Examiners' Report
June 2024

IAL Physics WPH14 01

Introduction

The assessment structure of Unit 4: Further Mechanics, Fields and Particles is the same as that of Units 1, 2 and 5, consisting of Section A with ten multiple choice questions, and Section B with a number of short answer questions followed by some longer, structured questions based on contexts of varying familiarity.

This paper allowed candidates of all abilities to demonstrate their knowledge and understanding of Physics by applying them to a range of contexts with differing levels of familiarity.

Candidates at the lower end of the range could complete calculations involving simple substitution and limited rearrangement, including short structured series of calculations, but could not always tackle calculations involving several steps or other complications, such as using radius when diameter was provided in the data, using the change in potential to approach one body as well as the change in potential to leave another. They also knew some significant points in explanations linked to standard situations, such as electromagnetic induction and linacs, and could generally set out their ideas in a logical sequence, but could not always identify which points were most relevant for a particular context, even when it was a familiar one. There was also a lack of specific detail in answers, such as stating constant ac rather than constant ac frequency.

Steady improvement was demonstrated in all of these areas through the range of increasing ability and at the higher end all calculations were completed faultlessly, with most points included in ordered explanations of the situations in the questions.

Section A

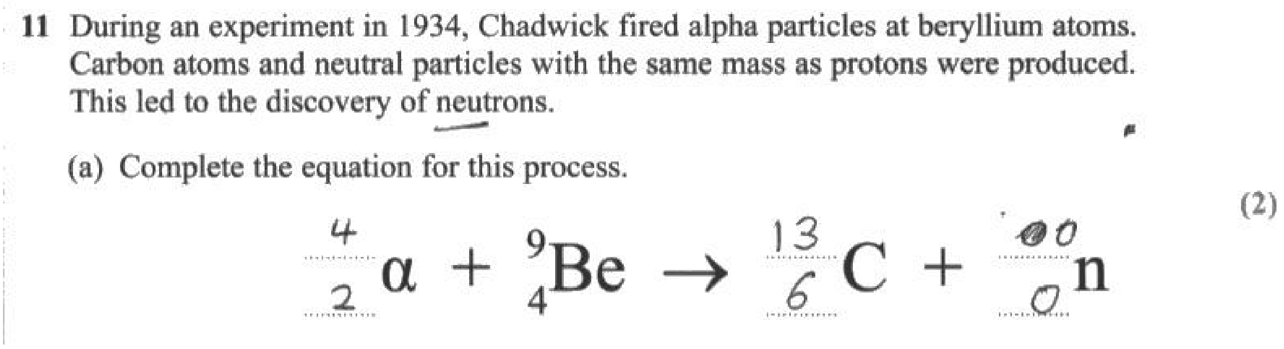
The percentages for those with correct multiple choice question responses are shown in the table.

Question	Percentage of correct responses
1	65
2	67
3	77
4	96
5	21
6	67
7	90
8	91
9	82
10	57

More details on the rationale behind the incorrect answers for each multiple-choice question can be found in the published mark scheme.

Question 11 (a)

The great majority of candidates completed this nuclear equation correctly for 2 marks. Some got the proton number and nucleon number the wrong way round for the neutron but balanced the numbers along the top correctly to get 4, (9), 13, 0. A few candidates didn't know the numbers for the alpha particle.



11 During an experiment in 1934, Chadwick fired alpha particles at beryllium atoms. Carbon atoms and neutral particles with the same mass as protons were produced. This led to the discovery of neutrons.

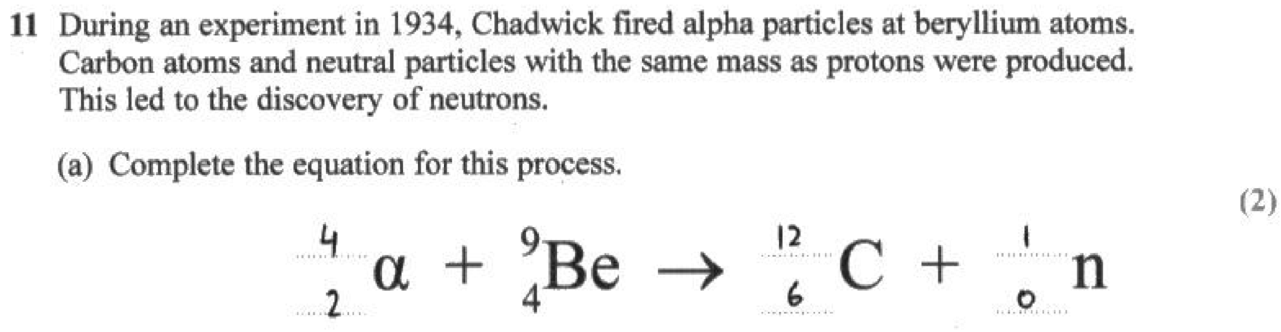
(a) Complete the equation for this process.

(2)

$${}^{4}_{2}\alpha + {}^{9}_{4}\mathrm{Be} \rightarrow {}^{13}_{6}\mathrm{C} + {}^{\cancel{0}0}_{0}\mathrm{n}$$

ResultsPlus
Examiner Comments

Here the neutron has been incorrectly assigned zero for both proton and nucleon numbers. The candidate has kept the totals equal on each side of the equation and has still been awarded the mark for proton numbers.



11 During an experiment in 1934, Chadwick fired alpha particles at beryllium atoms. Carbon atoms and neutral particles with the same mass as protons were produced. This led to the discovery of neutrons.

(a) Complete the equation for this process.

(2)

$${}^{4}_{2}\alpha + {}^{9}_{4}\mathrm{Be} \rightarrow {}^{12}_{6}\mathrm{C} + {}^{1}_{0}\mathrm{n}$$

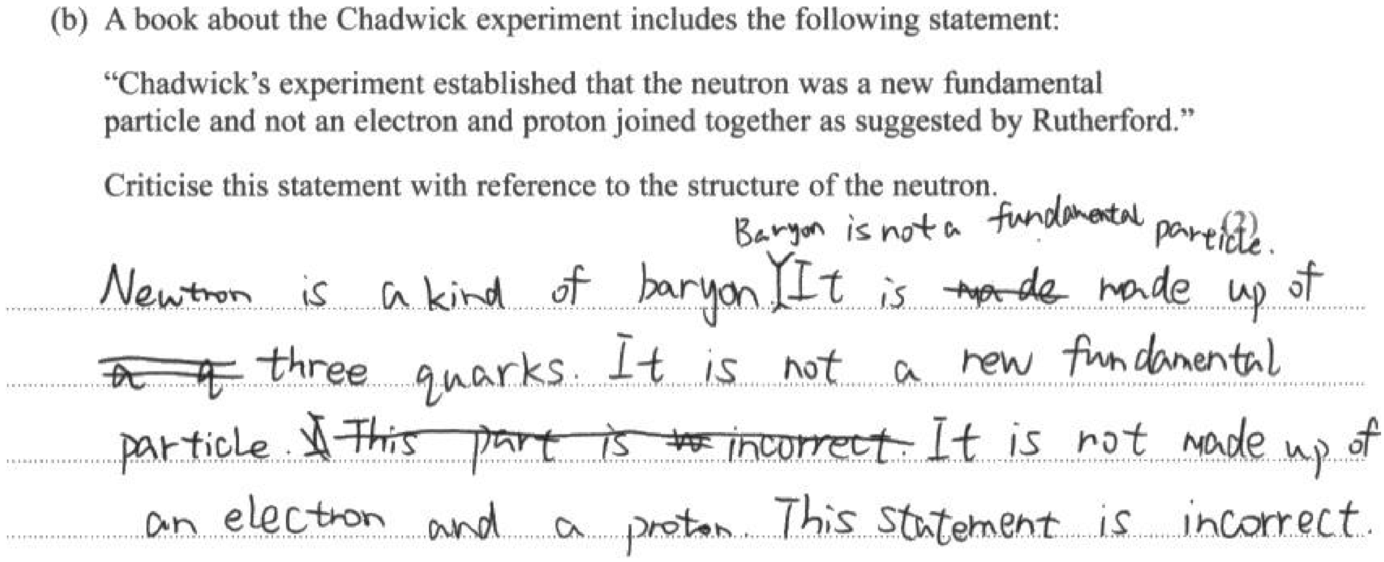
ResultsPlus
Examiner Comments

This is a typical fully correct answer.

Question 11 (b)

A good majority of candidates gained both marks here, nearly always from the first two of the three available marking points, stating that a neutron is not fundamental and that it is made of quarks, rather than commenting on the accuracy or inaccuracy of Rutherford's statement. A few candidates stated that a neutron could be made of an electron and a proton because the charge would be neutral. A minority of candidates were not awarded the second marking point because they used letters only to indicate neutron substructure, eg writing *qqq* or *ddu* without use of the word 'quark'.

Those candidates that commented on the statement often stated either that it was true or that it was false without specifying which part. As the first part was true and the second part false, this gained no credit.



(b) A book about the Chadwick experiment includes the following statement:

"Chadwick's experiment established that the neutron was a new fundamental particle and not an electron and proton joined together as suggested by Rutherford."

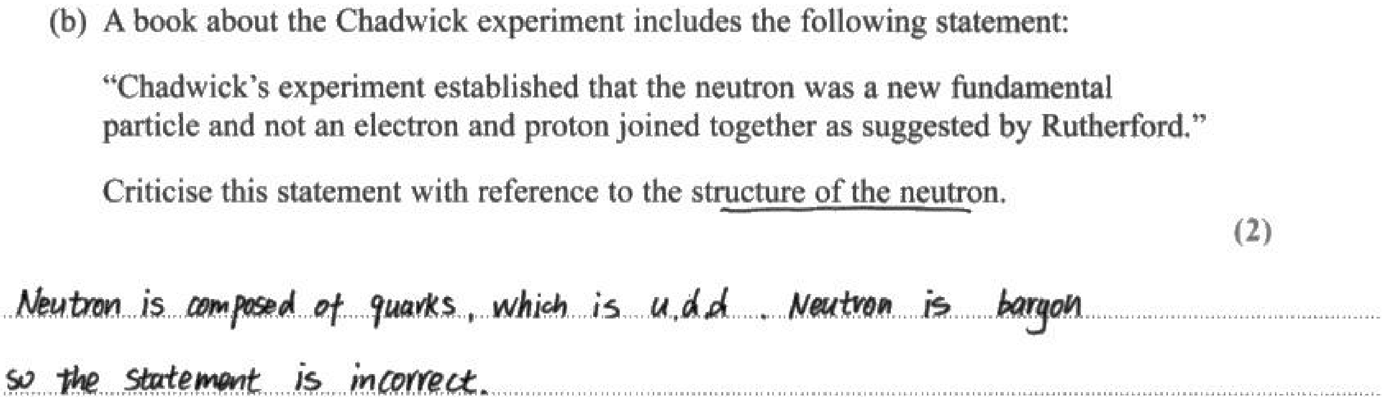
Criticise this statement with reference to the structure of the neutron.

(2)

Newtron is a kind of baryon. Baryon is not a fundamental particle. It is ~~made~~ made up of ~~a q~~ three quarks. It is not a new fundamental particle. ~~I This part is incorrect~~. It is not made up of an electron and a proton. This statement is incorrect.

ResultsPlus
Examiner Comments

Here the candidate gains marking points one and two for the first two lines. Lines 3 and 4 are ambiguous because it isn't clear that they know which part of the statement is incorrect, but this part doesn't contradict the two correct points they have already made.



(b) A book about the Chadwick experiment includes the following statement:

"Chadwick's experiment established that the neutron was a new fundamental particle and not an electron and proton joined together as suggested by Rutherford."

Criticise this statement with reference to the structure of the neutron.

(2)

Neutron is composed of quarks, which is u.d.d . Neutron is baryon so the statement is incorrect.

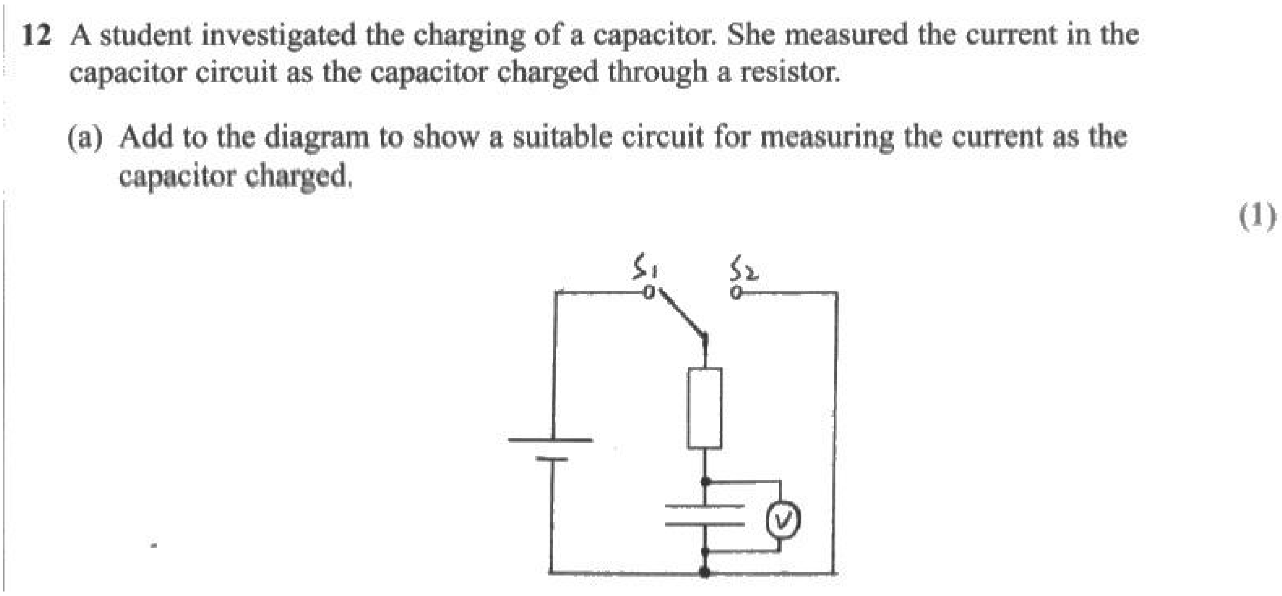
ResultsPlus

Examiner Comments

This gets 1 mark for outlining the quark structure. It says the statement is incorrect, but is not clear about which part. If anything, this answer supports the second part of the statement.

Question 12 (a)

About two thirds of candidates gained the mark for this simple circuit. A fair number omitted either the cell or ammeter and some candidates connected the ammeter in parallel when it should have been in series. Some circuits included a voltmeter as well as the required ammeter, but the additional voltmeter was sometimes in series, which would prevent a current. Some candidates went beyond the requirements of the question, showing a circuit that could be used to charge and then discharge, but they did not always put the ammeter in the correct branch.



12 A student investigated the charging of a capacitor. She measured the current in the capacitor circuit as the capacitor charged through a resistor.

(a) Add to the diagram to show a suitable circuit for measuring the current as the capacitor charged.

(1)

ResultsPlus
Examiner Comments

The question asks for a circuit to measure current while charging, but this circuit is suitable for measuring p.d. while discharging.

ResultsPlus
Examiner Tip

Read the question carefully so your answer is about what is asked and not about a similar thing you have revised from past papers.

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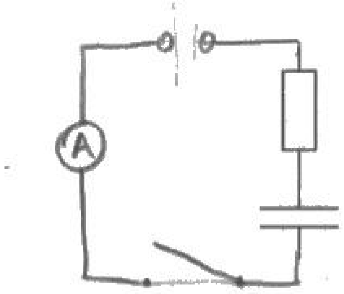
(a) Add to the diagram to show a suitable circuit for measuring the current as the capacitor charged.

(1)



ResultsPlus
Examiner Comments

Here we can see the terminals of a power supply, but without an indication as to whether it is DC, ie a plus and a minus, or AC. There is also the faint outline of a cell. It is not for the examiner to decide what a candidate means when it is left ambiguous.

Question 12 (b)(i)-(iii)

The overall performance on this set of calculations on a relatively familiar context was very good, with approaching half of the candidates gaining the full 8 marks.

