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Examiners' Report
June 2018

IAL Physics WPH04 01

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Introduction

The assessment structure of Unit 4, Physics on the Move 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 was a relatively straightforward paper that allowed students of all abilities to demonstrate their knowledge and understanding of Physics by applying them to a range of contexts with differing levels of familiarity.

Students at the lower end of the range of achievement could complete calculations involving simple substitution and limited rearrangement, including structured series of calculations, but could not always tackle calculations involving several steps or other complications, such as using the circumference of a circle correctly or using the correct mass for an alpha particle. They also knew some significant points in explanations linked to standard situations, such as electromagnetic induction and alpha particle scattering but failed to apply these to the context of the question and did not always set out their ideas in a logical sequence, sometimes just quoting as many key points as they could remember.

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

Section A Multiple Choice

Question	Answer	Most common incorrect answer
1	A	C (205 neutrons, 82 protons)
2	B	D (neither momentum or kinetic energy conserved)
3	C	B (1/2CV^2)
4	D	A (beta decay)
5	D	B (from the top of the tube to the bottom)
6	C	B ($\pi^+ \rightarrow e^- + \nu_e$), although other wrong answers were selected almost as frequently
7	B	C (uud)
8	C	A (2F)
9	B	C
10	D	B (2NC^{-1})

Possible reasons for some incorrect choices:

1. Students are subtracting 4 from the nucleon number and 2 from the proton number, mistaking the nucleon number for the number of neutrons

2. Students have misunderstood the definition of an elastic (and therefore, inelastic) collision

3. Perhaps this was chosen as students just rearranged the formulae provided on the data sheet without appreciating that the effective capacitance for capacitors in parallel is just the sum of the individual capacitors

4. Students may have selected beta decay as the mechanism for releasing electrons, perhaps never having seen a deflection tube

5. Students are probably thinking of the effect of an electric field

6. The fact that the three incorrect answers were selected with almost equal frequency suggests that students mis-read the question and chose a decay which would be possible

8. This wrong answer would be reached by doubling both charges and forgetting that the distance must be squared

9. Students realised that ε would be greater, without appreciating that the time would be shorter

10. Students used the wrong unit for the plate separation

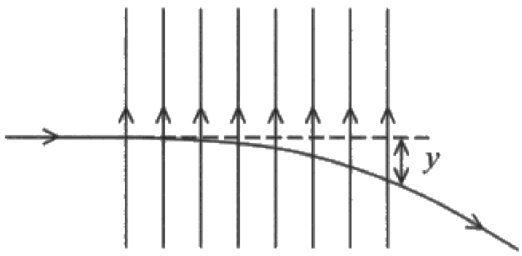
For the following questions, 11 to 18, the mark awarded for each student response is shown at the end of the Examiner Comment box.

Question 11

Over half of students had fully correct answers, with most scoring at least the first mark. However, some students were unable to progress any further. Of these incorrect responses, common attempts were to use $F = mv^2/r$, or to use the formula for a radial field. Others omitted the 0.5 or forgot to square t on the correct equation.

It was pleasing to see very few power of ten or unit errors.

11 An electron travels through a uniform electric field for a time of 4.3×10^{-9} s. It is deviated from its original path as shown.



Calculate the deflection y of the electron.

(4)

electric field strength = $1.3 \times 10^4 \text{ N C}^{-1}$

$E = \frac{F}{Q} \Rightarrow \frac{1.3\times10^4}{1.6\times10^{-19}} = 8.15\times10^{22}$

$E = KQ/r^2$

$r^2 = \frac{KQ}{E} \Rightarrow \frac{1.6\times10^{-19}}{4\pi\varepsilon_0 \times 8.15\times10^{22}}$

$r = 1.3\times10^{-16}$

$y =$ 1.3×10^{-16}

ResultsPlus
Examiner Comments

This student started promisingly by selecting the appropriate formula, but substituted in the wrong values (electric field strength for force) and calculated an answer they then tried to use in a wrong formula.

Often in multi-stage calculations, students can gain 'use of' marks for subsequent steps when they have previously made a simple mathematical slip or transcription error but in this case the value for electric field had been supplied in the question, and the quantity they were attempting to use was completely wrong. They also selected an incorrect formula to proceed with the calculation. Even if they had managed to reach the correct final answer, they would have missed the last mark due to the lack of a unit.

This attempt did not score any marks.

ResultsPlus
Examiner Tip

'Use of' marks are awarded for correct substitutions, not just for selecting the right equation. Always check that your values have been written in the same order as the symbols in the equation, particularly if this requires rearranging. Also make sure that you substitute fully, including the values of any constants you use.

11 An electron travels through a uniform electric field for a time of 4.3×10^{-9} s. It is deviated from its original path as shown.

Calculate the deflection y of the electron.

(4)

electric field strength = $1.3 \times 10^4 \text{ NC}^{-1}$

$E = \frac{F}{Q}$ $1.3 \times 10^4 \times 1.6 \times 10^{-19} = 2.08 \times 10^{-15}$ N

$F = ma$

$a = \frac{2.08 \times 10^{-15}}{9.11 \times 10^{-31}} = 2.28 \times 10^{15}$ ms^{-2}

$s = ut + \frac{1}{2}at^2$ $u = 0$

$s = \frac{1}{2}at^2$ $s = \frac{1}{2}(2.28 \times 10^{15})(4.3 \times 10^{-9})^2$

0.0211m

y = ~~0.02~~ 2.11×10^{-2} m

ResultsPlus
Examiner Comments

A very clear response for 4 marks. Each step of the calculation has been shown and intermediate answers calculated. The final answer has been given to an extra significant figure (although this was not required for this item) and the correct unit added.

ResultsPlus
Examiner Tip

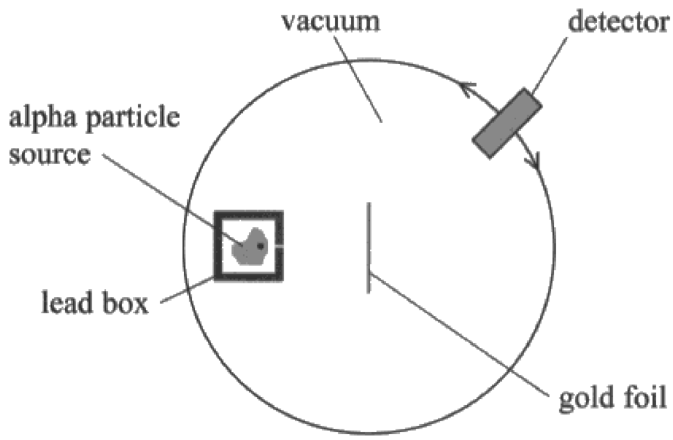
Always write down the formula being used, and show substitutions clearly. It is also helpful to give intermediate values in multi-stage calculations.

Question 12 (a)

This question has appeared in various forms on very many past papers, and the phrases used in students answers showed that they had used previous mark schemes when revising. A large minority failed to gain the first two marks due to stating "most alpha particles pass through with little or no deflection". It would seem that this statement is taught in some centres and may appear in some text books, however previous examiners' reports have highlighted that this will not be accepted on this examination. Other students missed full marks because their conclusions were not clearly linked to their observations. The most successful were those who labelled their statements or wrote them in order. Again, despite similar questions appearing frequently, there is still a lack of the clear, relative quantities; most, few, very few. Angles of deviation/deflection were also described too vaguely to score in many cases. Of those students who answered well in the main, there was still the deduction made that for large angles (greater than 90°) this was due to a concentration of mass and charge, when the only real deduction from this observation is that mass is concentrated or the mass of the nucleus is much greater than that of the alpha particle.

12 In the early 20th century, experiments were carried out in which high-speed alpha particles were directed at thin gold foil.

A simplified version of the apparatus used is shown.



(a) State two observations and corresponding conclusions made from the alpha particle scattering experiment.

(4)

- Most of alpha particles go through the gold foil
- This because most of the space in ~~nucleus~~ an atom is empty
- ~~Only~~ Very few alpha particles are deflected.
- This because ~~the~~ most of mass is concentrated in the nucleus which only occupy a small space in an atom.

ResultsPlus
Examiner Comments

This response fails to gain any marks, although it is clear that the student has a reasonable understanding of the experiment. Stating that most go through is not sufficient for marking point one, as there is no indication of whether the alpha particles are deflected or not. Consequently, their conclusion that most of the atom is empty space could not be credited as this was a dependent mark. Stating that very few were deflected cannot gain mark three or five, as they have not specified an angle of deflection. This means that they could not gain a mark for their final conclusion.

