time in each tube so that frequency can be kept constant.

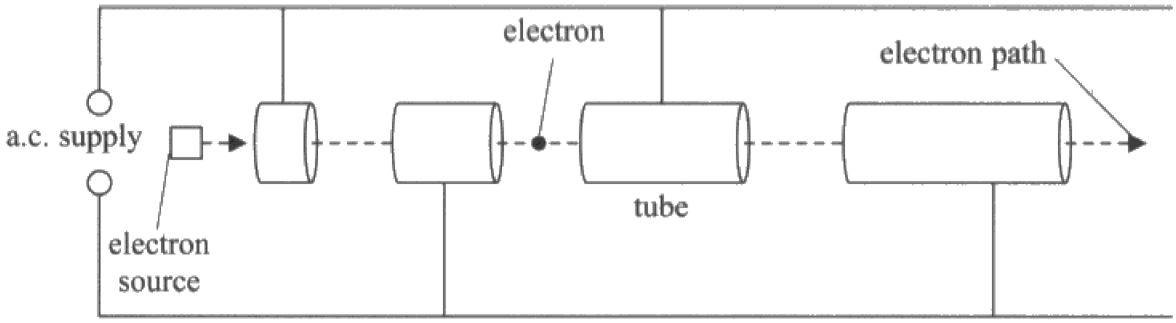
(ii) State why the tubes are the same length at the end of the accelerator. **(1)**

The linac is no longer accelerating the electron, it is just keeping it at the same speed.

ResultsPlus
Examiner Comments

The most common answer scoring 1 for each section.

(d) Bertozzi used an early type of linac to accelerate the electrons in his experiment. The diagram shows the essential structure of a modern linac.



In the first part of the accelerator the drift tubes gradually increase in length, but at the end of the accelerator, the tubes are of the same length.

(i) Explain why the tubes gradually increase in length in the first part of the accelerator. **(2)**

So in each tube, the particles takes the same amount of time to get through as speed increases. So in order to be not out of step with the frequency of the alternating voltage

(ii) State why the tubes are the same length at the end of the accelerator. **(1)**

The ~~speed~~ particles attain its maximum speed

ResultsPlus
Examiner Comments

This was sufficient to convey the idea of the changing polarity so scored 2 marks for (i) and 1 mark for (ii).

Paper Summary

This paper provided candidates with a wide range of contexts from which their knowledge and understanding of the physics contained within this unit could be tested. A sound knowledge of the subject was evident for many but sometimes the responses seen did not reflect this as the language lacked precision and its ambiguity prevented some marks from being awarded.

Based on their performance on this paper, candidates are offered the following advice:

- slow down during the multiple choice items so that key words in the command sentence responses are not missed.
- remember to check responses if there is time at the end of the paper in case careless mistakes have been made, especially powers of 10 or missing units.
- learn accurate definitions of all terms given in italics in the specification.
- practise drawing electric field patterns and always use a ruler for the best results.
- read the question and answer exactly what is being asked.

Grade Boundaries

Grade boundaries for this, and all other papers, can be found on the website on this link:

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