In part (b)(i), candidates were evenly divided between those using the time constant approach and those substituting values into the decay equation. A number of candidates had problems reading values from the graph correctly because they assigned incorrect values to the minor divisions, usually because they looked at the scale value below the one they were reading but not the next value. For example, 90 s would be read as 78 s, using a division of 1 s rather than 5 s. Some candidates went wrong by transposing their values for I and I_0 when using the formula.

A few candidates did not appreciate that the formulae for current for charging and discharging both involve a decay form only and attempted to use a current version of the charging formula for p.d. or charge. Some candidates tried to calculate charge from the graph, eg by using the area under the graph, and using it in $C = Q/V$.

A few candidates used an approximation that a capacitor may be considered as fully charged after approximately 5 times the time constant. This was not accepted as a satisfactory method, although they could still get the second marking point for use of the value.

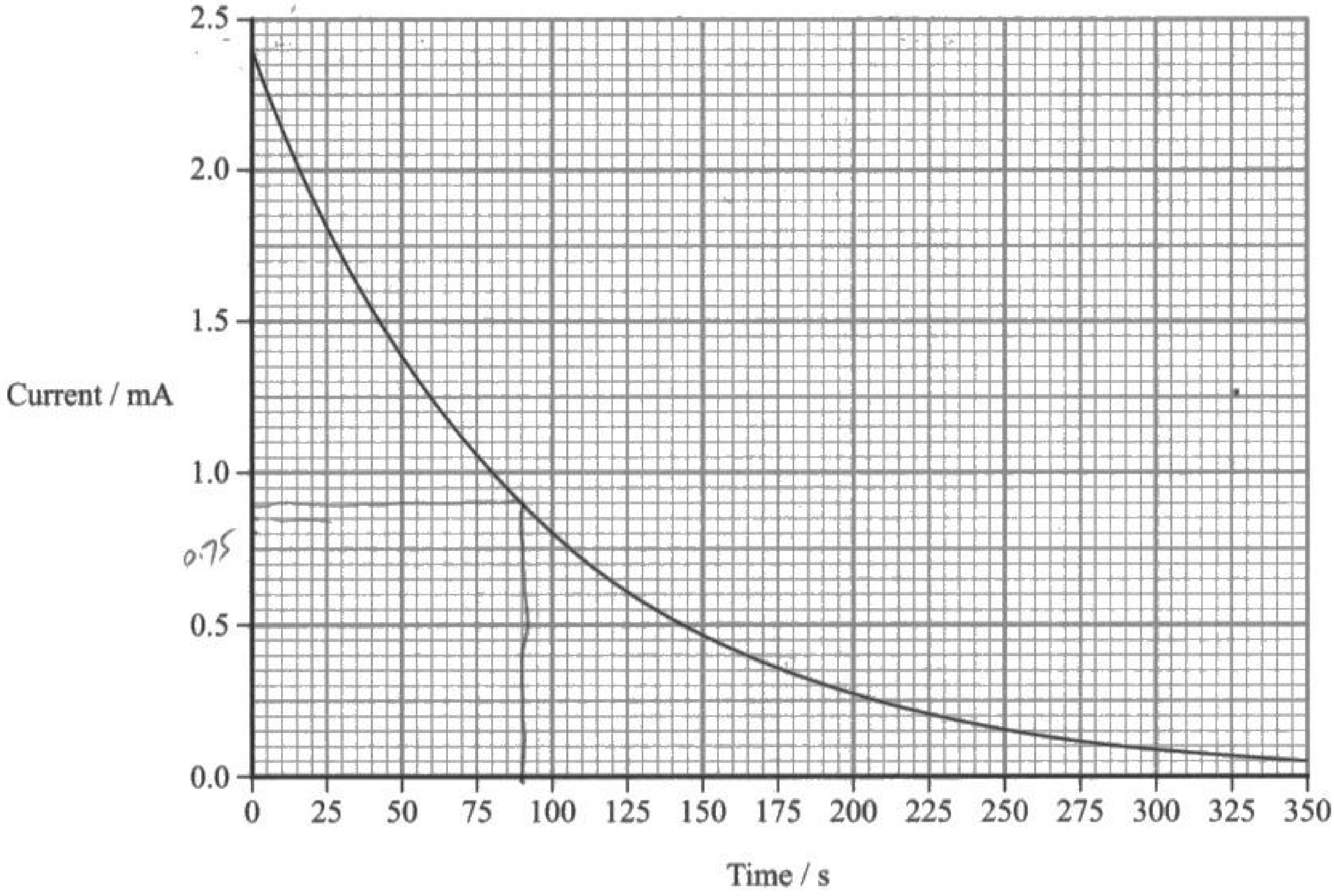
In part (b)(ii), the most common error was using the current value at 250 s, rather than the maximum current value, to calculate the p.d. when fully charged, presumably because they weren't thinking in terms of the initial current being when the p.d. across the capacitor was zero.

Power of ten errors with mA made a difference in part (ii), whereas they cancelled out in part (b)(i) and still allowed the correct answer for capacitance.

A number of candidates omitted the final unit for charge or gave it as Q.

In part (b)(iii) some candidates used $W = QV$, without ½, and some used a correct form with capacitance and p.d. but forgot to square p.d. in their calculation. Some candidates got the symbol C for capacitance mixed up with C for coulomb and used the wrong value in their calculation.

(b) The graph shows how the current in the circuit varied with time as the capacitor charged.



(i) The resistance of the resistor is 5.1 kΩ.

Show that the capacitance of the capacitor is about 0.02 F.

(3)

The capacitor is charged,

when $t = RC$, $I = I_0 \times e^{-1} = 37\% I_0$

$I_0 = 2.4mA$ read from the graph

so $I = 0.888mA$ $t = 80s$ read from the graph

so $RC = 80s$

$c = \frac{80}{5.1 \times 10^3} = 0.015686 F \approx 0.02F$

(ii) Calculate the charge on the capacitor when it is fully charged.

(3)

as $C = \frac{Q}{V}$

$Q = CV$ $V_0 = IR = 2.4mA \times 5.1 \times 10^3 \Omega = 12.24V$

so $Q = 0.015686 \times 12.24$

$= 0.192$ c

Charge = 0.192 c

(iii) Calculate the energy stored by the capacitor when it is fully charged.

(2)

$W = \frac{1}{2} C V^2$

$= \frac{1}{2} \times 0.015686 \times (12.24)^2$

$= 1.175$ J

Energy = 1.17J J

ResultsPlus
Examiner Comments

In part (b)(i) the method is correct, using the time constant method, but there has been a scale error reading from the graph. The candidate has looked at 100 s and gone two spaces back, but counted each of them as 10 s, arriving at 80 s rather than 90 s.

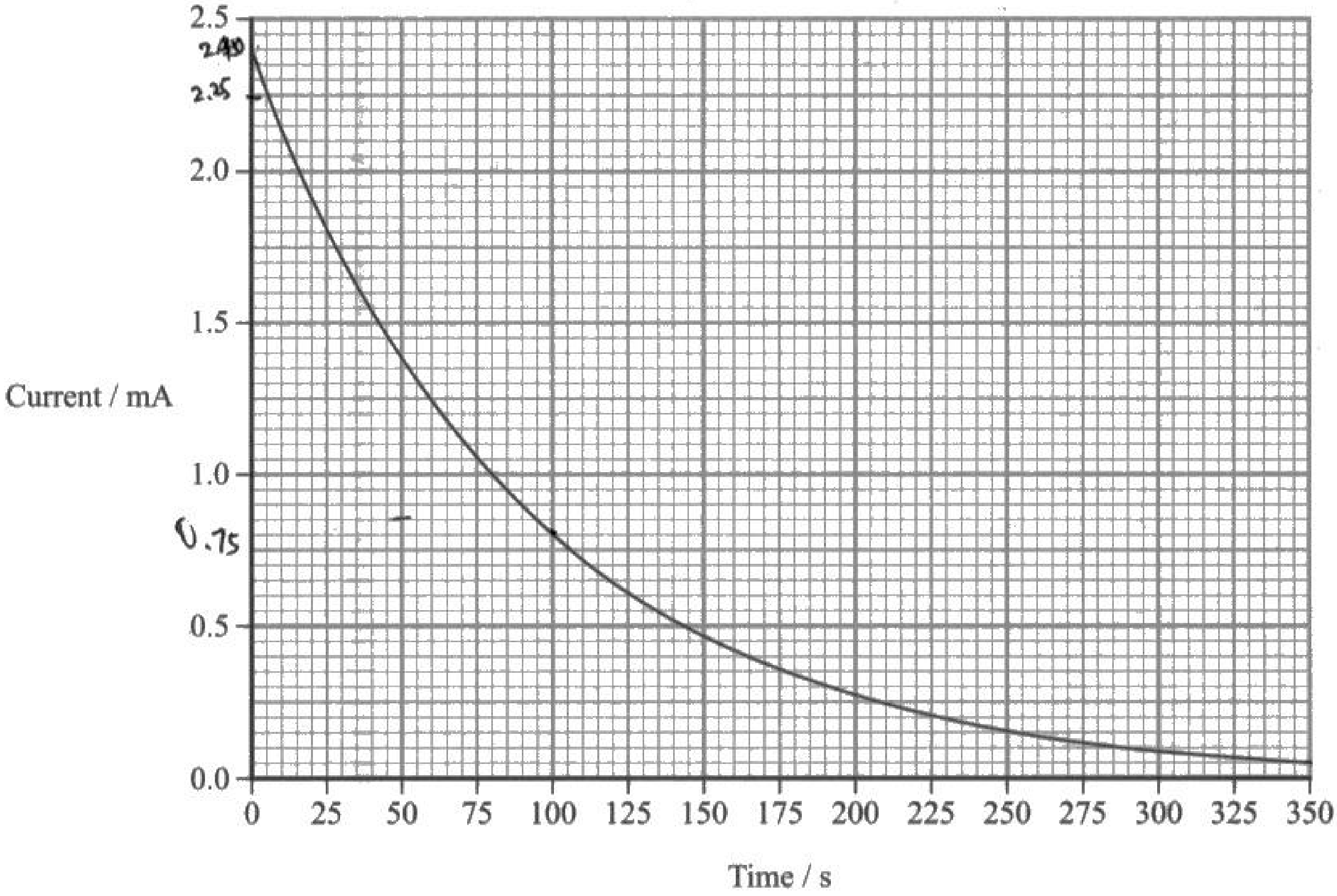
2 marks are awarded for the method, but the answer is out of the accepted range, so no third mark.

Parts (b)(ii) and (b)(iii) are completed fully with ecf for the incorrect value of capacitance.

ResultsPlus
Examiner Tip

When reading from graphs, be sure to check the scale on either side of your point to avoid interpolation errors.

(b) The graph shows how the current in the circuit varied with time as the capacitor charged.



(i) The resistance of the resistor is 5.1 kΩ.

Show that the capacitance of the capacitor is about 0.02 F.

(3)

~~$Q = Q_0 e$~~ $I = I_0 e^{-\frac{t}{RC}}$

I ~~Q~~$_0$ = 2.4mA When ~~Q~~ I = 0.8 mA, t = 100 s.

$\frac{0.8}{2.4} = e^{-\frac{100}{5.1\times1000\times C}}$

$\ln\frac{0.8}{2.4} = -\frac{100}{5.1\times1000C}$, $C = 0.018\text{ F} = 0.02\text{F}$

(ii) Calculate the charge on the capacitor when it is fully charged.

(3)

When full charge: current ≈ 0.05mA

$R = \frac{V}{I}$, $V = IR$ $V = 5.1\times1000\times0.05\times10^{-3}$

$= 0.255\text{ V}$

$Q = CV = 0.255 \times 0.018\text{ F} = 4.6\times10^{-3}\text{C}$

Charge = 4.6×10^{-3}C

(iii) Calculate the energy stored by the capacitor when it is fully charged.

(2)

~~$W = \frac{1}{2}CV^2 = \frac{1}{2}\cdot 4.6\times10^{-3}\cdot 0$~~

$W = \frac{1}{2}QV = \frac{1}{2}\cdot 4.6\times10^{-3}\cdot 0.255 = 5.865\times10^{-4}\text{J}$

Energy = 5.87×10^{-4} J

ResultsPlus
Examiner Comments

Part (b)(i) is fully correct, using the formula for exponential decrease of the current.

In part (b)(ii) the current at 350 s has been used to calculate the p.d. when charged, whereas the initial current should have been used. This means that the first mark cannot be awarded. The correct method is used for calculating charge, but the answer is incorrect, so there is 1 mark for part (b)(ii).

Part (b)(iii) is completed correctly with ecf for the incorrect capacitance.

Question 13 (a)

While most candidates were able to calculate the angle or the sine of the angle straightforwardly, some used 30 cm as the base of their triangle and incorrectly applied the tangent of the angle. Very few candidates did not apply $W = mg$ correctly.

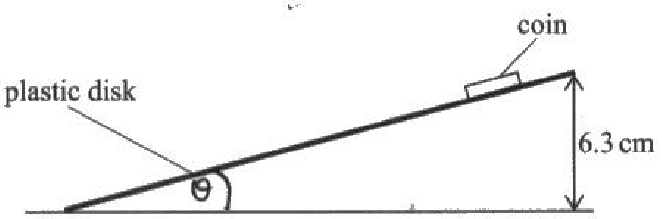
A significant minority of candidates could not apply trigonometry correctly to the forces, for example thinking that weight was equal to a component of the normal contact force rather than the reverse. Candidates should realise that the sum of normal contact force and frictional force is equal and opposite to weight so that weight is the hypotenuse of the force triangle. Weight must therefore be the largest of the three forces, so will be multiplied by the cosine and sine respectively and not divided by them.

Some candidates mistakenly attempted to apply centripetal force at this stage before it was relevant.

13 A student investigated the forces involved in circular motion, using a coin placed on a plastic disk.

The mass of the coin was 8.8 g. The diameter of the disk was 30 cm.

(a) The student determined the maximum frictional force between the coin and the disk by tilting the disk, as shown.



Not to scale

The edge was raised by 6.3 cm before the coin started to slide.

Show that the maximum frictional force was about 0.02 N.

(4)

$m = 8.8 g$

$W = (8.8 \times 10^{-3})(9.81)$

$= 0 86328 N$

$\sin \theta = \frac{(6.3 \times 10^{-2})}{(30 \times 10^{-2})}$

$\theta = \sin^{-1}\left(\frac{6.3}{30}\right)$

$\approx 12.122°$

$\sin 12.122 = \frac{0.86328}{F}$

$F = \frac{0.86328}{\sin 12.122}$

ResultsPlus
Examiner Comments

The sine of the angle has been used correctly and the angle calculated. *W* = *mg* has also been used correctly. Following this however, weight has been treated as equal to a component of the frictional force rather than the reverse. A free-body force diagram would have made this clear.

ResultsPlus
Examiner Tip

Using a free body force diagram doesn't take much time and can help to clarify a situation.

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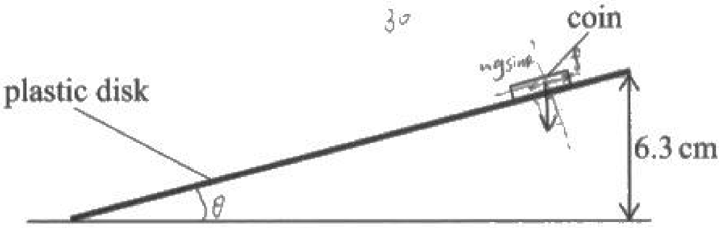

Not to scale

The edge was raised by 6.3 cm before the coin started to slide. $\frac{6.3}{30}$

Show that the maximum frictional force was about 0.02 N.

(4)

$\theta = \sin^{-1}\left(\frac{6.3}{30}\right) = 12.1°$

$mg\sin\theta = F_{max}$

$F_{max} = 8.8 \times 10^{-3} \times 9.81 \times \sin(12.1°) = 0.0181\,N$

ResultsPlus
Examiner Comments

This is an example of a correct solution with enough steps visible to satisfy the requirement to 'show that' and the required extra significant figure has been included for full marks.

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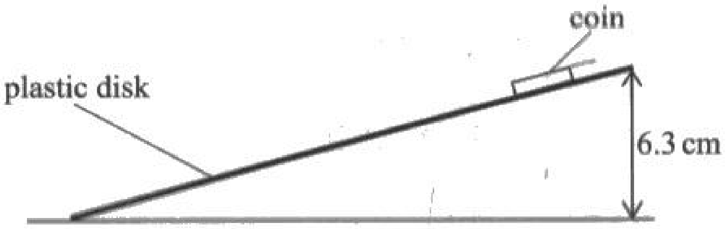


Not to scale

The edge was raised by 6.3 cm before the coin started to slide.