ResultsPlus
Examiner Tip

The description of observations and consequent deductions for this very familiar experiment need to be very specific in terms of relative numbers and angles for the observations. The conclusions need to be very clearly linked to the observations.

12 In the early 20th century, experiments were carried out in which high-speed alpha particles were directed at thin gold foil.

(a) State two observations and corresponding conclusions made from the alpha particle scattering experiment.

(4)

Most of the alpha particles went straight ~~st~~ through.
So the atom is mostly ~~em~~ empty space.
~~Only~~ Very ~~of~~ few of alpha ~~p~~ particles ~~are~~ were deflected to an ~~d~~ angle greater than 90°.
So there's ~~a~~ concentrated charge and mass on nucleus.

ResultsPlus
Examiner Comments

This student gains the first three marks but makes the common mistake of providing two deductions from their second observation (i.e linking the large angle deflection to a concentration of both mass and charge).

Note that went 'straight' through was acceptable for the first mark, although some students wrote 'went right through', which was not accepted.

12 In the early 20th century, experiments were carried out in which high-speed alpha particles were directed at thin gold foil.

(a) State two observations and corresponding conclusions made from the alpha particle scattering experiment.

(4)

·Most of the alpha particles are undeflected and pass through straightly, so we can conclude most space of atom of gold foil is empty.

· Few alpha particles are deflected of small angle, so we can conclude the nucleus in atom is positively charged.

· Very few alpha particles are deflected larger than 90°, so we can conclude the most mass of atom is concentrated in nucleus.

ResultsPlus
Examiner Comments

A clear four marks with the correct conclusions (for marking points 1 and 3) linked clearly to the correctly described observations. Although this question was only worth four marks, this student would have been able to score all six of the available marks. Note that 'nucleus' was considered acceptable for the idea of a concentration of charge or mass.

ResultsPlus
Examiner Tip

Ensure that the relative amounts of alpha particles is very clear (not just 'some') and that conclusions are clearly linked to the relevant observation.

Question 12 (b)

The first part of this item, the calculation, was handled extremely well by the majority of students with about half gaining 4 marks. Most did the conversion from MeV to eV and then from eV to J in one step and there were very few power of ten errors seen. It was also pleasing to see that students had learnt from previous similar calculations that it is not appropriate to use $E = hc/\lambda$ to calculate the wavelength associated with a particle. It was extremely rare for the final unit to be missing.

The second part was less well answered with only a quarter of students gaining the mark; the majority stating that diffraction was not significant just because the wavelength was smaller than the gap, failing to appreciate that they needed to qualify this with *much* smaller.

(b) (i) Calculate the de Broglie wavelength of the alpha particles.

(4)

kinetic energy of alpha particles = 5.00 MeV
mass of alpha particle = 6.64×10^{-27} kg

~~$\lambda = \frac{h}{p}$ $E_{KE} = \frac{1}{2}mv^2$ * $p = mv$~~ $\because E_{KE} = \frac{1}{2}mv^2$

~~$\therefore E_{KE} = \frac{1}{2}pv$~~ $\therefore v = \sqrt{\frac{2E_{KE}}{m}}$

$v = \sqrt{\frac{2 \times 5 \times 10^6 \times 1.6 \times 10^{-19} J}{6.64 \times 10^{-27} kg}} = 1.552 \times 10^7 ms^{-1}$

$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{6.63 \times 10^{-34} Js}{6.64 \times 10^{-27} kg \times 1.552 \times 10^7 ms^{-1}}$

$\approx 6.434 \times 10^{-15} m$

de Broglie wavelength = $6.434 \times 10^{-15} m$

(ii) Justify whether you would expect these alpha particles to be substantially diffracted by the gold foil.

(1)

separation of gold atoms = 2.88×10^{-10} m

No, these particles won't be diffracted by the gold foil as their wavelength (6.434×10^{-15} m) are ~~fall~~ far smaller than seperation of gold atoms (2.88×10^{-10} m)

ResultsPlus
Examiner Comments

This student scores full marks for both sections. They have used the alternative method of using kinetic energy to calculate velocity, before using velocity to calculate momentum, but at all stages their method and substitutions are clear. In the second part of the questions they have stated that the wavelength is far smaller to justify the lack of significant diffraction. Note that it was still possible to gain credit for part (b)(ii) even if their answer to part (i) was incorrect, providing that their comment was correct for their value.

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Examiner Tip

It is useful to add units to intermediate answers as well as quoting the formulae used, so that examiners can easily follow your working. This often means that marks can be gained, even if the final answer is incorrect.

(b) (i) Calculate the de Broglie wavelength of the alpha particles. hf $h\frac{c}{\lambda}$ **(4)**

kinetic energy of alpha particles = 5.00 MeV
mass of alpha particle = 6.64×10^{-27} kg

$E = \frac{hc}{\lambda}$

$5.00 \times 10^6 \times 1.6 \times 10^{-19} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{\lambda}$

$\lambda = 2.49 \times 10^{-13}$ m

de Broglie wavelength = 2.49×10^{-13} m

(ii) Justify whether you would expect these alpha particles to be substantially diffracted by the gold foil. **(1)**

separation of gold atoms = 2.88×10^{-10} m

No diffraction occurs as the 2.88×10^{-10} m is far greater than 2.49×10^{-13} m

ResultsPlus
Examiner Comments

This student gains the first mark for using the correct conversion from eV to J. However, they then go on to use an incorrect formula to calculate wavelength. In this case it led to an incorrect answer. However, they can still gain credit for part (ii) as their comment is correct for their values.

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Examiner Tip

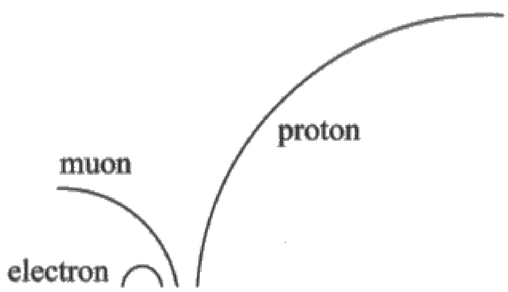
The formula $E = hc/\lambda$ is only appropriate for photons; for particles you must use $E_k = p^2/2m$ or equivalent.

Question 13 (a)

Around two thirds of students scored at least one mark on this item, most often for recognising that the mass of the muon was greater than the mass of the electron because its track curved less. The least successful mark was for comparing its mass to that of the proton, and it appears that many students did not think it necessary to compare to both electron and proton. Students often referred to muon as travelling in the opposite direction to the proton (or same direction as electron) but this was not sufficient; it was expected that students would refer to the way the particle tracks curved. Students also had difficulty describing the relative curvature, stating that the muon had greater curvature than the electron, when they meant a larger radius of curvature. A few recognised that it is actually charge to mass ratio that affects the degree of curvature and this was perfectly acceptable if described correctly.

13 The muon was identified in 1936 from the tracks of cosmic rays passing through a particle detector. The tracks for the muon were seen to be different from those of electrons and protons.

The diagram represents particle tracks for an electron, a muon and a proton passing through a uniform magnetic field. The particles have the same initial kinetic energy.



(a) Explain what can be deduced from the tracks about the mass and the charge of the muon.

(3)

The tracks show that the mass of the muon is more than the mass of the electron but less than the mass of proton. The charge on a muon is ~~the~~ ~~same~~ negative but not equal to the charge of electron.

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Examiner Comments

This answer correctly identifies the charge and relative mass of the muon but does not explain either deduction, so scores no marks.

ResultsPlus
Examiner Tip

Students should be familiar with the command words given in questions. Here, the instruction was to explain, so it was necessary to give the evidence leading to their deduction.

13 The muon was identified in 1936 from the tracks of cosmic rays passing through a particle detector. The tracks for the muon were seen to be different from those of electrons and protons.

The diagram represents particle tracks for an electron, a muon and a proton passing through a uniform magnetic field. The particles have the same initial kinetic energy.

(a) Explain what can be deduced from the tracks about the mass and the charge of the muon.

(3)

* Muon has a mass greater than electron.
* Muon has a negative charge as it opposes proton direction.
* $r = \frac{mv}{BQ}$, since muon has a greater mass this means it has a greater radius or curvature as $r \propto m$.

ResultsPlus Examiner Comments

This student has attempted to explain the charge and relative mass of the muon, but not sufficiently clearly to score. *It opposes proton direction* was not accepted for the first marking point as it does not link to curvature. They quote $r = mv/BQ$ to try to justify the relative mass but have confused radius and curvature and have thus contradicted themselves. It is also not clear which track they are referring to.

Note that it was not necessary to refer to $r = mv/BQ$ to gain the marks on this question.

ResultsPlus Examiner Tip

When comparing quantities, be very clear about which two quantities are being compared.

13 The muon was identified in 1936 from the tracks of cosmic rays passing through a particle detector. The tracks for the muon were seen to be different from those of electrons and protons.

The diagram represents particle tracks for an electron, a muon and a proton passing through a uniform magnetic field. The particles have the same initial kinetic energy.

(a) Explain what can be deduced from the tracks about the mass and the charge of the muon.

(3)

The muon has negative charge as it has same direction of curvature as electron. According to $r = \frac{mv}{Bq}$, muon has mass greater than electron but less than proton, since the radius of its curvature is greater than that of electron but less than that of proton. Mass is proportional to the radius of curvature.

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Examiner Comments

This student makes the correct deductions and explains all three clearly with reference to the diagram, scoring 3 marks.

Question 13 (b)

The vast majority of students gained full marks for this calculation, with marks being lost only for forgetting to square *c*.

(b) The muon has a mass of 106 MeV/c^2.

Calculate the mass of the muon in kg. $E = \Delta mc^2$

(3)

$106 \text{MeV}/c^2 \times c^2 = 106 \text{MeV}$

$106 \times 10^6 \times 1.6 \times 10^{-19} = 1.696 \times 10^{-11}$ J

$\Delta E = \Delta mc^2$

$m = \frac{E}{c^2} = \frac{1.696 \times 10^{-11}}{(3 \times 10^8)^2} = 1.88 \times 10^{-28}$ kg

Mass = 1.88×10^{-28} kg

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Examiner Comments

A fully correct response, with all stages in calculation clearly laid out.

ResultsPlus
Examiner Tip

It is good practice to include intermediate answers (with units) in multi-stage calculations.

$106 \times 10^6 \text{ eV} = 1.696 \times 10^{-11} \text{ J} \Rightarrow$ As $\Delta E = \Delta m c^2$

$\Downarrow$

$$\frac{1.696 \times 10^{-11}}{3 \times 10^8} = m \simeq 5.65 \times 10^{-20} \text{ Kg}$$

$$\simeq 5.7 \times 10^{-20} \text{ Kg}$$

Mass = 5.65×10^{-20} kg

ResultsPlus
Examiner Comments

This response starts correctly and gains the first mark for the coversion from eV to J. The student attempts to use the correct formula to calculate the mass, but (as is seen far too often) fails to square *c* thus gaining no further marks.

ResultsPlus
Examiner Tip

'Use of' marks are dependent on the correct quantities being substituted and used in a calculation. It is not enough simply to write down the formula.

Question 13 (c)

Just over half of students scored 1 mark on this question, with a quarter gaining both marks. Most students were able to make a correct statement about the character of muons or mesons, but often failed to make comparisons (for example, stating that a muon was a fundamental particle but not going on to explain whether or not a meson was fundamental). Correct responses regarding the strong force, or possible charges were credited but again, it was rare to see a complete comparison.

(c) The muon was originally called a mu meson. When other mesons were discovered, it was realised that the muon was not the same type of particle as other mesons.

Describe the differences between muons and mesons.

(2)

A muon is a lepton; a fundamental particle, whereas a ~~mu~~ meson is a hadron; a non fundamental particle. It has a sub-structure. Mesons are made up of a quark and an anti-quark, muons (leptons) have no quarks.

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Examiner Comments

This response gained both marks. It states clearly that the muon is fundamental but the meson isn't, and goes on to describe the muon as a lepton and the meson as having a quark and anti-quark. Note that stating that the meson is a hadron would also be an acceptable description, although it is not expected that students know the term 'hadron'.

A meson ~~cor~~ consists of one ~~quard~~ quark and an anti-quark. Muons however consists ~~of~~ of 3 quarks.

ResultsPlus
Examiner Comments

This response fails to score. Although their first comment is correct, the comparison is wrong. A large minority of students stated that a muon contained three quarks. The student failed to recognise that the question asked for differences, as they have only given one difference.

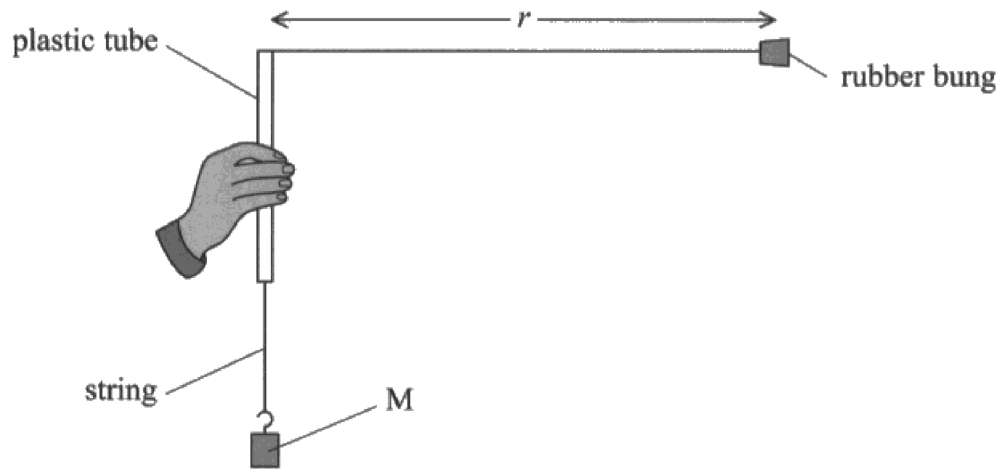
ResultsPlus
Examiner Tip

Read the question carefully; here more than one difference is expected and reference must be made to both particles under consideration when describing those differences.

Question 14 (a)

Over half of students gained all three marks on this item, with the majority scoring at least 1 mark for equating a weight with centripetal force. The common errors were to use the masses the wrong way round, or to add/subtract the masses. Occasionally a weight was used in place of a mass in the substitution into mv^2/r

14 The diagram shows an investigation of circular motion.



A small movement of the hand causes the rubber bung on the end of the string to move in a circular path of radius *r*. The rubber bung and the string may be assumed to rotate in a horizontal plane.

(a) For a particular experiment, *r* is 59 cm.

Calculate the speed of the rubber bung.

(3)

mass of M = 250 g
mass of rubber bung = 80 g

$mg = \frac{Mv^2}{r}$

$\left(\frac{80}{1000}\right)(9.81) = \frac{\frac{250}{1000} v^2}{\frac{59}{100}}$

$0.7848 = \frac{0.25v^2}{0.59}$

$v = 1.36 \text{ ms}^{-1}$

Speed = 1.36 ms^{-1}

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Examiner Comments

This is a fairly typical response where the masses are the wrong way round. The student fails to gain the first mark, as they have equated the weight of the wrong mass to the centripetal force. They have gone on to use the equation correctly (with a weight on the left hand side and a mass on the right), so gain the second mark.

ResultsPlus
Examiner Tip

Always substitute values clearly, as marks can be gained for a correct method even if the values are wrong.

14 The diagram shows an investigation of circular motion.

(a) For a particular experiment, r is 59 cm.

Calculate the speed of the rubber bung.

(3)

mass of M = 250 g
mass of rubber bung = 80 g

$$250\times10^{-3}\times9.81 = \frac{80\times10^{-3}\times v^2}{59\times10^{-2}}$$

$$v = \sqrt{\frac{250\times10^{-3}\times9.81\times59\times10^{-2}}{80\times10^{-3}}}$$

$v = 4.25\ ms^{-1}$

Speed = $4.25\ ms^{-1}$

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Examiner Comments

This student uses the correct masses and although they have not written any formulae, their substitution is clear enough to see that their method is correct and they go on to calculate the correct answer for full marks.

Question 14 (b)

This question proved to be very challenging to the majority of students and suggested that many still think of centripetal force as an actual force in its own right. It was also possible to answer the question in terms of the non-equilibirum situation as the mass is rising, or the final new equilibrium with the increased radius. Around a third of students scored one or two marks on this item, with only a small number gaining all three marks. The marks gained most often were for recognising that Mg was constant, and for stating that for a circular path, tension = mv^2/r so if v increases, r must increase. The final mark proved most challenging, perhaps students thought it was too obvious to mention. This is another example of students explaining physics without relating it to the specific situation. In this case they were asked to explain why M moved higher, so it was not enough just to explain why the radius of the circular motion increased.

(b) The speed of the rubber bung is increased.

Explain why M now moves to a higher position.

(3)

due to $F=m\frac{v^2}{r}$ when the speed of the rubber is increased, the centripetal force of the rubber bung is increased. So the vertical component of centripetal force is increased. the vertical component resultant force is larger than the weight of M. Due to $F=ma$ So the M has a upward acceleration, so moves to a higher position. the upthrust force is higher than the weight of M.