Show that the maximum frictional force was about 0.02 N.

(4)

$f = \frac{6.3}{\cancel{15}30} \times 8.8\times10^{-3} \times 9.81$

~~$= 0.036 \approx 0.02N$~~

$= 0.0181 \approx 0.02N$

ResultsPlus
Examiner Comments

This is a correct answer by a visibly correct method, but it has been done as a single calculation. This is fine when it is correct, but a single error can lead to zero marks whereas showing the steps and arriving at an incorrect answer can lead to most of the marks still being awarded.

ResultsPlus
Examiner Tip

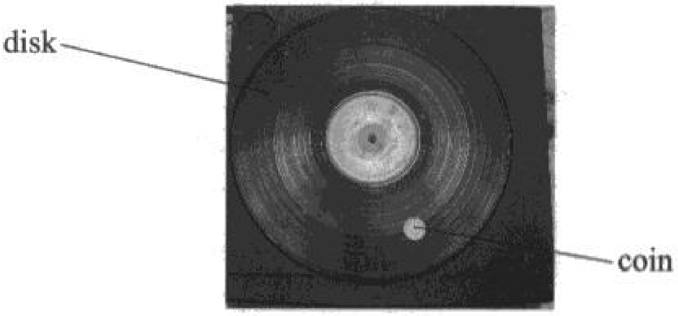
Show a sufficient number of steps in your calculations, especially when the question requires you to 'show that' a certain value is correct.

Question 13 (b)(i)-(ii)

In part (b)(i), most candidates were able to calculate angular velocity, but there were a few recurring errors. The unit was sometimes stated as metres per second, or even degrees per second. Some candidates applied 60/45 the wrong way up and effectively divided 2 pi by the frequency rather than the period. Some candidates did not complete the calculation and gave their answer as 1.5 pi or even 3 pi / 2. This is not acceptable as answers should be given as decimal fractions with few exceptions, such as fractional charge for quarks and for phase relationships.

In part (b)(ii), most candidates were able to apply the centripetal force equation, some using the force to calculate the radius of the path and some using radius to calculate force. Even so, candidates often only got 1 mark out of 3 because a deduce question such as this requires a clear comparison of values and a statement in conclusion, not just the calculation of a value. It was more difficult when they did not understand the significance of 5 cm being the distance to the edge. For example, many candidates calculated a radius of 10 cm and said it was unsuitable as it was greater than 5 cm. Others calculated force using a radius of 5 cm and obtained a force of half the required value. Some candidates confused diameter with radius and used 25 cm instead of 10 cm.

(b) The student placed the disk on a horizontal turntable and placed the coin on the disk, as shown below.



View from above

The disk rotated at 45 revolutions per minute.

(i) Calculate the angular velocity of the disk.

(2)

$\omega = \frac{45 \times 2\pi}{60} = 1.5\pi \text{ rad s}^{-1}$

Angular velocity = ...

(ii) When the student placed the coin near the centre of the disk, the coin remained in position and rotated with the disk.

When the student placed the coin at the edge of the disk, the coin slid off the rotating disk.

The student estimated that the closest the coin could be to the edge of the disk without sliding off was about 5 cm.

Deduce whether this was a suitable estimate.

You should assume that the maximum frictional force is 0.02 N.

(3)

$F = mr\omega^2 = 8.8\times10^{-3} \times r \times (1.5\pi)^2 = 0.02\,N$

$r = 0.102$ m

~~0.102 cos(90 − θ) = 6.3/30~~

~~θ = 12.12°~~

~~0.102 = sin θ 12.12' =~~

$\sqrt{30^2 - 6.3^2} = 29.3$

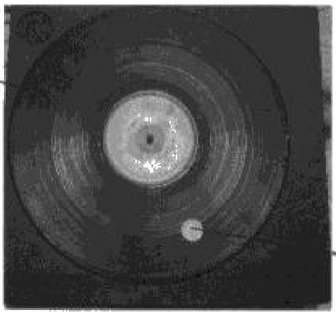
ResultsPlus
Examiner Comments

The working done here is correct, but incomplete in each section.

In part (b)(i) the answer has been left as a multiple of pi, which is only likely to be acceptable for a phase relationship.

In part (b)(ii) 0.102 m has been calculated correctly, but the relevance with respect to the distance from the edge has not been realised and there has been no attempt at a comparison and conclusion.

(b) The student placed the disk on a horizontal turntable and placed the coin on the disk, as shown below.



The disk rotated at 45 revolutions per minute.

(i) Calculate the angular velocity of the disk.

(2)

$\omega = \frac{45 \times 2\pi}{60}$

$= 4.71 \text{rads}^{-1}$

Angular velocity = 4.71 rads^{-1}

(ii) When the student placed the coin near the centre of the disk, the coin remained in position and rotated with the disk.

When the student placed the coin at the edge of the disk, the coin slid off the rotating disk.

The student estimated that the closest the coin could be to the edge of the disk without sliding off was about 5 cm.

Deduce whether this was a suitable estimate.

You should assume that the maximum frictional force is 0.02 N.

(3)

$F = m\omega^2 r$

$r = \frac{F}{m\omega^2}$

$= \frac{0.02}{(8.8 \times 10^{-3})(4.71)^2}$

$= 0.102\text{m}$

~~0.15 − 0.1~~ $\frac{30\text{cm}}{2} = 15\text{cm}$

$= 0.15\text{m}$

$0.15 - 0.102 = 0.048$

$= 4.8\text{cm}$

$\approx 5\text{cm}$

∴ yes it is.

ResultsPlus
Examiner Comments

This gains full marks.

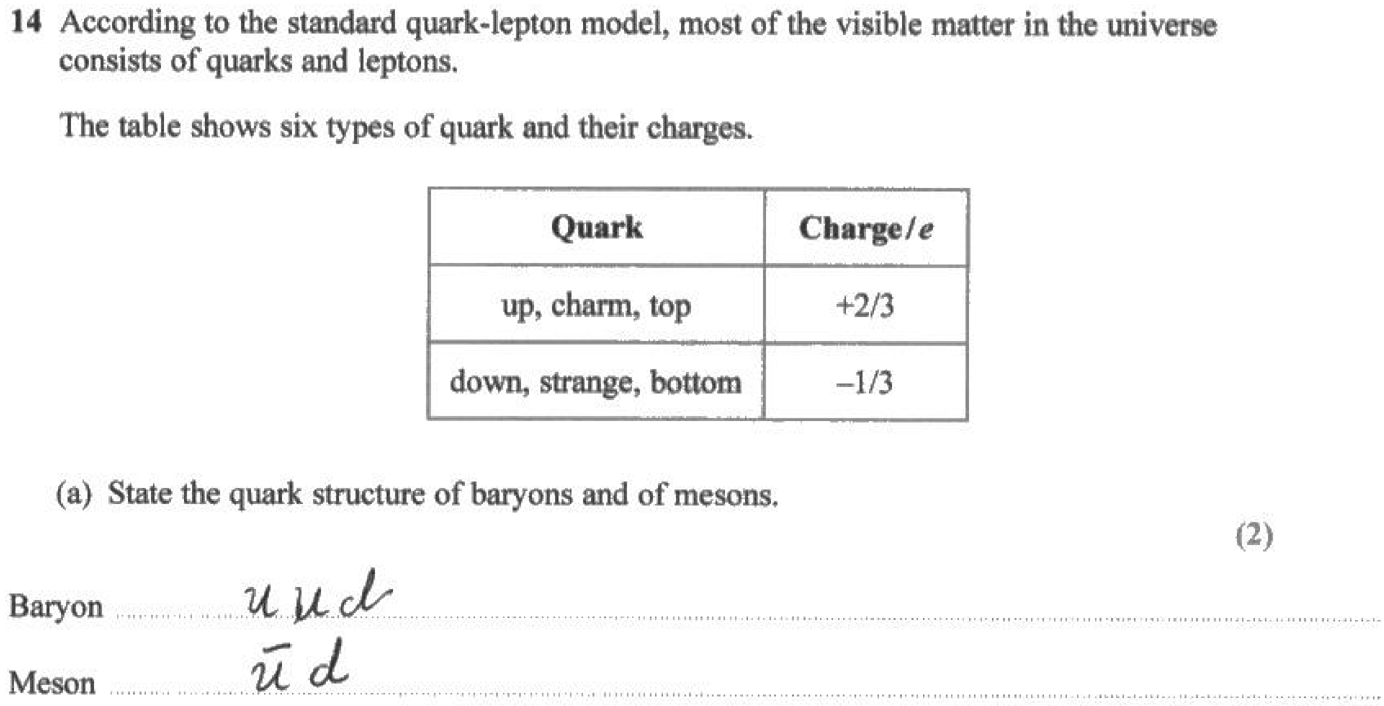
In part (b)(ii), this is the absolute minimum possible for a comparison and conclusion. We see 4.8 cm ≈ 5 cm, therefore yes it is.

ResultsPlus
Examiner Tip

When a question asks you to 'deduce whether' related to a numerical value, you are expected to make a direct comparison between two values, usually one stated and one calculated, and give a written conclusion.

Question 14 (a)

Two thirds of candidates got both marks. A frequent error was giving a specific baryon quark structure in letters, such as ddu, rather than the general description ‘three quarks’. While ‘three quarks or three antiquarks’ is accepted, some candidates said ‘three quarks or antiquarks’, which could be a mixture and was not accepted. Similarly, some candidates said that mesons are made of ‘quarks and antiquarks’ without specifying one of each.



14 According to the standard quark-lepton model, most of the visible matter in the universe consists of quarks and leptons.

The table shows six types of quark and their charges.

Quark	Charge/*e*
up, charm, top	+2/3
down, strange, bottom	–1/3

(a) State the quark structure of baryons and of mesons.

(2)

Baryon u u d

Meson $\bar{u}$ d

ResultsPlus
Examiner Comments

The question is asking about baryons and mesons in general, but this response is giving specific responses for a proton and a pion.

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The table shows six types of quark and their charges.

Quark	**Charge / *e***
up, charm, top	+2/3
down, strange, bottom	–1/3

(a) State the quark structure of baryons and of mesons.

(2)

Baryon made of any 3 quarks or antiquarks ↗ uud combinations

Meson made of one quark and one antiquark → $u\bar{u}$

ResultsPlus
Examiner Comments

The mark for meson is clear, but there is ambiguity in the answer for baryons so this mark has not been awarded. 'Baryon made of any 3 quarks antiquarks combination' would include those with a quark/antiquark mixture.

14 According to the standard quark-lepton model, most of the visible matter in the universe consists of quarks and leptons.

The table shows six types of quark and their charges.

Quark	Charge/e
up, charm, top	+2/3
down, strange, bottom	−1/3

(a) State the quark structure of baryons and of mesons.

(2)

Baryon ~~Have~~ Are made up of either 3 quarks, or three antiquarks.

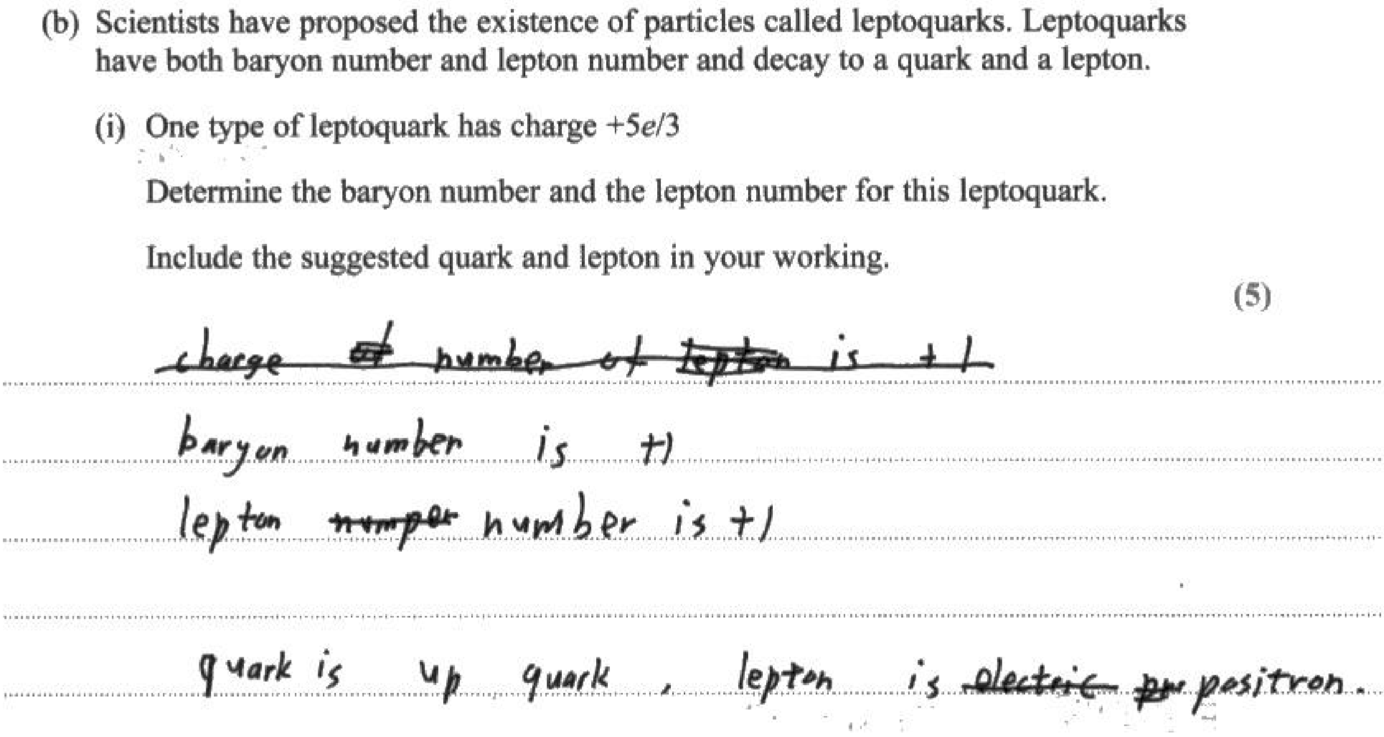
Meson Are made up of a quark and ~~a~~ antiquark pair.

ResultsPlus
Examiner Comments

The ambiguity is avoided here where it says 'either three quarks or three antiquarks'.

Question 14 (b)(i)

Half of the candidates did not score on this question, with those who did score being fairly evenly spread over the remaining mark outcomes. Most frequently identified was an up quark, then an anti-electron. Even having identified an anti-lepton, many candidates did not state the −1 lepton number. A surprising number of candidates said the baryon number was zero after identifying the up quark, not remembering that a single quark has a 1/3 baryon number. Candidates did not always make their reasoning clear with respect to the charge totals.



(b) Scientists have proposed the existence of particles called leptoquarks. Leptoquarks have both baryon number and lepton number and decay to a quark and a lepton.

(i) One type of leptoquark has charge +5*e*/3

Determine the baryon number and the lepton number for this leptoquark.

Include the suggested quark and lepton in your working.

(5)

~~charge of number of lepton is +1~~

baryon number is +1

lepton ~~numper~~ number is +1

quark is up quark , lepton is ~~electric~~ ~~po~~ positron.

ResultsPlus
Examiner Comments

This response shows a suitable pair of particles, but incorrect quantum numbers. There is no attempt to support them with evidence based on the charge. The command word 'determine' and reference to 'your working' indicate that more than a straight answer is expected and a candidate could be expected to consider whether there are at least 5 points in their answer when 5 marks are available.

(b) Scientists have proposed the existence of particles called leptoquarks. Leptoquarks have both baryon number and lepton number and decay to a quark and a lepton.

(i) One type of leptoquark has charge $+5e/3$ $+\frac{5}{3}e$

Determine the baryon number and the lepton number for this leptoquark.