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Examiner Comments

This response, which does not gain any marks, shows the typical confusion that students have about centripetal force. Many simply stated that as the bung went faster, the centripetal force increased, rather than mv^2/r increasing. The rest of the response (vertical component of centripetal force and upthrust) is not worthy of credit.

① The weight of M ~~is~~ is acted to be the centripetal force of rubber bung. ~~Tension~~ ~~provide~~ and the direction of tension is always perpendicular to the ~~velocity~~ velocity of rubber. This is circular motion.

② $T = \frac{mv^2}{r}$. T keep constant and ~~we~~ speed of rubber bung increase, so which lead to the radius ~~decrease~~ increases.

③ The total length of string is not changed, so r increases, the position of Mass M will be higher.

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Examiner Comments

This response gains full marks from their second and third points. *T keep constant* gains the first mark and as they have quoted $T = mv^2/r$ they gain the second mark for 'speed of bung increase which lead to the radius increases'. Their third point clearly gains the final mark.

ResultsPlus
Examiner Tip

Make sure that answers relate to the specific situation in the question, which in this case was to explain why M moves higher.

Question 14 (c)

One third of students gained at least one mark on this item. Of those not scoring, about half thought that student A had the best method because with a fixed time there would not be uncertainty due to reaction time. The others recognised method B as better but failed to mention the probability of measuring partial rotations with method A. Many thought it was better because a stopwatch has an uncertainty of 0.001s. Those students scoring the first mark rarely explained fully why this would lead to more accurate results, but realising that a two mark questions needed more went on to describe techniques for measuring time period, or said that measuring a partial rotation would be 'difficult' without referring to a lack of precision. Students should appreciate that saying something is difficult to do is not the same as 'can't be measured precisely'.

(c) In order to calculate the speed of the rubber bung, the time for one rotation must be determined.

Student A suggests the number of rotations in a fixed time should be counted.
Student B suggests measuring the time for a fixed number of rotations.

Explain which method will produce more accurate results for the time of one rotation.

(2)

Student B's Method. It would be very hard to determine the number of rotations in a fixed time if ~~the~~ after the fixed time the bung is in the middle of a rotation / hasn't completed / integer. So better to count rotations & ~~[illegible]~~ measure time for them.

ResultsPlus
Examiner Comments

This is a typical one mark response. The student recognises that with method A there is unlikely to be a whole number of rotations in a fixed time, but fails to compare the precision of the two methods, just stating that it would be 'hard' to determine the number.

The method of student B.

It is very likely that the number of rotations would not be a whole number. The precision of Student A's idea is about $\frac{1}{10}$ of a rotation while the precision of Student B's idea has the precision of 0.01s which would be much smaller.

ResultsPlus
Examiner Comments

This student gains both marks. They recognise that for method A, it is unlikely that there would be an integer number of rotations, and (for the second mark) make a creditable attempt to compare the precisions of the two methods. It was not expected that students would attempt to put a value on the degree of uncertainty associated with the two methods but in this case it did help to make their answer clear.

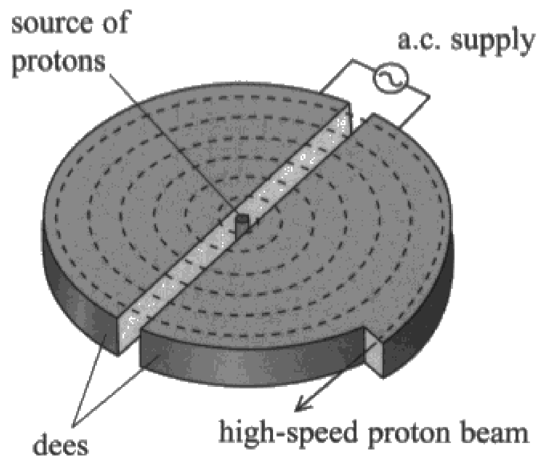
ResultsPlus
Examiner Tip

In questions asking to compare methods, it is nearly always expected that students will suggest relative precision of measuring data, with numerical values if possible.

Question 15 (a) (i)

This proved challenging for the majority of students, as is often the case with derivations. Less than half scored one mark with around a third scoring both. The first marking point, arriving at a version of *r = mv/BQ* proved most straightforward, but many getting this far used the standard formula for the time period of a whole circle only to end up with an extra '2' at the end, which was often just ignored or scribbled out. Some just said 'but it's only half a circle, so...' but this rarely scored unless they had made this clear earlier on in their attempt. The best students followed a method very close to the mark scheme, appreciating the difference between *T and t* and making this clear, or stating that for half a circle $v = \pi r/t$. Many seemed more comfortable using ω and this was acceptable as long as their working was clear.

15 The diagram shows a cyclotron.



A magnetic field of uniform magnetic flux density B acts vertically upwards through the plane of the cyclotron. Protons travel along paths of increasing radius as their speed increases.

(a) (i) A proton of mass m and charge Q is travelling at a non-relativistic speed in the cyclotron.

Show that the time t for which a proton is in one of the dees is given by

$$t = \frac{\pi m}{BQ}$$

(2)

Centripetal force $= m\frac{v^2}{r} = m\omega^2 r = mv \cdot \omega$.

Force provided by magnetic field $= Bqv$.

$mv^2/r = Bqv$. $\quad r = \frac{mv}{Bq}$

$t = \frac{2\pi r}{v} = \frac{2\pi m}{Bq}$

and time in one dee is $\frac{1}{2}t = \frac{\pi m}{Bq}$

ResultsPlus
Examiner Comments

This is an example where the student gains the first mark, albeit via a roundabout route. The final two lines are typical of a response where the student realises that they have an extra '2' in their answer, but just divides by 2 to solve this. The comment that 'time in one dee is 1/2 t' was not sufficient for the second mark, as the question clearly states that *t* is the time for one dee (i.e. not *1/2t*). Better students who realised their error at the end went back and changed their working, some using *T* for the whole circle and *t* for one dee.

ResultsPlus
Examiner Tip

In derivations, in particular 'show that' type questions, it is very important to use the symbols stated in the question or the usual symbols such as shown on the data sheet. This avoids any ambiguity. Never attempt to fiddle answers to match the question; if your answer is wrong, go back to the beginning to sort out the error.

$$\frac{mv^2}{r} = F_{centripedal}$$

$$BQv = F_{magnetic}$$

$$F_{magnetic} = F_{centripedal}$$

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

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

$$m\frac{2\pi}{T} = BQ$$

$$\frac{2\pi m}{T} = BQ$$

$$\frac{2\pi m}{2t} = BQ$$

$$t = \frac{\pi m}{BQ}$$

As given

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

$$\omega = \frac{2\pi}{T}$$

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

Time in dee is half a cycle therefore $t = \frac{1}{2}T$

$$2t = T$$

ResultsPlus
Examiner Comments

In this response, the student has used the time period for a whole cycle, but has clearly labelled this *T* and has shown all working clearly. Although this is very similar to the previous example, the student has done enough to convince examiners that they appreciate the difference between the time periods and are not just trying to get rid of the 2 at the end.

Question 15 (a) (ii)

There was a widespread misconception that the frequency must be constant to cause the protons to spend the same amount of time in each dee, rather than because the protons spend the same time in each dee. However, around a third of students managed to score the first mark, usually for a comment about constant time rather than time being independent of radius or velocity. There were many examples of excellent descriptions drawn from the mark schemes of recent previous papers, but they rarely answered the question that had been asked, and it seemed that students did not appreciate that they were being asked to explain the *constant* frequency as most just explained how the cyclotron works. Many discussed the polarity reversing as the proton leaves the dee (rather than whilst it was inside the dee) and although they may have intended to suggest that it had reversed when the proton reached the gap their answers were not clear enough to say this. Very few students mentioned that the time for half a cycle must equal the time spent in a dee and students may have felt this too obvious to mention. A similarly small number recognised that the direction of the field needs to change every half cycle because the proton is travelling in the opposite direction. Overall, just under half of students gained two marks, with around a third gaining one mark.

(ii) Explain why an alternating potential difference of constant frequency is applied to the dees.

(3)

The proton is accelerated every constant time interval so the polarity of dees ~~[illegible]~~ need to be changed every half period of the cycle.

The proton is accelerated in dees between each ~~[illegible]~~ tubes.

The ac supply needs to switch every constant time interval.

The velocity of ~~particle~~ protons increase and the radiue also increace so the frequency is constant.