Include the suggested quark and lepton in your working. proton

(5)

$+1$

$+\frac{1}{3}e$ $+e$

Leptoquarks = quark + lepton

due to the conservation law of charge

leptoquarks has charge $+\frac{5}{3}e$.

quark has $+\frac{2}{3}e$ and lepton has $+e$.

due to the conservation law of baryon number

so the leptoquarks have 1 baryon number

Quark has one baryon lepton has no baryon number

due to the conservation law of lepton number.

quark has 0 baryon number lepton has ~~0~~ −1 ~~baryon~~ lepton number

so the lepton of leptoquarks are −1

the the quark may be up. lepton may be ~~electron~~ ~~muon~~ proton.

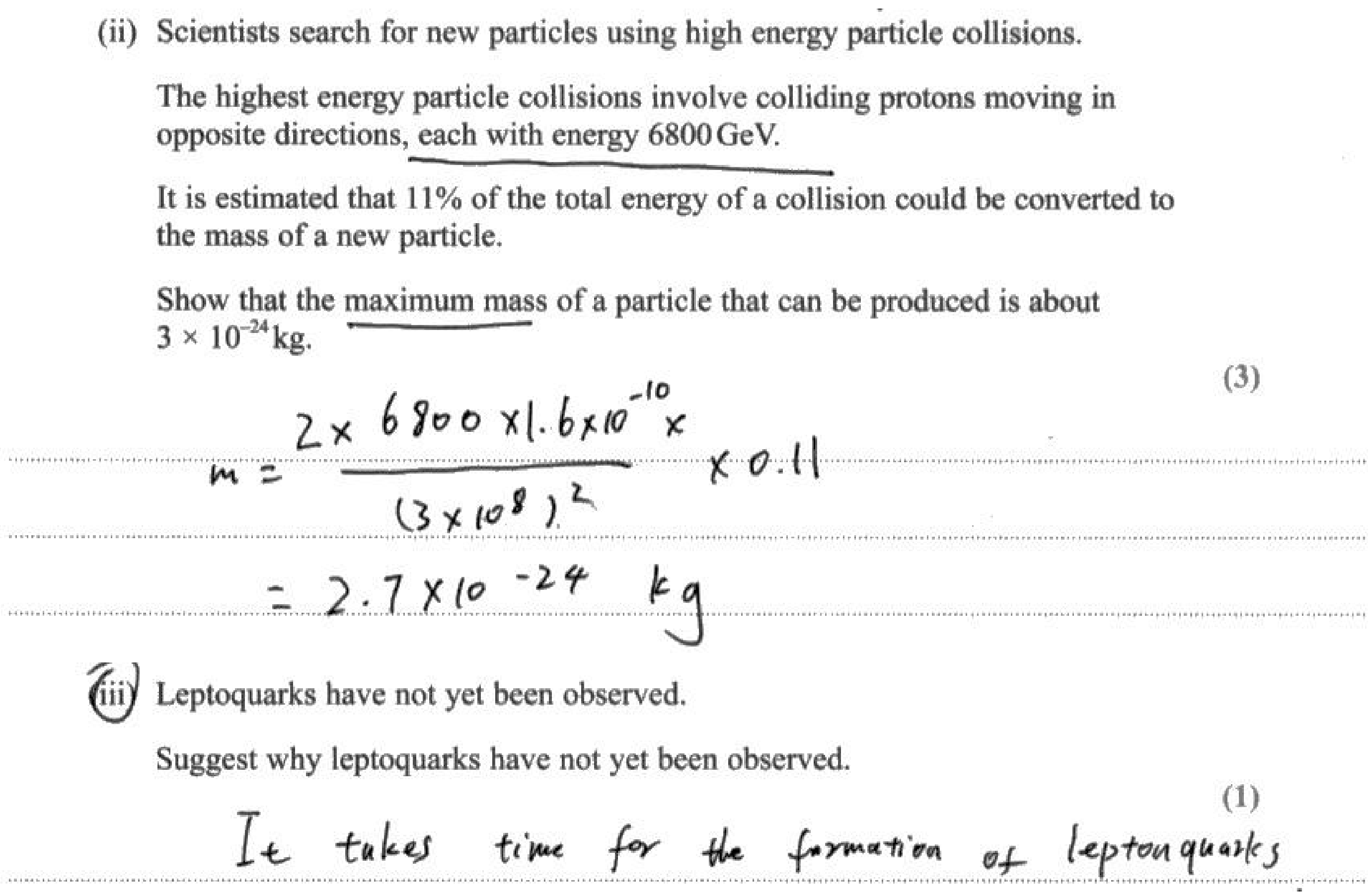
ResultsPlus
Examiner Comments

Lines 3 and 4 show the determination of charges and the lepton number and suggested quark are correct. In common with quite a few other candidates, the baryon number has been stated as zero.

Question 14 (b)(ii)-(iii)

In part (b)(ii) most candidates were able to calculate the maximum mass straightforwardly. Some did not apply the correct power of ten for 6800 GeV. Some omitted the square for the speed of light when substituting or when calculating.

Few candidates scored for part (b)(iii), the most common incorrect answers referring to a short lifetime. The answer required some sense of comparison of energy available with energy required, but those who referred to energy often just stated a requirement for a lot of energy without relating it to the energy available.



(ii) Scientists search for new particles using high energy particle collisions.

The highest energy particle collisions involve colliding protons moving in opposite directions, each with energy 6800 GeV.

It is estimated that 11% of the total energy of a collision could be converted to the mass of a new particle.

Show that the maximum mass of a particle that can be produced is about 3×10^{-24} kg.

(3)

$$m = \frac{2 \times 6800 \times 1.6 \times 10^{-10} \times}{(3 \times 10^{8})^{2}} \times 0.11$$

$$= 2.7 \times 10^{-24} \text{ kg}$$

(iii) Leptoquarks have not yet been observed.

Suggest why leptoquarks have not yet been observed.

(1)

It takes time for the formation of leptonquarks

ResultsPlus
Examiner Comments

Part (b)(ii) is fully correct. It has been done as a single calculation, but all of the required steps are visible in the substitution. The answer has been given to the required extra significant figure.

Part (b)(iii) is an incorrect suggestion and, even on its own terms, is not clear as there is no suggestion as to whether this is a short or a long time.

(ii) Scientists search for new particles using high energy particle collisions.

The highest energy particle collisions involve colliding protons moving in opposite directions, each with energy 6800 GeV.

It is estimated that 11% of the total energy of a collision could be converted to the mass of a new particle.

Show that the maximum mass of a particle that can be produced is about 3×10^{-24} kg.

(3)

$\frac{1}{2}\Delta E = 6800\times10^{9}\times1.6\times10^{-19} = 1.088\times10^{-6}$ J

$\Delta E = mc^2$

$m = \frac{2\times1.088\times10^{-6}\text{J}\times0.11}{(3\times10^{8})^2} = 2.66\times10^{-24}$ kg

(iii) Leptoquarks have not yet been observed.

Suggest why leptoquarks have not yet been observed.

(1)

the mass is too big

& the energy ~~is~~ is not enough

ResultsPlus
Examiner Comments

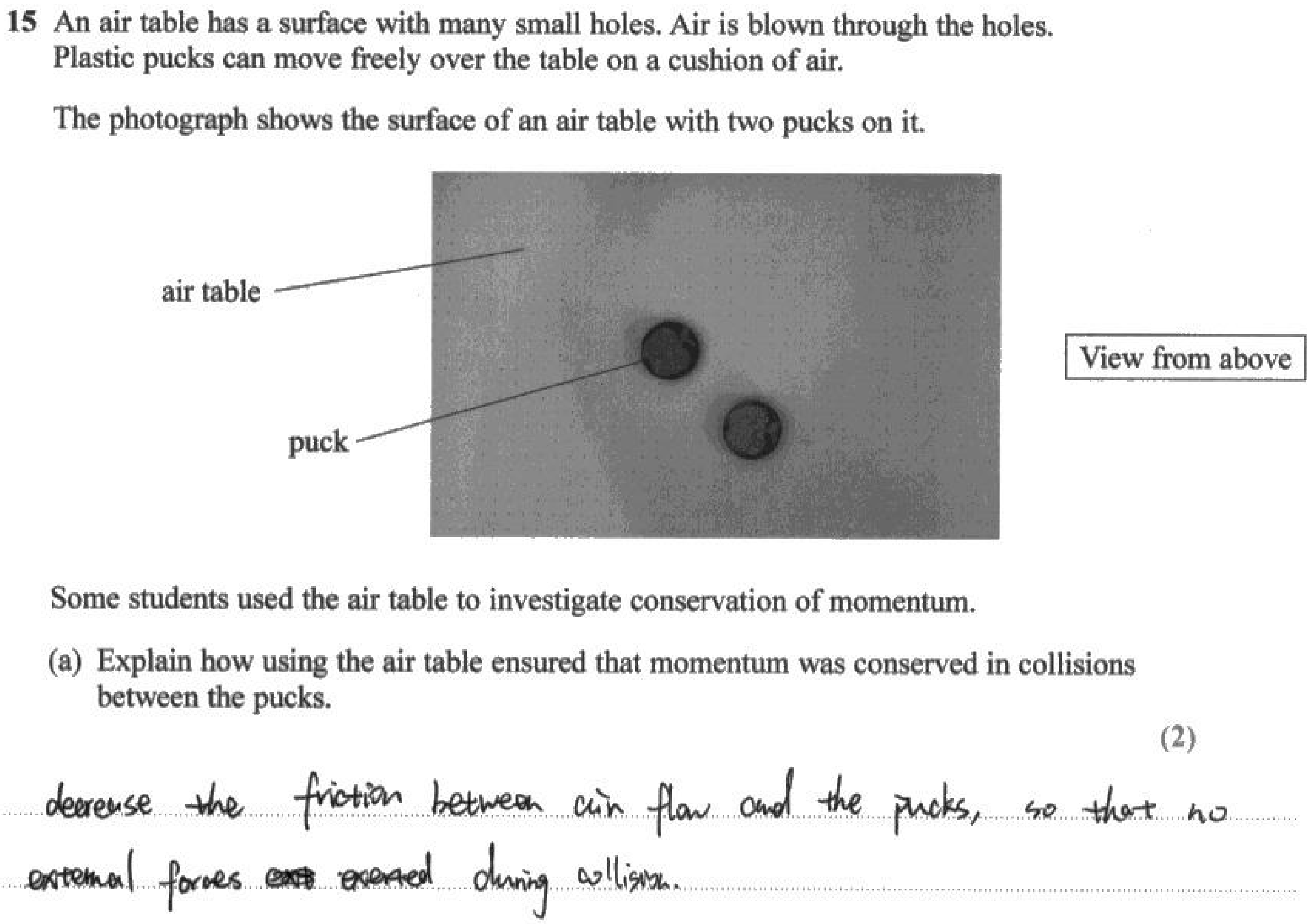
This is an example of a fully correct answer for both parts. It is probable that this candidate's answer did not match the 'show that' value first time as the added factors of 1/2 on the first line and 2 on the next appear as afterthoughts, but they have been correctly applied and we can see all of the reasoning, so this is a sensible reaction.

ResultsPlus
Examiner Tip

Be ready to check and repeat a calculation if you do not get the expected answer.

Question 15 (a)

A good majority of candidates referred to little or no friction, although some just referred to reduced friction, which was not sufficient. They usually said that this meant there were no external forces. Clearly there is weight at all times, so candidates were required to state that there was no resultant external force.



15 An air table has a surface with many small holes. Air is blown through the holes. Plastic pucks can move freely over the table on a cushion of air.

The photograph shows the surface of an air table with two pucks on it.

air table

puck

View from above

Some students used the air table to investigate conservation of momentum.

(a) Explain how using the air table ensured that momentum was conserved in collisions between the pucks.

(2)

decrease the friction between air flow and the pucks, so that no external forces ~~ext~~ exerted during collision.

ResultsPlus
Examiner Comments

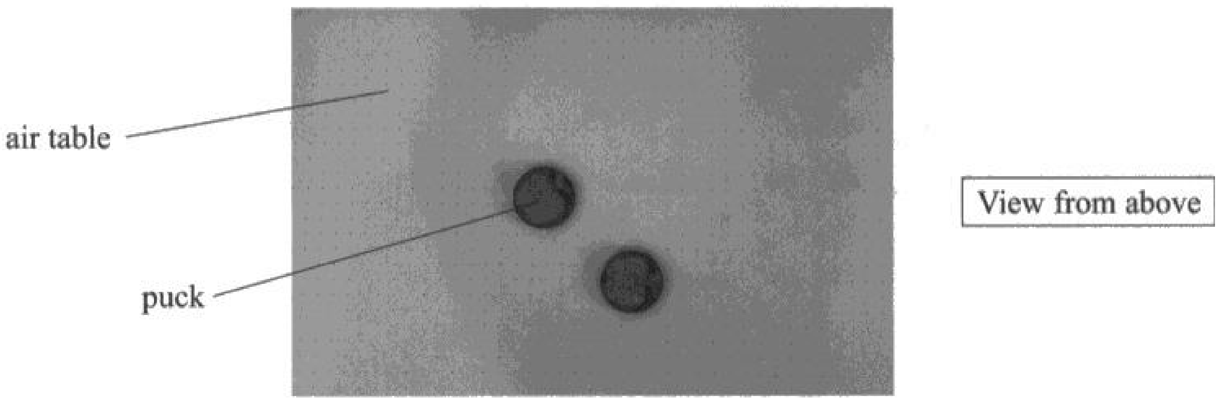
Decreases friction is not sufficient as it could still be substantial. 'No external forces' is not correct – it should say that the sum of the external forces is zero.

ResultsPlus
Examiner Tip

Learn standard definitions, laws and principles in detail so they can be applied appropriately in new question contexts.

15 An air table has a surface with many small holes. Air is blown through the holes. Plastic pucks can move freely over the table on a cushion of air.

The photograph shows the surface of an air table with two pucks on it.



Some students used the air table to investigate conservation of momentum.

(a) Explain how using the air table ensured that momentum was conserved in collisions between the pucks.

(2)

to ensure there is no friction

to provide no external force acting on the puck

ResultsPlus
Examiner Comments

This response shows an improvement in suggesting that there is no friction, but still refers to no external forces.

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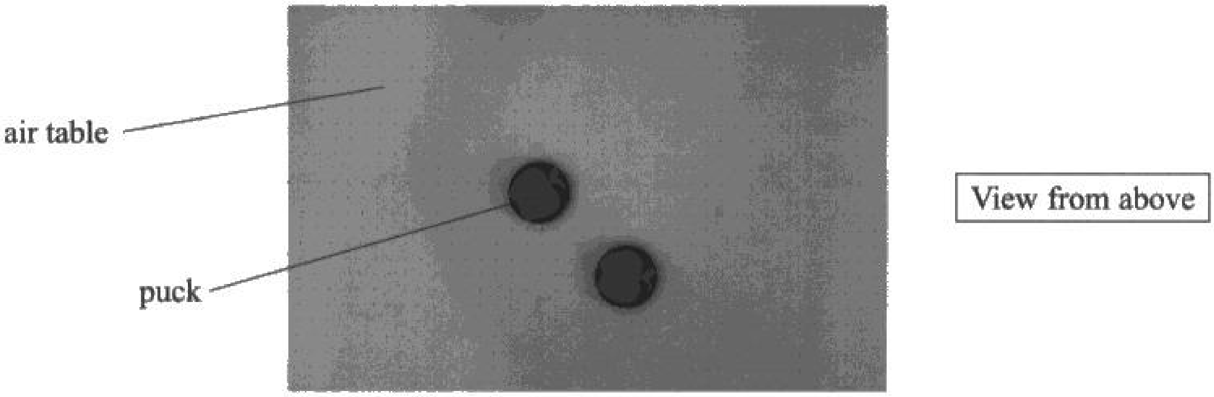


Some students used the air table to investigate conservation of momentum.

(a) Explain how using the air table ensured that momentum was conserved in collisions between the pucks.

(2)

The momentum before collision will equal to momentum after collision. As there will be no external resultant forces acting on the the system, due to use of air table.

ResultsPlus
Examiner Comments

'No external resultant forces' isn't quite in the right order, but is acceptable. Friction has not been mentioned.

Question 15 (b)(i)-(ii)

Half of the entry scored at least 8 out of 10 for these two linked sections of relative familiarity. Those scoring 8 marks had completed all of the calculations correctly but did not make the required comparison of values and written conclusion using this comparison to answer the question as to whether the condition stated was correct. A comparison will require an explicit statement including two values and that one value is greater than, less than or equal to the other.

In part (b)(i) some candidates did not use a two-dimensional approach and attempted to solve it without taking components of momentum after the collision. Others attempted to apply the angle to find components before the collision.

Most candidates were able to arrive at an angle of 58 degrees and they usually added it to 33 degrees, but they did not always state that 91 degrees is about 90 degrees, so it is correct to say that the angle between the paths is 90 degrees.

In part (b)(ii) the great majority of candidates were able to calculate at least one kinetic energy correctly. Some candidates made it more difficult by using the momentum to calculate velocity and then using that for kinetic energy. They should be aware of the formula $E_K = p^2/2m$. Candidates were generally able to calculate the momentum of puck B and go on to calculate all of the kinetic energies, although a fair number did not give the unit J at any stage. Candidates should note that we do not expect absolutely identical values of kinetic energy to judge a collision to be elastic and 9.62×10^{-3} J and 9.75×10^{-3} J may be considered as approximately equal for this purpose.

(i) Deduce whether the angle between the paths of the pucks after the collision was 90°.

You should use the principle of conservation of momentum.

(5)

$0.039 \times \cos 33° = 0.0327$ ~~ms~~ $\mathrm{kg\,m\,s^{-1}}$

$0.046 - 0.0327 = 0.0133$ $\mathrm{kg\,m\,s^{-1}}$

$0.039 \times \sin 33° = 0.0212$ $\mathrm{kg\,m\,s^{-1}}$

~~$\tan^{-1}\left(\frac{0.0212}{0.0133}\right) = 86.4°$~~

~~$86.4 < 90°$~~

$\sqrt{0.0133^2 + 0.0212^2}$

$= 0.025\ \mathrm{kg\,m\,s^{-1}}$

$\tan^{-1}\left(\frac{0.0212}{0.0133}\right) = 57.9°$

$57.9° + 33° = 90.9°$

$90.9°$ ~~$> 90°$~~

(ii) Deduce whether the collision was elastic.

mass of each puck = 0.110 kg

(5)

~~$\frac{1}{2}mv^2 = p$ $E = \frac{p^2}{2m}$~~

$E = \frac{p^2}{2m}$

~~$p = \sqrt{0.046 \times 2 \times 0.11}$~~

$E = \frac{0.046^2}{2 \times 0.11}$

~~$p = 0.1$~~

$E = 9.62 \times 10^{-3}\ \mathrm{J}$

$0.039^2 \div (2 \times 0.11) = 6.91 \times 10^{-3}$

~~$E = \frac{1}{2}mv^2 = \frac{1}{2}v$~~ ~~$0.212^2$~~ $\frac{0.0212^2}{2 \times 0.11} = 2.04 \times 10^{-3}$

~~6.91 +~~ $6.91 \times 10^{-3} + 2.04 \times 10^{-3} = 8.95 \times 10^{-3}\ \mathrm{J}$

~~8.95 <~~ $8.95 \times 10^{-3} < 9.62 \times 10^{-3}$

inelastic

ResultsPlus
Examiner Comments

All of the working in part (b)(i) is correct, but the first attempt at a comparison has been crossed out and not replaced. 90.9 is about 1 percent more than 90, so, after a long sequence of calculations based on experimental data given to only 2 significant figures, it is justified to say they are equal in this context.

Part (b)(ii) has an error in substitution where a component of momentum has been used in the third kinetic energy calculation. The final answers have been compared and a minimal, but sufficient, conclusion has been written.

(i) Deduce whether the angle between the paths of the pucks after the collision was 90°.

You should use the principle of conservation of momentum.

(5)

In horizotal. $P_{initial}$ = ~~P_{final}~~ ^{final} ~~after~~. = 0.046 kgms^{-1}

~~P initial = final =~~ P ~~after~~ $_{final}$ = P final of A ~~cos~~ ~~× P final of B~~ × cos 33° + P final of B × cos b.

0.046kgms^{-1} = 0.039 kgms^{-1} × cos 33° + P final of B × cos b.

P final of B · cos b = 0.01329 kgms^{-1}.

In vertical $P_{initial}$ = P_{final} = 0.

P final of A · sin 33° = P final of B · sin b.

P final of B · sin b = 0.039 kgms^{-1} × sin 33° = 0.021 kgms^{-1}

$\tan b = \frac{P \sin b}{P \cos b} = \frac{0.021 \text{ kgms}^{-1}}{0.01329 \text{ kgms}^{-1}} = 0.0279\ldots$

b = tan^{-1} (0.0279..) = 57.67°.

57.67° + 33° = 90.7°. ≈ 90°. ~~it is~~ angle after collision was $_{almost}$ 90°.

(ii) Deduce whether the collision was elastic.

mass of each puck = 0.110 kg

(5)

$KE_{initial} = \frac{P^2}{2m} = \frac{(0.046 \text{ kgms}^{-1})^2}{2 \times 0.110 \text{ kg}} = 9.62 \times 10^{-3}$ J.

$KE_{final} = KE_A + KE_B = \frac{P_A^2}{2m} + \frac{P_B^2}{2m}$ $P_B = \frac{0.021 \text{ kgms}^{-1}}{\sin 57.67°} = 0.025 \text{ kgms}^{-1}$

$= \frac{(0.039 \text{ kgms}^{-1})^2}{2 \times 0.110 \text{ kg}} + \frac{(0.025 \text{ kgms}^{-1})^2}{2 \times 0.11}$

$= 9.75 \times 10^{-3}$ J.

K.E initial ≈ K.E final. ~~therefore~~ elastic.

ResultsPlus
Examiner Comments

This is an example of a fully correct response, with comparisons and conclusions in both parts. Notice that in part (b)(ii) the values have not been compared directly, but KE initial and KE final have been clearly calculated and identified, so this is satisfactory.

Question 16 (a)

Most candidates were able to show that treating this as kinetic energy of a non-relativistic particle, this energy would require a speed of 1.5×10^{11} m s^{-1}, but many did not make a statement that this is greater than the speed of light. Quite a few candidates who did make a comparison of the numbers omitted the unit m s^{-1} entirely, meaning that they were not making a valid comparison.

There were occasional difficulties with applying GeV in the energy conversion. Some candidates used proton mass, limiting themselves to the first mark and would benefit from careful familiarisation with the list of data at the end of the paper.

16 Scientists at CERN are planning an upgrade to the Large Hadron Collider called the Large Hadron Electron Collider (LHeC).

The scientists plan to use a linear accelerator (linac) to produce high energy electrons. Collisions between these electrons and high energy protons will allow the structure of protons to be investigated.

(a) The high energy electrons produced will have energy 60 GeV.

Show that these electrons will be travelling at relativistic speeds.

(3)

$E = mc^2$

$60 \times 10^9 \times 1.6 \times 10^{-19} =$ ~~$E = 9.8 \times 10$~~

$E = \frac{1}{2}mv^2 \qquad E = 9.6 \times 10^{-9}$ J

$V = \sqrt{\frac{2E}{m}}$

$E = \frac{1}{2}mv^2 \qquad E = 9.6 \times 10^{-9}$ J

$\sqrt{\frac{2 \times (9.6 \times 10^{-9})}{9.11 \times 10^{-31}}}$ ~~$\times (9.11 \times 10^{-31})$~~

$\boxed{V = 1.45 \times 10^{11}}$

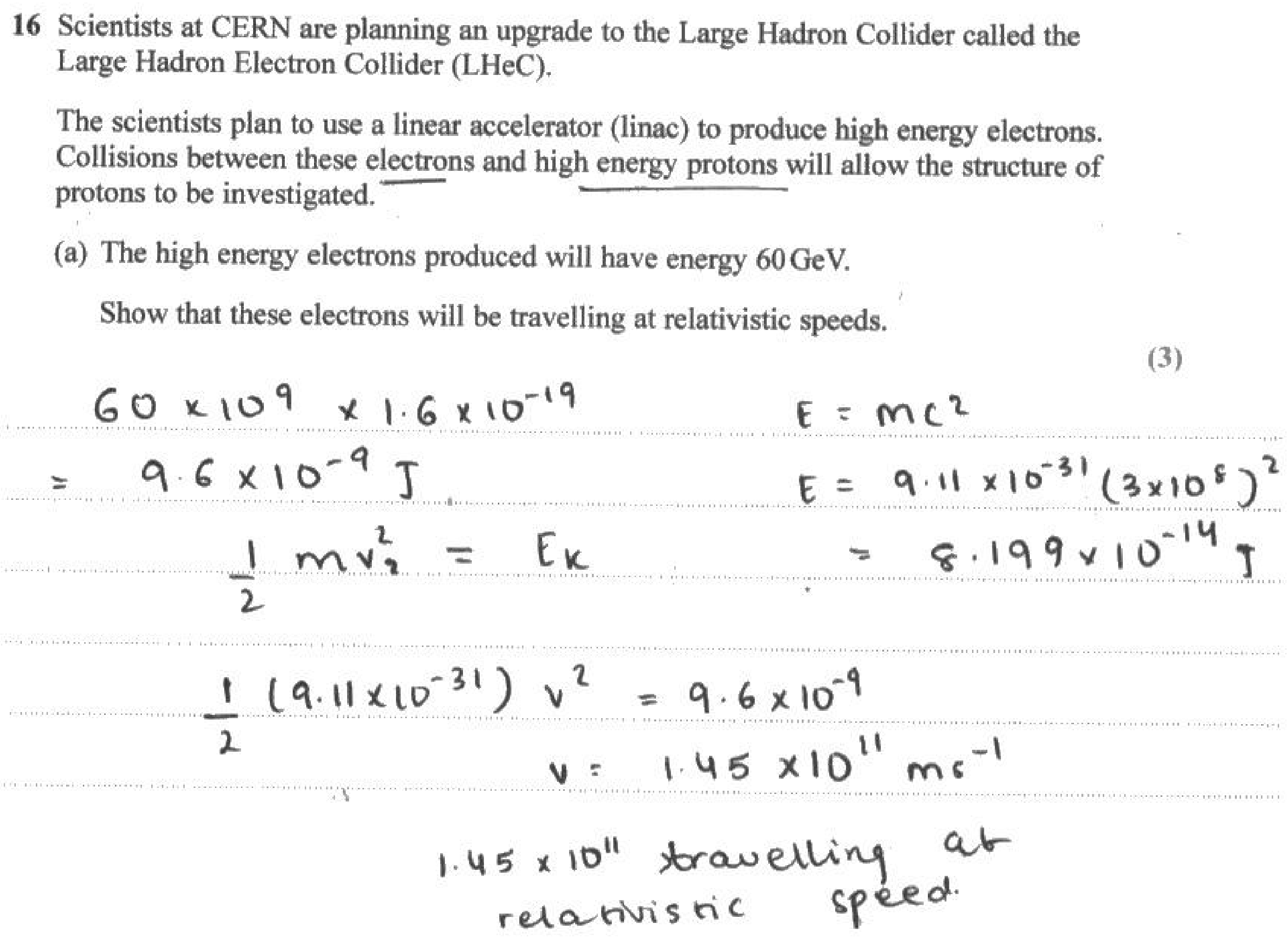
$V > C$ therfore relativistic Speed

ResultsPlus
Examiner Comments

This calculation is correct and the candidate has related it to the speed of light, but the unit of the calculated speed must be included to make it a valid comparison.

ResultsPlus
Examiner Tip

Always include the unit with your numerical answers.



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(a) The high energy electrons produced will have energy 60 GeV.

Show that these electrons will be travelling at relativistic speeds.

(3)

$60 \times 10^9 \times 1.6 \times 10^{-19}$

$= 9.6 \times 10^{-9}$ J

$E = mc^2$

$E = 9.11 \times 10^{-31} (3 \times 10^8)^2$

$= 8.199 \times 10^{-14}$ J

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

$\frac{1}{2} (9.11 \times 10^{-31}) v^2 = 9.6 \times 10^{-9}$

$v = 1.45 \times 10^{11}$ ms^{-1}

1.45×10^{11} travelling at relativistic speed.

ResultsPlus
Examiner Comments

This calculation is correct, but there is no comparison with the speed of light, so the conclusion is not fully supported.

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(a) The high energy electrons produced will have energy 60 GeV.

Show that these electrons will be travelling at relativistic speeds.

(3)

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

$v = \sqrt{\frac{2E_k}{m}} = \sqrt{\frac{2 \times 60 \times 10^9 \times 1.6 \times 10^{-19}}{9.11 \times 10^{-31}}} \approx 1.45 \times 10^{11} \, ms^{-1} > 3 \times 10^8 \, ms^{-1}$

Thus they will be travelling at relativistic speeds.

ResultsPlus
Examiner Comments

This is an example of a fully correct answer. It has been done as a single calculation, supported by a combined formula. Substitution errors and calculation errors with this approach can prevent the award of 'use of' marks when the final answer is incorrect, so it is suggested that separate steps are shown.

Question 16 (b)

This was well answered overall, with nearly half of the entry gaining 4 or more marks. Candidates were generally familiar with the context of linacs and answers were usually set out with a coherent and logical structure.

Candidates frequently missed IC1 because they did not refer to the electric field accelerating the electrons, often just mentioning the potential difference, or even alternating current. Note that the specification refers to the role of electric fields in linacs, so this was a requirement. Quite a few candidates slipped up and referred to acceleration between the gaps rather than between the drift tubes.

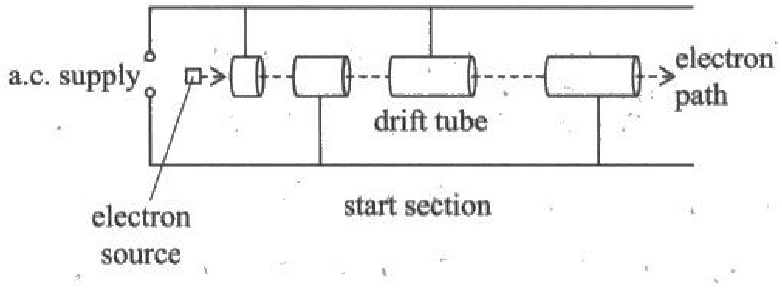
Candidates usually made an attempt at IC2 but could not always express the idea of the polarity change maintaining the direction of acceleration sufficiently clearly.

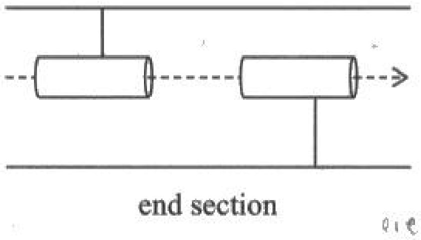
With IC3, some candidates missed out because they stated that the ac was constant without mentioning frequency.

Even though IC4 required two linked ideas – constant time and increasing length – it was generally given correctly.

Most candidates mentioned the constant length for IC5 and explained it in terms of approaching the speed of light, although some did not mention that this meant that the speed was then almost constant. A few candidates stated that the particles were travelling at the speed of light.

*(b) The diagram shows the start section of a linac and the end section of a linac.





elec mag field

Explain how a linac produces high energy electrons.

You should refer to the a.c. supply and to the length of the drift tubes in each section.

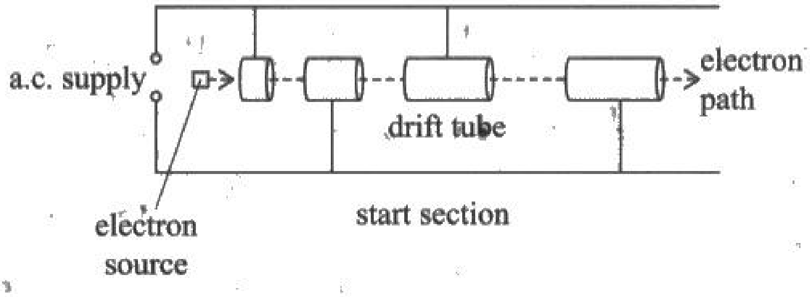
(6)

linac consists of series of tube shaped electrodes
charged particles are fired into linac
these charged particles are accelerated by
electric field ~~by~~ inside the electrode which provides force on charge particle causing acceleration and accelerated
by magnetic field between the gaps, when
a charged leaves an electrode the a.c supply
causes the polarity of the electrodes to
reverse so charged particle is attracted to
the next electrode and repelled by ~~previous~~ previous
one as this causes velocity to increase however
charged particle must spend same amount of time
in each ~~electrode~~ drift tube and maintain constent frequency so
to compensate increase of speed, length of linac drift tube ~~tube~~
increase. it keeps increasing until theres no more change in
velocity high energy electrons then leave the drift tube

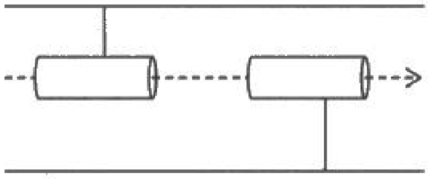
ResultsPlus
Examiner Comments

This response was awarded indicative content points 2 and 4 for describing the polarity reversal and the increase in drift tube length to keep the time constant. It refers to particle acceleration by magnetic fields and to it taking place between the gaps. The constant frequency part refers to the particle and does not mention ac. There is a reference to no more increase in velocity, but not the speed of light.