ResultsPlus
Examiner Comments

This response did not gain any marks. Proton accelerated in dees is not worth a mark and it seems that the student has some confusion about which part of the cyclotron is the 'dees'. Although they say 'constant time interval' several times, they don't make it clear that these are the same time intervals, so fail to score either the first or third mark. Note that we accepted 'electrode' for dee. It needed to be clear that f needs to be constant BECAUSE time in each dee is the same, not to make time in each dee the same. Students must be talking about the frequency of polarity changing, not frequency of protons circling.

The electric field produced by A.C p.d. is used to accelerate the protons.
So the polarity must reverses before the protons moves into gap again.
So it must keep constant ~~to~~ to accelerate protons when protons are in the gap
and reverse itselves' polarity when protons are in the dee, because the
Time for proton to do circular motion in the dee is constant since r increase ~~of~~
v increase. So it ~~will~~ must have constant frequency to reverse polarity half a cycle.

ResultsPlus
Examiner Comments

This response gains 2 marks, one for stating that the polarity must reverse whilst the proton is inside the dee, and the second for noting that the time in each dee is constant. This did not gain the second marking point, which was awarded most rarely.

ResultsPlus
Examiner Tip

Make sure that you answer the question asked and don't just write everything you know about a topic. Where there could be more than one time period, frequency etc. you must be very clear about the one you are discussing.

Question 15 (b)

This question discriminated very well and there was a full range of marks from 4 to 0. Many quoted the law of conservation of momentum which was not required in this case. Others, with good understanding, failed to gain full credit as they only described one or other of the accelerators (usually the LHC) so did not adequately explain the difference in masses of the particles created. A lot of students did not use momentum at all (despite this being instructed in the question) but attempted to use ideas of energy, stating that in the LHC there would be twice as much kinetic energy as there were two particles. Again, it was clear in the stem of the question that the initial total energy was the same in both cases. It was concerning how many thought that the colliding beams had twice the initial momentum and went on to say that in this case momentum wasn't conserved, often after they had just quoted the principle of conservation of momentum. The final mark was awarded least often as even if students discussed conservation of mass-energy thay failed to link it to anything in their answer.

*(b) In a cyclotron, high-energy protons are directed towards a stationary target.

In the Large Hadron Collider, beams of high-energy protons circulating in opposite directions cross, so that protons moving in opposite directions collide.

For the same initial total energy, the colliding proton beams allow the creation of particles of greater mass than the use of a stationary target.

Explain why, using the principle of conservation of momentum.

(4)

Stationary target : ~~As the Momentum~~ The system ~~have~~ has momentum before the collision, so it will also have momentum after the collision.

So the created particles will have kinetic energy, which means not all of mass-energy before the collision transferred to mass after collision.

Moving in opposite direction : If particles have the same magnitude of momentum, the total momentum of the system could ~~be~~ be zero, by which the total momentum of the system after the collision could be zero.

There might be stationary particle ~~produ~~ created, which means all kinetic energy ~~as~~ of the ~~syse~~system is transferred to mass by $\Delta m = \frac{\Delta E}{c^2}$.

So these allow the creation of particles of greater mass than the use of a stationary target.

ResultsPlus
Examiner Comments

This response gains full marks. The student compares the momentum before and after the collision for both methods, going on to explain that if there is momentum afterwards there will be some kinetic energy afterwards (for the cyclotron) but that the colliding beams could produce a stationary particle. They use $E = mc^2$ to justify the creation of a greater mass particle.

ResultsPlus
Examiner Tip

When presented with alternatives to discuss, make sure that you explain both and compare. It is useful to consider the number of marks available for a question and try to present your answer as a series of bullet points with one for each mark. This will also help you to present your argument in a logical order.

until the next dee' alters to the opposite charge.

*(b) In a cyclotron, high-energy protons are directed towards a stationary target.

In the Large Hadron Collider, beams of high-energy protons circulating in opposite directions cross, so that protons moving in opposite directions collide.

For the same initial total energy, the colliding proton beams allow the creation of particles of greater mass than the use of a stationary target.

Explain why, using the principle of conservation of momentum.

(4)

As the beam of high energy particles circulate in opposite direction ~~the~~ ~~there is an~~ the initial momentum is zero so the protons collide in opposite directions this would cause the final momentum to be zero. Therefore according to the conservation of momenta, the total vector sum of momenta before collision is equal to ~~to~~ the total vector sum of momenta after the collision. The speed of the protons increases, according to $E = mc^2$, energy would also be high. This energy is enough ~~for~~ to allow the creation of new particles.

ResultsPlus
Examiner Comments

Although this response correctly identifies zero momentum in the colliding beams, they fail to compare with the stationary target, so cannot gain the first mark. The speed of protons increasing is not correct on this occasion, as we are only considering the moment of collision. Although they quote $E = mc^2$ it is used in the wrong context, so cannot gain the final mark. Momentum is mentioned frequently, but not used to explain any difference in the masses of particles created. This response did not gain any marks.

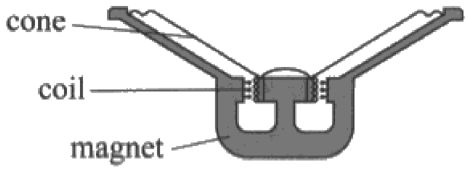
ResultsPlus
Examiner Tip

Follow instructions in the stem of the question; if asked to use a principle to explain a situation, it is not sufficient to merely quote that principle. Although it is often good practice to use formulae in answers, their relevance must be explained clearly.

Question 16 (a) (i)

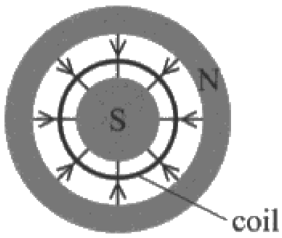
Around half of students gained at least one mark for this question, appreciating that coil (or wire, or current) was always perpendicular to the field. Of those failing to gain this mark, it was common to see 'because it's a radial field' with no further explanation. A few muddled their words, stating that the coil was perpendicular to the force. The second mark was awarded more rarely with most completely ignoring the sin *θ*, or not stating that it equalled 1.

16 The diagram and photograph show a moving coil loudspeaker.



(a) The loudspeaker contains a coil connected to a cone that is free to move. The coil is in a radial magnetic field. When there is a varying current in the coil, the magnetic force on it varies. This varying force causes the coil and cone to vibrate, producing sound waves.

The diagram below shows the magnet and the coil in the magnetic field.



(i) Explain why, even though the wire is not straight, the force F on a single turn of the coil can be calculated using

$$F = BIl$$

where l is the length of a single turn.

(2)

In a radial magnet, the magnetic force F acting from any point is perpendicular to the point of the wire it acts on and the magnetic field.

ResultsPlus
Examiner Comments

This response fails to score as the student has not made it clear that the field is perpendicular to the wire (the force being perpendicular to the wire/field is not sufficient). They have not mentioned sin θ.

ResultsPlus
Examiner Tip

In an explanation worth 2 marks, think what two separate points need to be made. If you are attempting to derive a formula, refer to the data sheet to see if it is a version on a formula provided.

Question 16 (a) (ii)

This apparently straightforward calculation proved to be quite challenging for the majority of students with just under half gaining a mark. The mark scheme was a little more rigorous than in previous similar questions with the students required to use πd to gain the first mark. It was common to see πr^2 instead of πd.

(ii) Calculate the force acting on a coil of 120 turns.

(2)

$I = 0.11\,A$
$B = 0.80\,T$
diameter of coil = 4.5 cm

$F = n.BIl$

$= 120 \times 0.80 \times 0.11 \times 4.5 \times 10^{-2}$

Force = 0.4752 N

ResultsPlus
Examiner Comments

This is an example of a very common incorrect answer. The student has realised that they need to use the formula from part (a)(i) and has remembered to multiply by the number of turns. However they have used the diameter instead of the length of a turn.

$F = BIl\sin\theta$ $l = 2\pi r$

$F = 0.80 \times 0.11 \times \left(\frac{9\pi}{200}\right) \times 120$ $= \frac{2\pi \times \left(\frac{4.5}{100}\right)}{2}$

$F = 1.49$ $= \frac{9\pi}{200}$

Force = 1.5N

ResultsPlus
Examiner Comments

A correct response gaining both marks. Typically, the student has used *2πr/2* but although this introduces an unnecessary step it is perfectly correct.

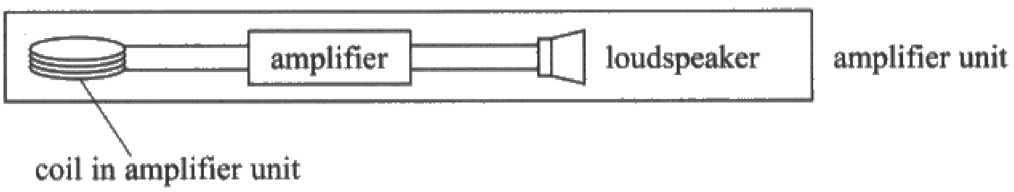
ResultsPlus
Examiner Tip

Previous parts of a question often point the way to a method to be used subsequently. Think carefully about the quantities you are substituting.

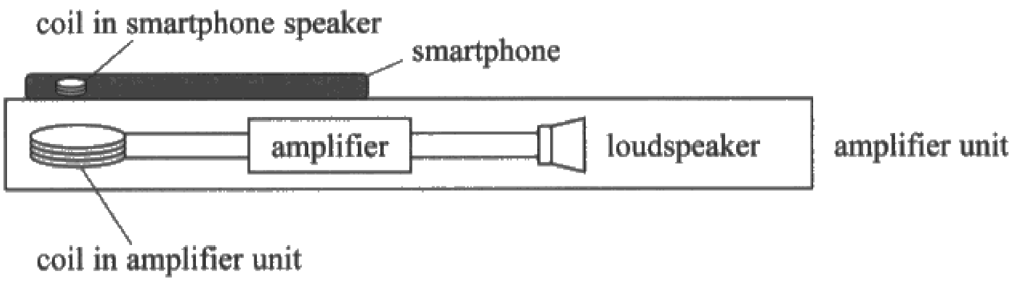
Question 16 (b)

The mark awarded most often on this question was for an emf being induced in amplifier coil. The reason that some students failed to gain more marks was because they did not distinguish between the coil in the smartphone and the coil in the amplifier unit, so that answers did not make it clear where the emf was induced. Weaker students merely described a mechanical transfer of vibrations from one coil to another, and rarely described magnetic fields as varying. There were also several examples of descriptions of the workings of the loudspeaker, which was not necessary. However, it was pleasing to see use of the term 'induced' in connection with the emf, far more frequently than in previous sessions.

*(b) An amplifier unit can be used to amplify music from devices with small speakers, such as smartphones. In the amplifier unit there is a coil connected to an amplifier and a loudspeaker as shown.



A smartphone is placed on the amplifier unit so that the coil in the smartphone speaker is above the coil in the amplifier unit.



Explain how the music played by the smartphone is also played through the loudspeaker in the amplifier unit.

(4)

The alternating current in a charger coil produce a magnetic field.
~~The flux~~ The varying flux in the coil.
e.m.f is induced.
It's in a completed circuit.
The magnetic field through a coil.

ResultsPlus
Examiner Comments

This response does not gain any marks despite several statements that are close to those on the mark scheme. This is an example of a student being too brief and thus not sufficiently clear. The magnetic field produced by alternating current in the 'charger coil' (presumably describing the smartphone speaker) is not described as varying, and they do not say which coil experiences the varying flux, or has the emf induced. Something is in a complete circuit, but again it is not clear what and the significance of this is not explored further.

When music is played by the smartphone, a current flows through its coil. This produces a magnetic field. As the current flow varies, so does the magnetic field it produces. As the coil in amplifier unit is in the magnetic field produces, it experiences a change in flux linkage. This induces an emf. As the coil in amplifier unit is connected to the amplifier, it is a complete circuit and current flows. The varying magnetic field causes there to be a continuous change in flux linkage. $\mathcal{E} = -\frac{dN\phi}{dt}$. The current produced in the coil in amplifier unit is opposite to that of the smartphone due to Lenz law.

ResultsPlus
Examiner Comments

This response gains full marks. It is clear that the current in the smart phone is varying, and so the magnetic field it produces is varying. They go on to state that the flux linkage in the amplifier coil is changing, thus inducing an emf (although they do not state explicitly that the emf is induced in the amplifier coil, it is reasonable to assume that this is the case, as they have just been discussing that coil). Finally, they explain why there is a current in the loudspeaker.

ResultsPlus
Examiner Tip

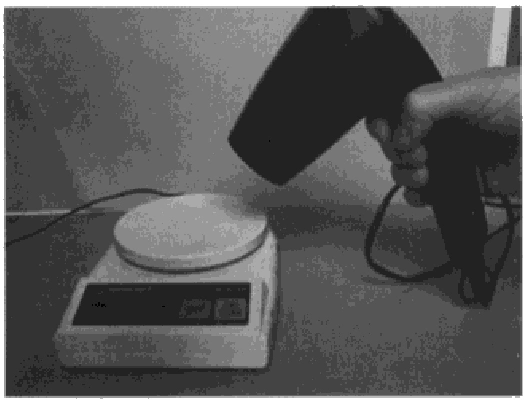
In stituations like this, where there are two similar objects, be sure to make it clear which you are talking about. It only takes a few seconds to qualify statements to make them unambiguous.

Question 17 (a)

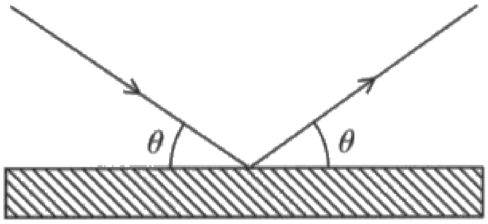
Another explanation of a derivation which proved very challenging for students. Many appeared to be working backwards from the given formula, attempting to justify (often with incorrect physics) where the factor of 2 and the sin θ came from. It was common to see suggestions that it was the vertical component of mass or force that was needed, and several thought it was the horizontal component (of something) that resulted in the sin θ. The best responses clearly stated that it was only the vertical component of momentum (or velocity) that was important. Reference to the change in momentum being $p - (-p)$ was an indication of a student who understood the situation; with others the factor of 2 was often inserted at the end, with a comment such as 'because the air bounces back it's x 2'.

Overall just over a third of students gained three marks for a satisfactory derivation, with the majority of these using the first route (i.e. change in momentum). The final mark (for recognising that the relationship they have proved was actually for the force on an air particle, so they needed a reference to Newton's third law to justify the same relationship applying to the balance) was awarded extremely rarely.

17 A student attempts to measure the speed of air leaving a hairdryer by measuring the force exerted by the air on an electronic balance.



(a) The diagram shows the path of an object of mass m colliding with a surface at speed v at an angle θ.



The collision takes a time t.

Explain why the force F exerted on the surface by a single collision is given by

$$F = \frac{2mv\sin\theta}{t}$$

(4)

~~$F = \frac{mv\sin\theta}{t} + \frac{mv\sin\theta}{t}$~~ $F = \frac{mv\sin\theta}{t}$

~~$= \frac{2mv\sin\theta}{t}$~~ ~~As~~ Taking both directions must be taken into account,

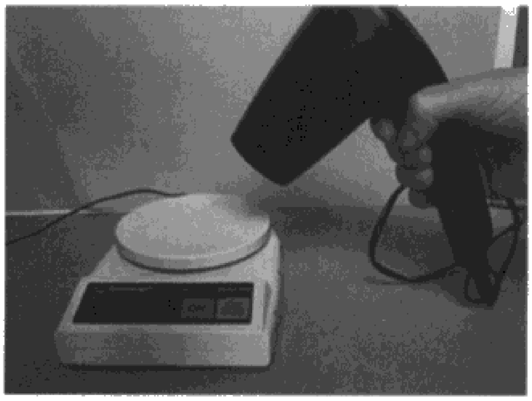
$p = mv$ $F = \frac{mv\sin\theta}{t} + \frac{mv\sin\theta}{t}$

$F = \frac{mv}{t}$ $= \frac{2mv\sin\theta}{t}$

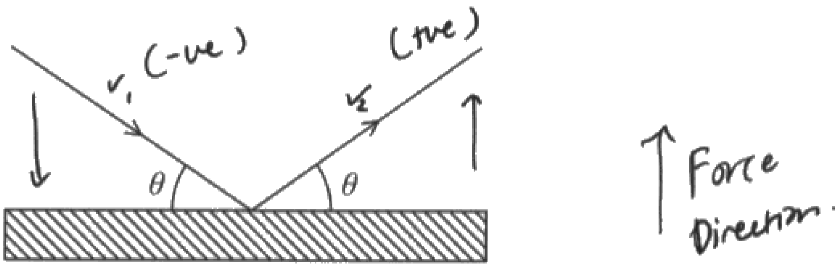
ResultsPlus
Examiner Comments

This response just gained the first marking point for use of $p = mv$. They did not gain the second mark as there is no indicatication of where $\sin\theta$ comes from (they could just be copying it from the stem of the question). Their attempt to use 'force = rate of change of momentum' is not clear enough for the third mark (if they had given $mv - (-mv)$ it would have gone some way to convincing examiners that they were using correct physics, but this just appears to be a way to arrive at the factor of 2 with insufficient justification). There is no mention of an N3 type statement for the final mark.