*(b) The diagram shows the start section of a linac and the end section of a linac.



start section



end section

Explain how a linac produces high energy electrons.

You should refer to the a.c. supply and to the length of the drift tubes in each section.

(6)

There is an electric present in the linac that accelerates the electron beams. This causes them to gain velocity and accelerate at high speeds. There is an alternating current supply which constantly changes the polarity of the potential difference as the particles approach the gap. This causes the a.c to have a constant frequency. This enables particles to spend the same amount of time within each tube. Since speed is increasing and time need to remain constant, the distance need to increase according to $s=v/t$. Therefore the length of the tubes is increased successively. The electric field is in the correct direction to accelerate the particles until they reach relativistic speed after which they dont accelerate further. length of the tubes stops increasing as well since speed and time is constant. The particles are detected at other end with high enough kinetic energy.

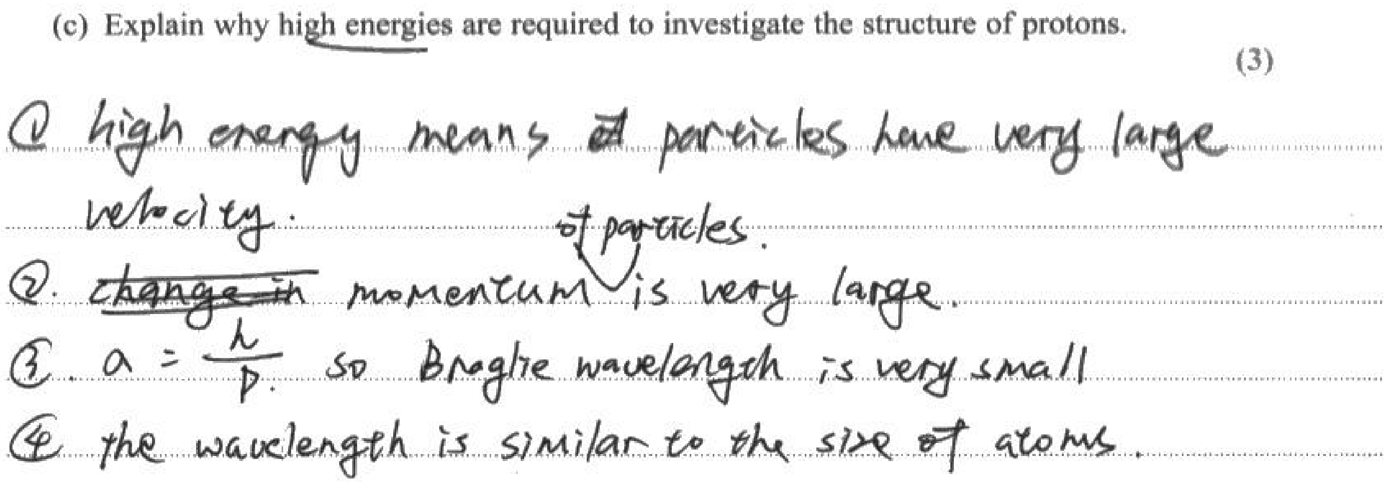
ResultsPlus
Examiner Comments

This response has everything but the first two indicative content points. It starts 'There is an electric present', so the word 'field' has been omitted, and it doesn't state 'between the drift tubes'. The second point is not made at all. The rest is clear to read and logically structured, so the available linkage mark is awarded as well as 3 marks for 4 indicative content points.

Question 16 (c)

More than half of the candidates achieved at least 1 mark, with most of those scoring 2. The most frequent mark was for the small de Broglie wavelength and the next for linking this to high momentum, but relatively few candidates were able to go on to link this to better resolution.

Quite a few candidates referred to high energy being needed to overcome repulsive forces between the electron and the proton without considering that they have opposite charges so this would not be the case. Some others gave answers in terms of energy to create new particles, possibly because they were thinking of the answer to a past paper question on a different aspect of the topic.



(c) Explain why high energies are required to investigate the structure of protons.

(3)

① high energy means ~~of~~ particles have very large velocity.

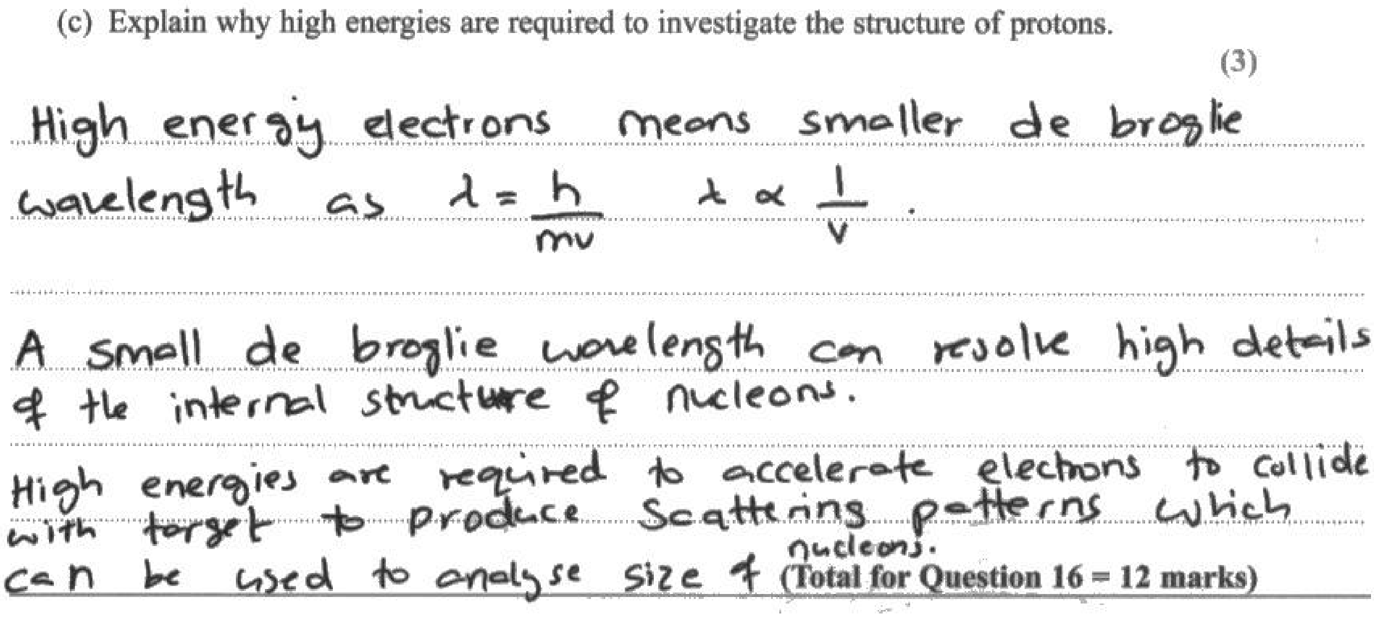
② ~~change in~~ momentum of particles is very large.

③ $a = \frac{h}{p}$. so Broglie wavelength is very small

④ the wavelength is similar to the size of atoms.

ResultsPlus
Examiner Comments

This is awarded the first 2 marks for the parts numbered 2 and 3. It does not go on to tell us how a small wavelength is of benefit.



(c) Explain why high energies are required to investigate the structure of protons.

(3)

High energy electrons means smaller de broglie wavelength as $\lambda = \frac{h}{mv}$ $\lambda \propto \frac{1}{v}$.

A small de broglie wavelength can resolve high details. of the internal structure of nucleons.

High energies are required to accelerate electrons to collide with target to produce Scattering patterns which can be used to analyse size of nucleons.

(Total for Question 16 = 12 marks)

ResultsPlus
Examiner Comments

This is credited for small wavelength and high detail, but the explanation of high momentum is insufficient. The formulae used would be sufficient if it also stated that high energy particles have high speeds.

Question 17 (a)(i)-(ii)

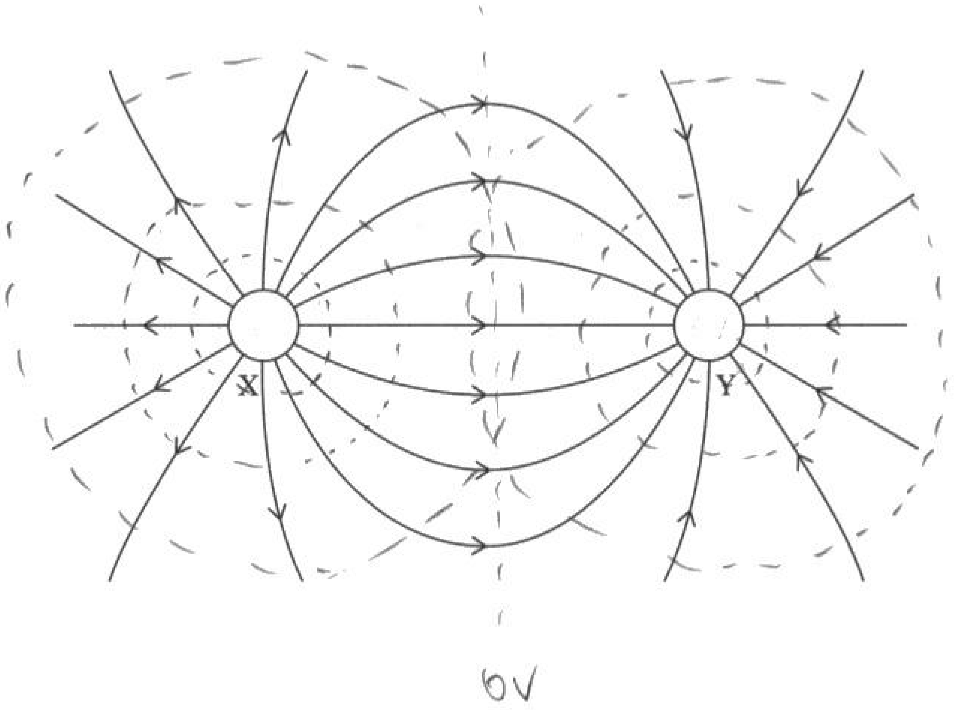
Most candidates gained some credit for their equipotential diagrams, but often just 1 mark for concentric lines circling the charges or 2 marks if they included the straight line in the middle. The difference in spacing in the different sections was often not shown. Some candidates did not add a 0 V label, but most of those who had included that equipotential labelled it correctly. A fair few candidates did not take sufficient care and drew lines that crossed. A small number of candidates just drew parallel lines.

17 Scientists are developing safe methods for removing old satellites from orbit.

Some scientists plan to use electrostatic forces. A spacecraft will fire a beam of electrons at a satellite. This will give the satellite a negative charge and the spacecraft a positive charge.

There will be an electrostatic force of attraction between the satellite and the spacecraft. The spacecraft will then move away, taking the satellite with it.

(a) The diagram shows the electric field around the spacecraft X and the satellite Y when they have equal and opposite charge. You may assume that the spacecraft and the satellite are both spherical and have the same diameter.



(i) Add dashed lines to the electric field diagram to show equipotentials at intervals of equal potential difference.

(3)

(ii) Label the equipotential that represents 0 V.

(1)

ResultsPlus
Examiner Comments

In part (a)(i) a mark is awarded for the circular form, but no more because some of the circles cross and the spacing doesn't change.

Part (a)(ii) is awarded the mark.

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Some scientists plan to use electrostatic forces. A spacecraft will fire a beam of electrons at a satellite. This will give the satellite a negative charge and the spacecraft a positive charge.

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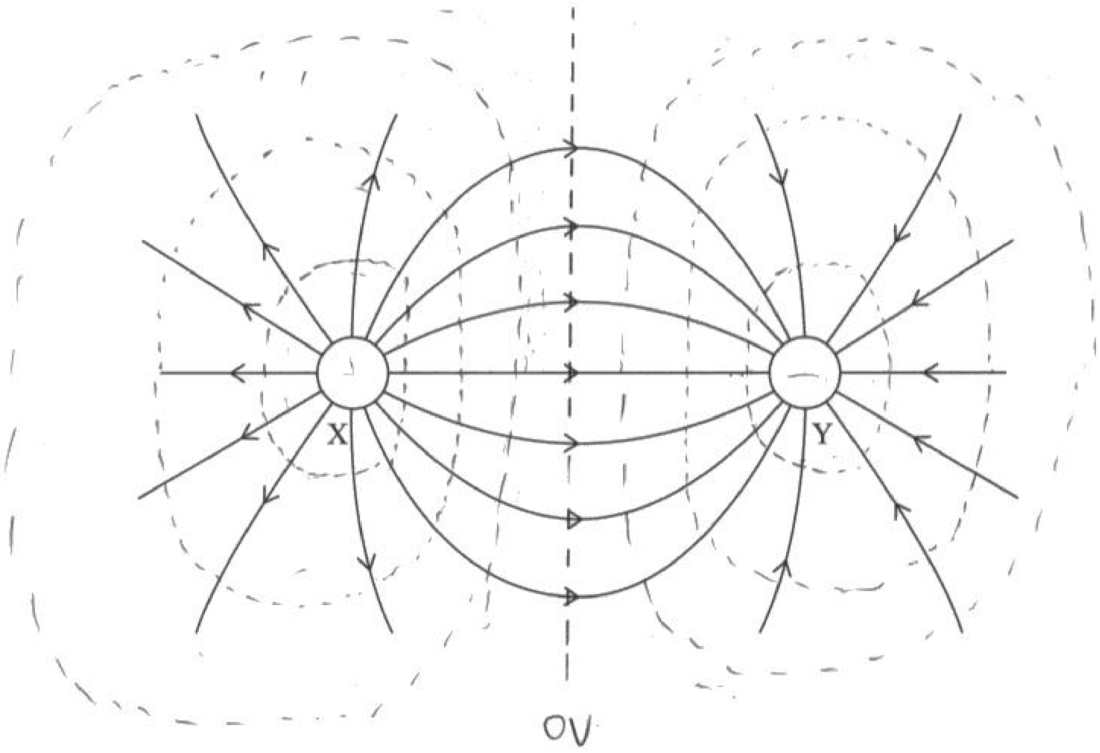


(i) Add dashed lines to the electric field diagram to show equipotentials at intervals of equal potential difference.

(3)

(ii) Label the equipotential that represents 0 V.