17 A student attempts to measure the speed of air leaving a hairdryer by measuring the force exerted by the air on an electronic balance.



(a) The diagram shows the path of an object of mass m colliding with a surface at speed v at an angle θ.



The collision takes a time t.

Explain why the force F exerted on the surface by a single collision is given by

$$F = \frac{2mv\sin\theta}{t}$$

(4)

Force acts perpendicular to surface ∴ only components of v perpendicular to surface are considered.

$V_1 = -V\sin\theta$ $\quad$ $V_2 = V\sin\theta$

$F\Delta t = \Delta p$

$F = \frac{mv - mu}{t}$ = ~~$mv\sin\theta - m(-v\sin\theta)m$~~ $\frac{mv\sin\theta - m(-v\sin\theta)}{t}$

$F = \frac{2mv\sin\theta}{t}$

ResultsPlus
Examiner Comments

This response has clearly used $p = mv$ for the first mark. The initial and final components of velocity have been stated, with this being further explained on the diagram. Clear working on the penultimate line gains the third mark, but unfortunately they have stopped there with no discussion of the force exerted on the surface, so three marks in total.

ResultsPlus
Examiner Tip

It is rare that something can be explained using just mathematical rearrangements and substitutions; explanations need words. Remember that forces come in pairs and be clear about which force you are discussing.

Question 17 (b) (i)

The most common error on this question was to use $m = VA\rho$ rather than $m/t = VA\rho$ causing students to end up with a '*t*' they did not want. This was often ignored or even just scribbled out. Better responses realised that $t = 1$ and as long as this was stated clearly these could go on to score all marks. As in similar questions, students assumed too much and did not start their explanation from the beginning, with otherwise good answers failing to state that the gradient was $F/\sin\theta$ or making this clear in some way. There was also confusion over the use of 'm' for gradient and for mass; another example where words would really help.

(i) The student assumes that the air behaves as in part (a).

Show that, in this case, the gradient of the graph is $2v^2A\rho$.

(3)

$F = \frac{2mv\sin\theta}{t}$

$\frac{F}{\sin\theta} = \text{gradient}$

$\frac{2mv}{[\text{scribbled out}]} = \text{gradient}(m)$

As $m = VA\rho$ so

$m = \frac{2(VA\rho)V}{[\text{scribbled out}]}$

$m = \frac{2V^2A\rho}{[\text{scribbled out}]}$

ResultsPlus
Examiner Comments

This is an example of a student who has not picked up on the fact that $VA\rho$ is mass per unit time, and so has ended up with a factor of *t* which they have just decided to ignore. Their use of m for gradient could also be considered to be ambiguous. This response just scores the first mark for stating that gradient = $F/\sin\theta$.

ResultsPlus
Examiner Tip

If you find terms or factors that should not appear in your answer, you should go back and see where the mistake has occurred.

(i) The student assumes that the air behaves as in part (a).

Show that, in this case, the gradient of the graph is $2v^2A\rho$.

(3)

Compare $F_B = \frac{2mv \sin\theta}{t}$ to $y = mx + c$, the gradient is $\frac{2mv}{t}$.

Since $\frac{m}{t} = vA\rho$, gradient $= 2vA\rho \times v = 2v^2A\rho$.

ResultsPlus Examiner Comments

This is a response that does not clearly follow either of the suggested routes, yet clearly has all the necessary stages. In questions such as these it is not possible to list every possible combination of steps that students might take, but as long as answers are well structured and clear, they will gain the marks. Here, the student has wisely used a few words to link their steps, making their reasoning unambiguous and gaining full marks.

ResultsPlus Examiner Tip

Use words to explain your stages in a derivation and be sure to show every step in 'show that' questions.

Question 17 (b) (ii)

Just under half of students approached this correctly and arrived at an answer that was inside the accepted range. Of those with answers out of range, it was often because their best fit line was very poorly drawn, often without a ruler. A significant number of students did not draw a best fit line at all, and just used a pair of points. A wrong response seen fairly often was to take the sine of the values on the horizontal axis even though these numbers were already sines of angles!

(ii) Calculate the speed of the air.

(3)

area of hairdryer nozzle = $2.0 \times 10^{-3}\,m^2$
density of air = $1.2\,kg\,m^{-3}$

$$\text{gradient} = \frac{0.29 - 0.05}{0.88 - 0.16} = \frac{1}{3}$$

$$\frac{1}{3} = 2v^2A\rho$$

$$\frac{1}{3} = 2v^2(2\times10^{-3})(1.2)$$

$$v^2 = \frac{\left(\frac{1}{3}\right)}{2(2\times10^{-3})(1.2)} = \frac{625}{9}$$

$$v = \frac{25}{3} = 8.3\,ms^{-1}$$

Speed of the air = $8.3\,ms^{-1}$

ResultsPlus
Examiner Comments

This response, gaining all three marks, starts well with a good attempt at a best fit line and large triangle drawn on the graph to use to calculate the gradient. They have read the values from their line correctly and shown all their working clearly to arrive at an answer in the middle of the accepted range with the correct unit.

Question 17 (c)

This question proved challenging for many students, with around two thirds suggesting errors of technique, faulty apparatus or calculation. Many stated that because the points were fairly scattered, the gradient could be wrong. Of those gaining the first mark, the most common answers were regarding the changing density of air, not all the air striking the balance, and the air hitting the balance at a range of angles. Very few went on to explain how or why this would affect the calculated speed, with most students attempting to gain two marks by suggesting two reasons. Several students referred to the range of angles being too small, saying that there were no angle between 0 and 0.4, obviously not noting that the axis was sin *θ.*

(c) Suggest why the speed calculated in part (b)(ii) might be incorrect.

(2)

The speed is calculated using the gradient of a scatter graph, the data hence is very varied. the line drawn might not be the line of best fit. The forces measured are very small ~~ant~~ and the ~~angles used are a very small~~ range of angles used ~~as~~ are very small.

ResultsPlus
Examiner Comments

This response failed to score. In questions asking why experimental data might not be accurate, it is never acceptable to suggest that mistakes have been made. This student has referred to the values measured being very small, and for this question that was not an accepted response but even so, without reference to uncertainty due to the resolution of measuring instruments, the suggestion is without merit.

(c) Suggest why the speed calculated in part (b)(ii) might be incorrect.

(2)

~~The speed of air from obtains is not roug~~

Collisions of air particles take place therefore the force on the scale balance value would be less than the actual force value as work is done against resistive forces, the value shown is actually the resultant force.

ResultsPlus
Examiner Comments

This response gained both marks. Collisions of air particles gains the first mark and the fact that this would reduce the force on the balance gains the second mark.

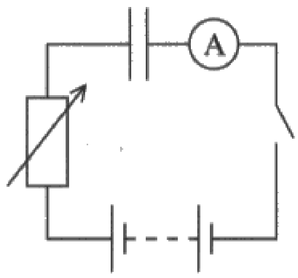
ResultsPlus
Examiner Tip

When asked to suggest why a value may be wrong, look at the design of the experiment or the measuring instruments used rather than suggesting that mistakes have been made. You should also suggest why and how this will affect the calculated value.

Question 18 (a)

This question split students with a clear majority appreciating that the exponential decay equation (and time constant formula) were not relevant in this instance as the current was being kept constant. Most of these students went on to score full marks. Those using the exponential rarely scored any marks. The majority of responses failing to score used *T* = *RC,* which leads to the 'show that' answer and it is strange that these students did not question why such a simple substitution yielded four rather than two marks.

18 A student investigating capacitors uses the circuit shown.



The capacitor is initially uncharged. When the switch is closed, there is a current in the circuit and the capacitor charges.

The resistance of the variable resistor is adjusted as the capacitor charges in order to maintain a constant current in the circuit.

After a time of 132 s the capacitor is fully charged.

(a) Show that the capacitance of the capacitor is about 5000 μF.

(4)

initial resistance = 28.0 kΩ
applied potential difference = 6.00 V

$t = RC$

$C = \frac{t}{R}$

$= \frac{132}{28 \times 10^3}$

$= 4.71 \times 10^{-3} \times 1 \times 10^6$

$C = 4710\ \mu F$

$\approx C = 5000\ \mu F$

ResultsPlus
Examiner Comments

It is understandable that some students may have thought that this was a correct method, as the answer reached rounds to the 'show that' value, and this was a fairly typical response, seen in around a quarter of cases. However, students should know that the time constant is the time for an exponential decay to fall to 1/*e* of its original value, so has no meaning in this situation.

ResultsPlus
Examiner Tip

A four mark calculation will require the use of three relationship (or conversions) plus the correct final answer. If you have only used one formula, you have missed something out!

(a) Show that the capacitance of the capacitor is about 5000 μF.

(4)

initial resistance = 28.0 kΩ
applied potential difference = 6.00 V

$V = IR \Rightarrow 6.00 = I(28000) \Rightarrow I = 2.14 \times 10^{-4}$ A

$Q = It \Rightarrow Q = (2.14 \times 10^{-4})(132) \Rightarrow Q = 0.028$ C

$C = \frac{Q}{\Delta V} \Rightarrow C = \frac{0.028}{6} \Rightarrow C = 4.67 \times 10^{-3}$ F $\times 10^{6}$

$\Rightarrow C = 4670\ \mu F$

ResultsPlus
Examiner Comments

This is a clear four mark response. Every step in their calculation is shown clearly with intermediate answers given.

ResultsPlus
Examiner Tip

In 'show that' calculations, quote the formula you are using (in words of usual symbols), then substitute, then give the answer plus unit. Do this for every stage of your calculation.

Question 18 (b)

Around half of students managed to gain at least one mark on this question, most often for appreciating that without reducing the resistance the current would fall. However, it was surprising how many thought the resistance should be increased. Not many attempted to use ideas about the potential differences across the capacitor and resistor to explain why the current would fall, and even then there was a lot of confusion about how the potential differences would change. Answers rarely made it clear which p.d. they were talking about.

(b) Explain whether the resistance of the variable resistor is steadily increased or steadily decreased in order to maintain a constant current.

(3)

The resistance ~~should~~ of the variable resistor is steadily decreased to maintain a constant current. This is because as the capacitor been charged, the resistance ~~of the~~ ~~decrease~~ of the circuit increase. So, to balance the resistance from the beginning until the end, the variable resistor should decrease ~~its~~ the resistance.

ResultsPlus
Examiner Comments

This response did not gain any marks. They have not discussed changes in potential difference across either component, and have just said that the resistance of the circuit increases. For the third mark there were two alternatives on the mark scheme and this answer is insufficient for either (just saying resistance must decrease to maintain a constant current is insufficient, as constant current has already been stated in the question).

ResultsPlus
Examiner Tip

Marks will never be awarded for a '50:50' guess (i.e. just stating whether resistance increases or decreases with no explanation or incorrect explanation will not gain a mark).

(b) Explain whether the resistance of the variable resistor is steadily increased or steadily decreased in order to maintain a constant current.

(3)

As capacitor charges, p.d across capacitor increases while p.d across resistor decreases, since p.d decreases, V=IR, V decreases, R decreases to keep current constant so resistance of resistor steadily decrease.

ResultsPlus
Examiner Comments

This response gains all three marks and follows the mark scheme closely. They have quoted $V = IR$ to justify their final mark and it is clear which p.d. they are discussing from the previous part of their answer.

ResultsPlus
Examiner Tip

If there are two of the same quantity under discussion (for example, p.d.s in this situation) make it clear which you are talking about.

Question 18 (c) (i)

More than half of students scored both marks here. Confusion often arose where students used a combination of quantities and units, with *C* meaning coulombs, capacitance and even current in some cases! Some students went beyond what was expected and attempted to break down to base units, which merited both marks if carried out correctly although often led to a muddle.

(c) A textbook states "In a circuit with constant resistance, the time to fully discharge a capacitor is equal to $5RC$".

(i) Show that RC has the unit of seconds.

(2)

$RC = \Omega F$

$= \frac{V}{A} \times \frac{C}{V}$

$= \frac{C}{A}$

$= t \rightarrow$ seconds.

ResultsPlus
Examiner Comments

This is an example of a student choosing to work in units rather than quantities. This would be perfectly acceptable if they had not missed out the link from C/A to *t*. They needed to show that C = As for the second mark, so one mark only.

ResultsPlus
Examiner Tip

In 'show that' questions, do not miss out a single step in an attempt to be concise; you need a formula to link quantities and units.

(c) A textbook states "In a circuit with constant resistance, the time to fully discharge a capacitor is equal to 5*RC*". $Q = It$

(i) Show that *RC* has the unit of seconds.

(2)

~~T = RC~~ ~~time constant~~

(1) $V = IR$

(2) $C = Q/V$ (3) $V = \frac{Q}{C}$

~~$T = (28 \times 10^3) \times 5000$~~

(6) $\frac{Q}{I} = t$ ~~$T = 140 \times 10^6$~~

(4) $IR = \frac{Q}{C}$ (5) $RC = \frac{Q}{I}$

(7) $RC = t$

ResultsPlus Examiner Comments

Although this response looks untidy, the student has clearly numbered the stages of their reasoning which makes it possible for examiners to keep track. Both marks were awarded.

ResultsPlus Examiner Tip

If you have to cross out part of an answer help the examiner to see the order in which you worked. This will maximise your chance of gaining marks.

Question 18 (c) (ii)

This fairly straightforward question seemed to confuse students, with many just multiplying *RC* by 5 with the comment that this was (slightly) larger than 132 seconds. Some students, who had done a valid calculation using the exponential function failed to gain the final mark by just stating that 'the book is correct' with no justification about the charge left being a tiny proportion of the original charge (or close to zero). Some used actual values from the previous part of the question (rather than the ratio Q/Q_0) but as long as their conclusion about the proportion of charge remaining was correct this was given full credit.

(ii) Evaluate the statement from the textbook. Your answer should include a suitable calculation. **(3)**

τ = time taken to discharge the capacitor to 37% of it's charge

~~$Q = Q_0 e^{-t/RC}$~~

~~$37 = 100 e^{-t/...}$~~

$\tau = RC$

∴ ~~if~~ $t = 5RC$

% of charge left = $\left(\frac{1}{e}\right)^5 = 6.7 \times 10^{-3}$ %

As capacitor ~~discharge~~ discharges exponentially there will still be charge after 5RC as calculated below and so textbook is wrong

ResultsPlus

Examiner Comments

This student has explained the significance of *RC* being the time for the charge to fall to 1/*e* of its original value and has used Q/Q_0 as shown by their use of $(1/e)^5$. However, they cannot gain the second mark as they have mistakenly added a percentage sign after their numerical answer. This does not prevent them from gaining the final mark for a sensible comment. Two marks in total.

(ii) Evaluate the statement from the textbook. Your answer should include a suitable calculation.

(3)

Q initial $= 0.0282$.

$Q_o = Q_o e^{-\frac{t}{RC}}$, $Q_o \cdot e^{-\frac{t}{RC}} = 0.0282 \times e^{-5}$

~~$= 1.9 \times 10^{-4}$~~ $= 1.9 \times 10^{-4}$ C

$1.9 \times 10^{-4} \approx 0$, is very small compared with Q_o

So, statement from the textbook is right.

ResultsPlus

Examiner Comments

This is a completely different approach but it works well. They have calculated the initial charge (from data in part (a) and worked out the charge remaining after 5RC.

Along with the sensible comment, this gets all three marks

ResultsPlus

Examiner Tip

When asked to evaluate, it is expected that you will compare numerical values if available.

Paper Summary

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

- Understand that a 4 mark calculation will require the use of three formulae or conversions and check that the final answer is the correct type of quantity
- When asked to state observations and conclusion, ensure that it is clear which conclusions are linked to which observations
- If comparing or describing quantities, be very specific (e.g. much greater, very few)
- Learn standard descriptions of physical processes, such as electromagnetic induction, 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;
- Explanations can often be supported by reference to formulae on the data, formulae and relationships sheet, however it is rarely sufficient merely to quote the relationship; it must be applied to the specific situation
- While past paper mark schemes can be useful revision aids, questions will not be identical so quoting them directly is unlikely to answer a particular question. Be sure to answer the question on the paper and not a question from a previous paper with a similar situation
- When using a mass or a charge in calculations, ensure that it is the correct mass or charge. Candidates often use the mass/charge of an electron for other particles
- When substituting in an equation with a power term, e.g. x^2, *do not suddenly miss off t he power. This is a particular issue for questions requiring the use of* $\Delta E = c^2 \Delta m$
- If asked to compare or desribe differences, it is necessary to refer to both subjects under consideration (e.g. proton has a positive charge but electron has a negative charge)
- In derivations candidates should check that transitions between steps are clearly explained; memorised formulae rarely gain credit, as it is expected that the required relationship should be derived from formulae provided on the data sheet.

Grade Boundaries

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

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