(1)

ResultsPlus
Examiner Comments

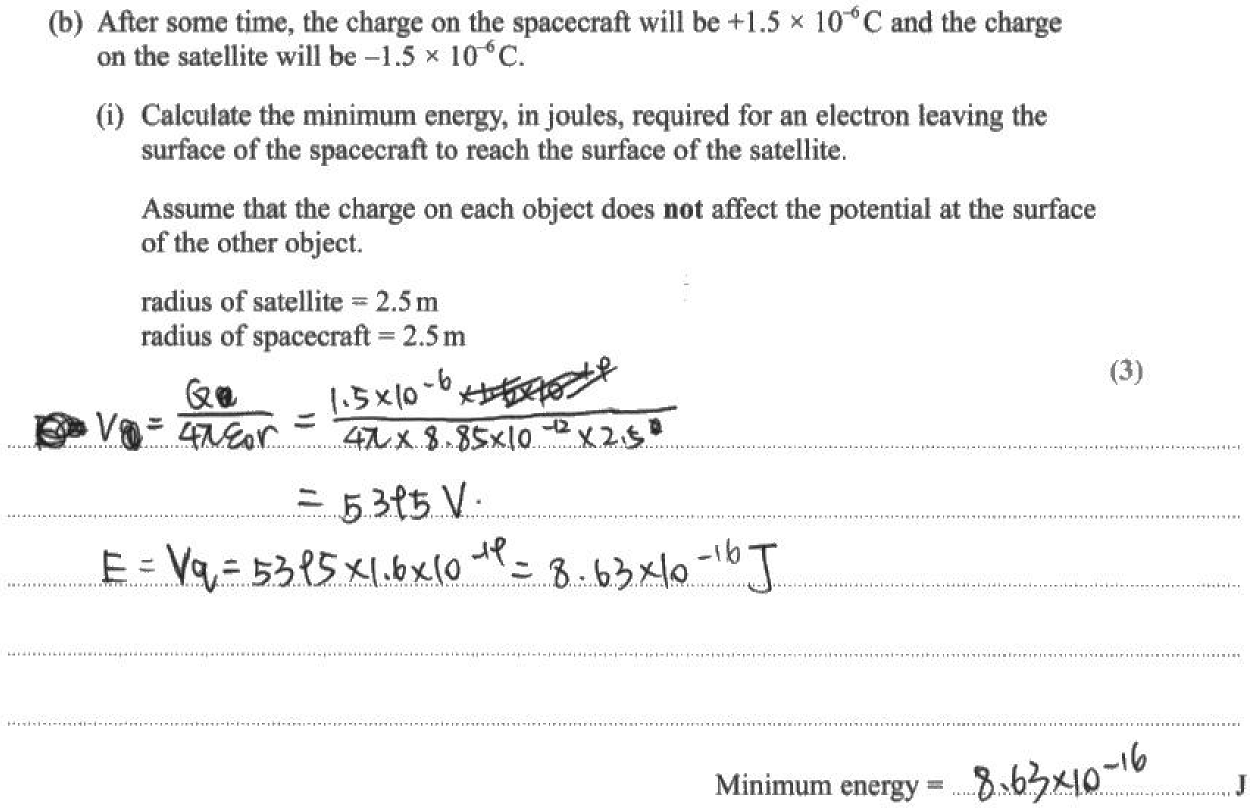
Although some of the lines are slightly flattened, this has all of the features required for full marks.

Question 17 (b)(i)

About half of the candidates scored at least 1 mark for applying the equation to calculate potential, although some used 5 m instead of 2.5 m. Half of these then applied $W = QV$ and a majority of those went on to calculate the correct answer.

A variety of errors and incorrect approaches were seen. Having calculated the correct potential, some candidates used the same charge for the work calculation, rather than the electron charge, and some did not multiply by 2 to apply it for both bodies. Some candidates used r^2 in the denominator and some just used the force formula. One approach was to use the force formula and multiply by distance, even though force was clearly not constant.

When substituting in the formula, quite a few candidates did not substitute fully for k or ε_0. When they made a mistake in their calculation, or substituted the incorrect value of r, they could not be awarded the 'use of' mark because this requires full substitution of all constants, with the exception of pi and Euler's number.



(b) After some time, the charge on the spacecraft will be $+1.5 \times 10^{-6}$ C and the charge on the satellite will be -1.5×10^{-6} C.

(i) Calculate the minimum energy, in joules, required for an electron leaving the surface of the spacecraft to reach the surface of the satellite.

Assume that the charge on each object does **not** affect the potential at the surface of the other object.

radius of satellite = 2.5 m
radius of spacecraft = 2.5 m

(3)

$$V = \frac{Q}{4\pi\varepsilon_0 r} = \frac{1.5\times10^{-6} \cancel{\times 1.6\times10^{-19}}}{4\pi\times8.85\times10^{-12}\times2.5}$$

$$= 5395\text{ V}.$$

$$E = Vq = 5395\times1.6\times10^{-19} = 8.63\times10^{-16}\text{ J}$$

Minimum energy = 8.63×10^{-16} J

ResultsPlus Examiner Comments

2 marks are awarded for 'use of' the required relationships. This is missing a factor of 2, effectively just representing the energy to remove an electron and not to get it to the surface of the satellite.

(b) After some time, the charge on the spacecraft will be $+1.5 \times 10^{-6}$ C and the charge on the satellite will be -1.5×10^{-6} C.

(i) Calculate the minimum energy, in joules, required for an electron leaving the surface of the spacecraft to reach the surface of the satellite.

Assume that the charge on each object does **not** affect the potential at the surface of the other object.

radius of satellite = 2.5 m
radius of spacecraft = 2.5 m

(3)

$$V = \frac{kQ}{r} = \frac{8.99\times10^{9} \times 1.5\times10^{-6}}{2.5} = 5394\,V.$$

~~2×5~~3 $W = VQ$

$= (5394\times2) \times 1.6\times10^{-19}$

$= 1.72\times10^{-15}$ J

Minimum energy = 1.72×10^{-15} J J

ResultsPlus
Examiner Comments

This is a fully correct answer with all the stages fully and clearly set out.

Question 17 (b)(ii)

About half of the candidates scored at least 1 mark for applying the force equation and about half of those then went on to calculate a suitable value of distance or time, but not all of those went on to compare it explicitly to the value in the question and state the conclusion that the estimate was correct.

Typical errors in the force calculation included omitting the square at the substitution or calculation stage, being confused over the distance and adding the diameter to the distance between the centres.

While most candidates who calculated force could calculate acceleration, some of those used it to calculate a velocity then went on to treat it as constant and use it in $v = s/t$ when they should have halved it to give average velocity.

Some candidates thought that they should use formulae for circular motion since the objects were in orbit.

(ii) The spacecraft moves to a new position, taking the satellite with it.

The distance between the satellite and the spacecraft remains constant, so the electrostatic force is constant.

The scientists estimate that the satellite could be moved a distance of 300 km in about 60 days.

Deduce whether this estimate is correct.

Assume gravitational forces are negligible and the satellite is initially at rest.

distance between centre of satellite and centre of spacecraft = 20 m
mass of satellite = 2500 kg

(4)

$F = EQ$ conserved $F = ma$

~~$5.63\times10^{-14} = \frac{1}{2}mv^2$~~

~~$v = 351\ 61\times10^{6}\ \mathrm{ms^{-1}}$~~

60 days $= 60\times24\times60^2$

$= 5184000\ \mathrm{s}$

$v = \frac{s}{t} = \frac{300\times10^3}{5.184\times10^6}$

$= 0.0579\ \mathrm{ms^{-1}}$

$F = \frac{Kq}{r^2} = \frac{8.99\times10^9\times1.5\times10^{-6}}{20^2} = 33.7125\times1.5\times10^{-6}$

$= 5.056875\times10^{-5} = ma$

$s\ 300\times10^3$
$u\ 0$
v
$a\ 2.02275\times10^{-8}$
t

$a = 2.02275\times10^{-8}\ \mathrm{ms^{-2}}$

$s = ut + \frac{1}{2}at^2$ 1.011375×10^{-8}

$t = 5446337 \rightarrow 63$ days ∴ estimate approximatel correct.

ResultsPlus
Examiner Comments

This calculation is fully correct and the time at the end has been converted to units (days) comparable to the value in the question, but the direct comparison, such as 63 is approximately equal to 60, has not been made so the final mark has not been awarded.

(ii) The spacecraft moves to a new position, taking the satellite with it.

The distance between the satellite and the spacecraft remains constant, so the electrostatic force is constant.

The scientists estimate that the satellite could be moved a distance of 300 km in about 60 days.

Deduce whether this estimate is correct.

Assume gravitational forces are negligible and the satellite is initially at rest.

distance between centre of satellite and centre of spacecraft = 20 m
mass of satellite = 2500 kg

(4)

$$F = \frac{kQ_1Q_2}{r^2} = \frac{8.99\times10^9\times(1.5\times10^{-6})^2}{20^2} = 5.06\times10^{-5}\,N.$$

$$a = \frac{F}{m} = \frac{5.06\times10^{-5}}{2500} = 2.02\times10^{-8}\,m\cdot s^{-2}.$$

$$S = ut + \tfrac{1}{2}at^2.$$

$$S = 0 + \tfrac{1}{2}\times 2.02\times10^{-8}\times(60\times24\times60\times60)^2$$

$$S = 2.71\times10^5\,m = 271\,km < 300\,km.$$

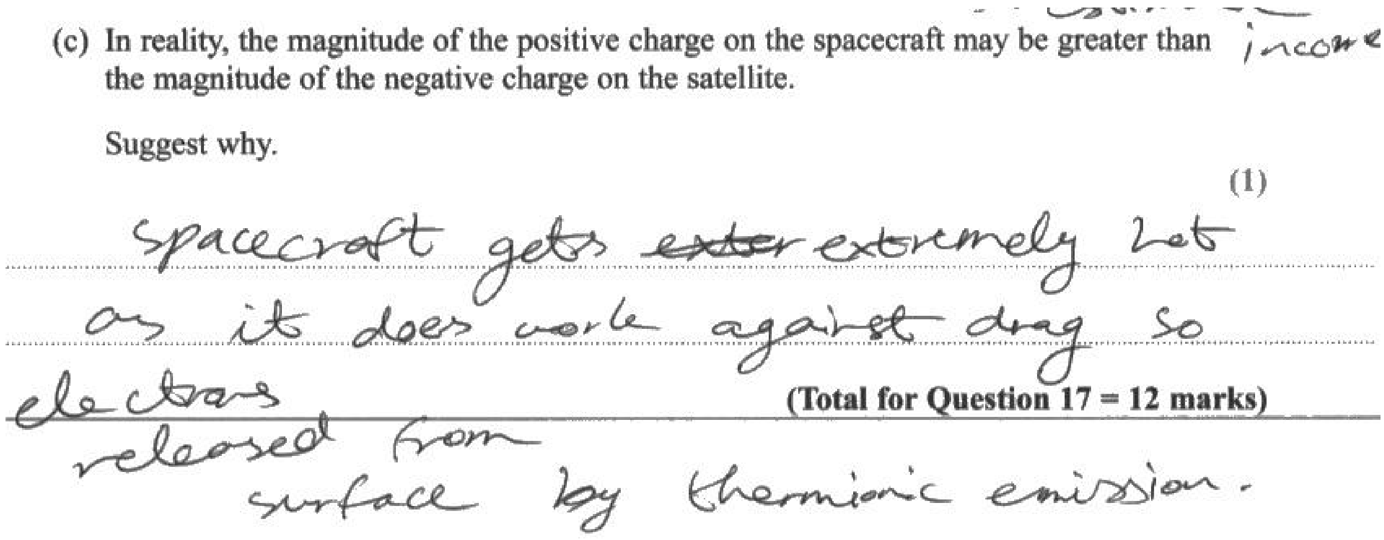
So this estimate is incorrect.

ResultsPlus
Examiner Comments

This is a good example of a well set out response with the required numerical comparison and written conclusion.

Question 17 (c)

Only 1 in 6 candidates gave a sensible suggestion here, usually expressing the idea that some of the electrons missed the satellite.



(c) In reality, the magnitude of the positive charge on the spacecraft may be greater than the magnitude of the negative charge on the satellite.

incorre

Suggest why.

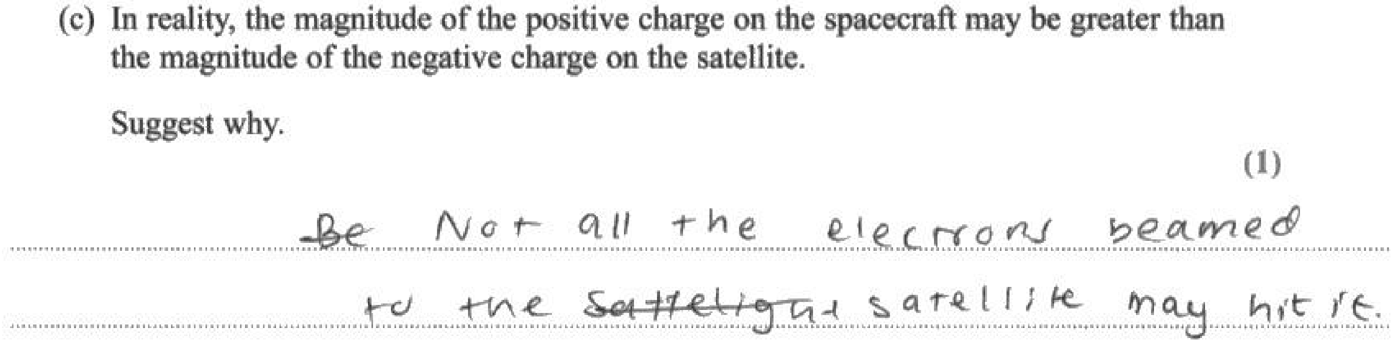
(1)

spacecraft gets ~~exter~~ extremely hot as it does work against drag so electrons released from surface by thermionic emission.

(Total for Question 17 = 12 marks)

ResultsPlus
Examiner Comments

This was an interesting idea, but candidates may safely assume that the satellite is in a vacuum.



(c) In reality, the magnitude of the positive charge on the spacecraft may be greater than the magnitude of the negative charge on the satellite.

Suggest why.

(1)

~~Be~~ Not all the electrons beamed to the ~~Sattelight~~ satellite may hit it.

ResultsPlus
Examiner Comments

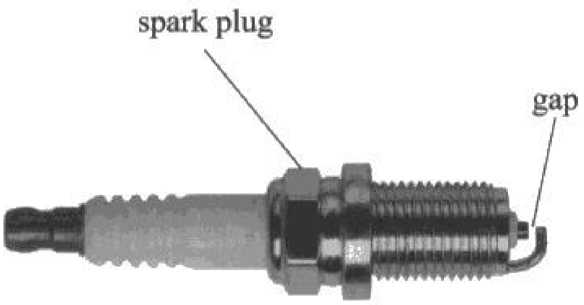
This is representative of the correct answers seen.

Question 18 (a)

Most of the candidates scored at least 1 mark, usually for stating that an emf is induced, and nearly half also mentioned that a magnetic field was produced by the current. Only about 1 in 6 candidates got full credit. MP3 was often attempted but not awarded because they did not mention a change in current or just referred to a change in flux generally and not a change in flux linkage with the secondary.

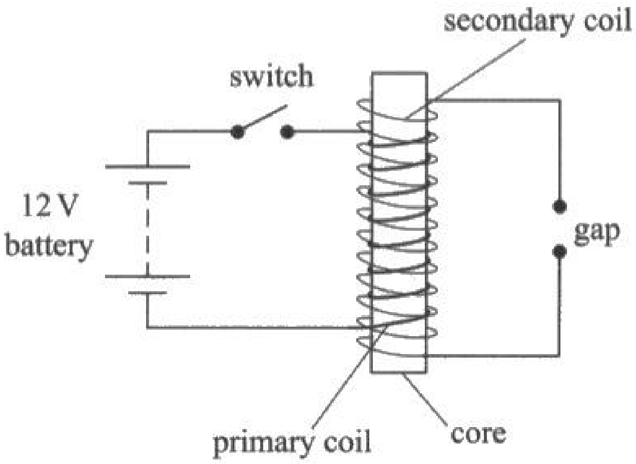
18 In some car engines the power is provided by burning a mixture of fuel and air.

The photograph shows a spark plug. The spark plug creates a spark that ignites the mixture. A very high potential difference (p.d.) across the gap in the spark plug is needed to produce the spark.



(Source: © Miro Novak / Alamy Stock Photo)

The very high p.d. is produced using the arrangement shown in the diagram below.



The switch is closed and the current in the primary coil increases to a maximum value. The switch is then opened and the current falls to zero almost immediately. The secondary coil produces a large p.d., creating an electric field strong enough to cause a spark across the gap.

(a) Explain how a p.d. is produced across the secondary coil when the switch is opened.

(3)

Magnetic field is associated with the current.

As the switch is opened, change in magnetic flux linkage

$\varepsilon = \frac{-dN\varphi}{dt}$, so ~~larger~~ large e.m.f. induced

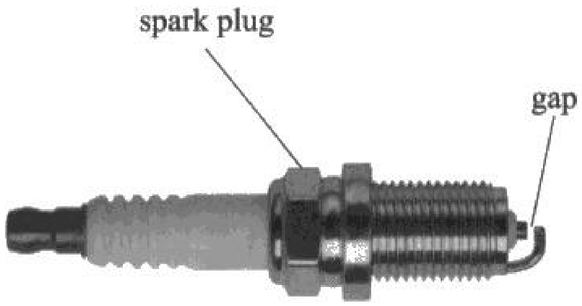
small Δt, so the p.d. produced is very large.

ResultsPlus
Examiner Comments

This response is awarded the first and third marking points. It does refer to a change in flux linkage when the switch is opened, but doesn't mention that this is because of the decrease in the current.

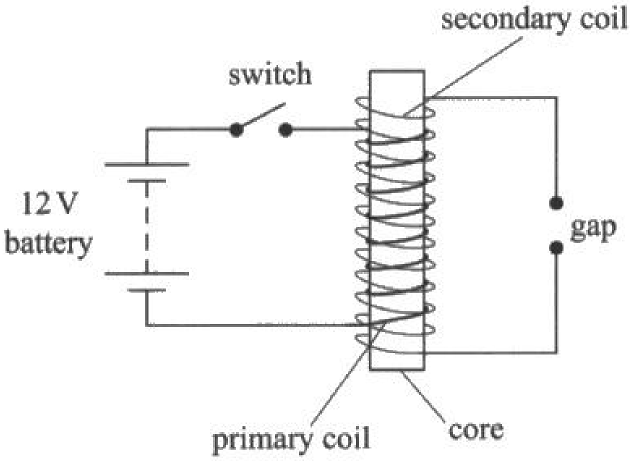
18 In some car engines the power is provided by burning a mixture of fuel and air.

The photograph shows a spark plug. The spark plug creates a spark that ignites the mixture. A very high potential difference (p.d.) across the gap in the spark plug is needed to produce the spark.



(Source: © Miro Novak / Alamy Stock Photo)

The very high p.d. is produced using the arrangement shown in the diagram below.



The switch is closed and the current in the primary coil increases to a maximum value. The switch is then opened and the current falls to zero almost immediately. The secondary coil produces a large p.d., creating an electric field strong enough to cause a spark across the gap.

(a) Explain how a p.d. is produced across the secondary coil when the switch is opened.

(3)

When the switch is opened, the magnetic flux linkage of the secondary coil changes. This is due to the change in current. As aresu Of the magnetic flux linkage changing an e.mf is induced as the circuit is closed and a potential difference is produced.

ResultsPlus

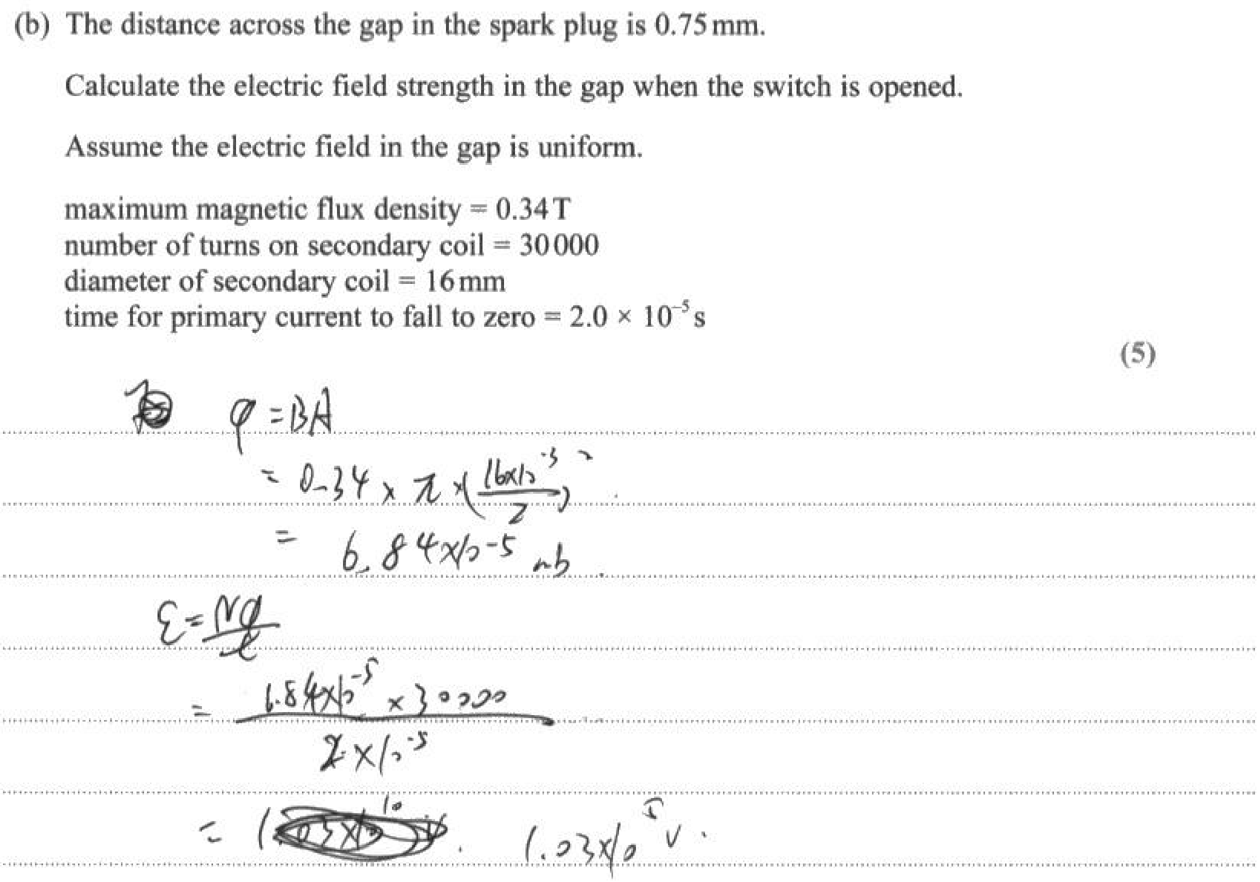
Examiner Comments

This is a typical example of one of the answers gaining full credit.

Question 18 (b)

Although this calculation included a long sequence of calculations, nearly half of the entry scored full marks. One pitfall was using the diameter instead of the radius in the area calculation and some candidates just used radius or diameter instead of area when calculating flux. There were some power of ten errors with mm. Some candidates were not awarded the final mark because they did not include a correct unit – or any unit at all.

Quite a few candidates combined several formulae and did the calculation in two steps using $V = B\pi r^2 N/t$ and $E = V/d$, and some did it in one. While most candidates who did this were able to complete the calculation correctly, some made calculation errors and then were not awarded all of the marks for 'use of' along the way because there was no clear substitution of each step.



(b) The distance across the gap in the spark plug is 0.75 mm.

Calculate the electric field strength in the gap when the switch is opened.

Assume the electric field in the gap is uniform.

maximum magnetic flux density = 0.34 T
number of turns on secondary coil = 30 000
diameter of secondary coil = 16 mm
time for primary current to fall to zero = 2.0×10^{-5} s

(5)

$\phi = BA$

$= 0.34 \times \pi \times (\frac{16\times10^{-3}}{2})^2$

$= 6.84\times10^{-5}$ wb

$\varepsilon = \frac{N\phi}{t}$

$= \frac{6.84\times10^{-5} \times 30000}{2\times10^{-5}}$

$= 1.03\times10^{5}$ V.

ResultsPlus
Examiner Comments

The emf has been calculated here, with clear working through the steps, but then it just stops without an attempt to calculate electric field strength. The candidate knows that their answer is not electric field strength because they have included the unit V.

(b) The distance across the gap in the spark plug is 0.75 mm.

Calculate the electric field strength in the gap when the switch is opened.

Assume the electric field in the gap is uniform.

$B \propto I$.

maximum magnetic flux density = 0.34 T
number of turns on secondary coil = 30000
diameter of secondary coil = 16 mm
time for primary current to fall to zero = 2.0×10^{-5} s

(5)

$$\frac{d(\phi N)}{dt} = \frac{d(BAN)}{dt}.$$

$$\frac{0.34 \times (8 \times 10^{-3})^2 \times \pi \times 30000}{2 \times 10^{-5}} = 102541.6$$

$$E = \frac{V}{d} = \frac{\cdot 102541.6}{0.75 \times 10^{-3}}$$

Electric field strength = 136.7×10^6 .

ResultsPlus
Examiner Comments

The calculations are all correct and clearly set out but the unit has been omitted, so only 4 marks have been awarded.

(b) The distance across the gap in the spark plug is 0.75 mm.

Calculate the electric field strength in the gap when the switch is opened.

Assume the electric field in the gap is uniform.

maximum magnetic flux density = 0.34 T
number of turns on secondary coil = 30 000
diameter of secondary coil = 16 mm
time for primary current to fall to zero = 2.0×10^{-5} s

(5)

$\varepsilon = -\frac{\Delta \Phi}{\Delta t} =$ ~~30 000 ($-\frac{\Delta NBA}{\Delta t}$ = $-$)^3~~

$= -\frac{\Delta NBA}{\Delta t}$

$= -\frac{30000(0.34)(\pi)\left(\frac{16\times10^{-3}}{2}\right)^2}{2\times10^{-5}}$

$= 102541.5842 \approx 1.03\times10^{5}$ V

$E = \frac{V}{d}$

$= \frac{1.03\times10^{5}}{0.75\times10^{-3}}$

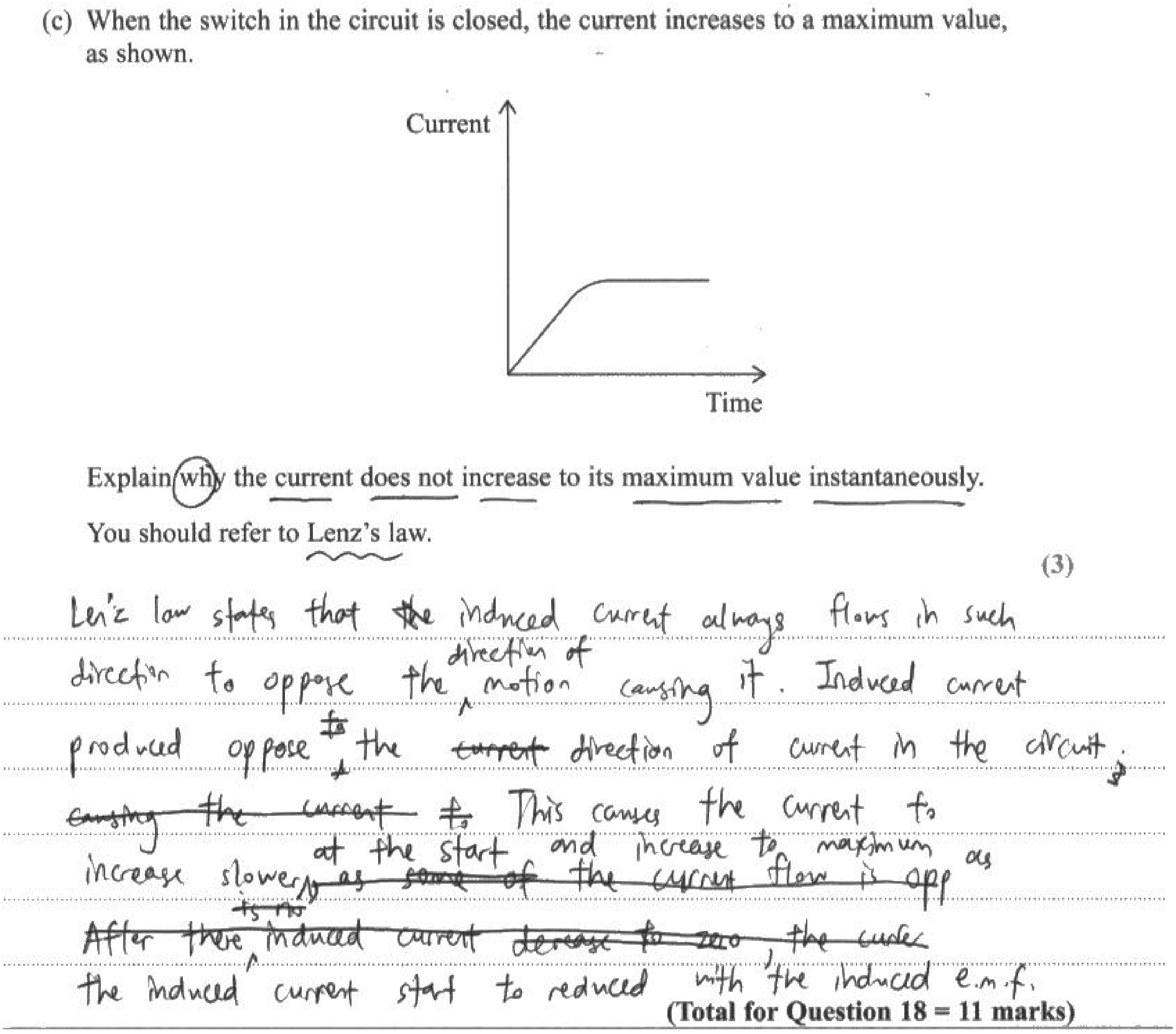
Electric field strength = 1.37×10^{8} Vm^{-1}

ResultsPlus
Examiner Comments

This is an example of a response scoring full marks.

Question 18 (c)

Only about a third of candidates scored here, usually just 1 mark for stating that induced e.m.f./current/field is such as to oppose the change causing it. Many more candidates attempted a Lenz's law statement, but not as it applied to this situation. For example, they referred to a force opposing the movement that caused the induced emf, but there were no moving parts in this context. Some candidates were awarded the second marking point, but usually because they had heard of 'back emf'. Some candidates seemed to suggest that there were two opposing currents in the wire rather than citing opposing p.d.s. Very few candidates got the idea of reducing the rate of increase of the current, being more likely to state that it decreased the current, which was clearly not what was shown on the graph.



(c) When the switch in the circuit is closed, the current increases to a maximum value, as shown.

Explain why the current does not increase to its maximum value instantaneously.

You should refer to Lenz's law.

(3)

Len'z law states that ~~the~~ induced current always flows in such direction to oppose the direction of motion causing it. Induced current produced oppose ~~to~~ the ~~current~~ direction of current in the circuit. ~~causing the current~~ ~~to~~ This causes the current to increase slower at the start and increase to maximum as ~~as some of the current flow is opp~~

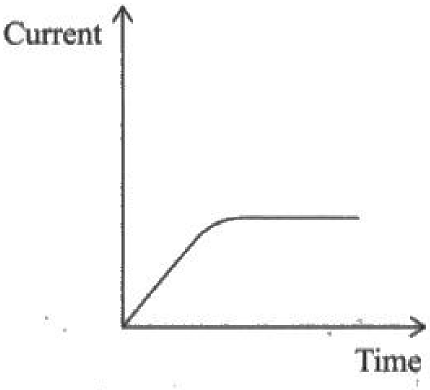
~~After there is no induced current decrease to zero, the cudec~~ the induced current start to reduced with the induced e.m.f.

(Total for Question 18 = 11 marks)

ResultsPlus
Examiner Comments

This has elements of the required explanation, but not with the correct detail. The Lenz's law part refers to resisting motion, but there is none here. The response describes two currents in opposite directions in the same wire, which is not possible. It also, finally, refers to current decreasing, which it is clearly not doing in the graph.

(c) When the switch in the circuit is closed, the current increases to a maximum value, as shown.



Explain why the current does not increase to its maximum value instantaneously.

You should refer to Lenz's law.

(3)

Lenz's law states that induced emf is such that to oppose the change causing it and as it opposes the motion current cannot increase to its maximum value instantaneouly.

ResultsPlus
Examiner Comments

This was allowed the first mark for the general statement of Lenz's law, up to '... causing it'. The continuing part about motion does not apply here, but the general part is still correct.

Paper Summary

Based on their performance on this paper, candidates should:

- Remember when you are asked to deduce whether a statement is true using numerical evidence, that you must make a direct comparison of two values and state your conclusion in words.
- Learn standard descriptions of physical processes, such as electromagnetic induction, and required contexts, such as linacs, and be able to apply them with sufficient detail to specific situations, identifying the parts of the general explanation required to answer the particular question.
- Ensure when substituting in an equation with a power term, eg square, that they don’t forget it in the calculation.
- Be sure to know the standard SI prefixes and be able to apply the correct power of ten.
- Remember when using graphs, to read the scale values on either side of the point of interest to ensure you are using the scale correctly.
- Remember that physical quantities have a magnitude and a unit and both must be given in answers to numerical questions.