



A-level
Physics

7408/3BD Paper 3 Section B Turning Points in Physics

Report on the Examination

7408
June 2024

Version: 1.0

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Question 1

Question 1 was about the determination of the specific charge of the electron.

- 01.1 Most students found the question accessible, however many answers lacked the details required. In order to establish that the electron beam is undeflected, students needed to identify the two forces as electrostatic and magnetic. They then had to state these were equal in magnitude and opposite in direction, which meant that the forces were balanced.

It was hoped that students would refer to either Newton's first or second law to explain why balanced forces meant that the electron beam was undeflected; however, this was only seen in a very small number of responses, so it was not insisted upon. It is, however, an essential part of why the electron beam is undeflected.

Most students' responses lacked detail, choosing only to refer to balanced forces without naming the forces or stating why they were balanced or just referring to the forces as equal and opposite, rather than equal in magnitude and opposite in direction.

A very small number referred to gravity being a factor. As the magnitude of the weight on an electron is negligible, references which included gravity as a downwards force were allowed provided they were otherwise correct, while references which replaced the magnetic force with the weight scored no marks.

- 01.2 Students were required to determine the specific charge of the electron from the data supplied in the question. Answers had to equate magnetic force with electric force and electrostatic potential energy with kinetic energy. They could then either combine these two to find $\frac{e}{m}$ or carry this out in two steps, first determining the speed of the electrons before calculating $\frac{e}{m}$. Either route scored full marks. Students who used the values of the charge and mass from the data and formulae booklet were therefore only able to access the first two marks.

Many students knew how to complete this calculation and were able to score all four marks. Some students mixed up the scenario and used either the magnetic or electrostatic force as a centripetal force; they were generally only able to score one mark for equating the electrostatic potential and kinetic energy.

Question 2

Question 2 was about Millikan's experiment to determine the charge on the electron.

- 02.1 This was the question marked on a levels-of-response basis and concerned the method used to determine the radius of the oil droplet. While many found this question accessible and were familiar with the experiment, a large number of answers lacked detail or discussed parts of the experiment that were not asked about. References to how the charge was determined or the significance of the Millikan's experiment were ignored by examiners. A small number of responses seemed not to be familiar with Millikan's experiment.

To address the question fully, students had to refer to the field being switched off. Student responses which dealt with the determination of Q could gain this point provided it was clear that r

was determined with the field switched off. The method also required a description of how the terminal velocity was determined. While many were able to refer to measuring the time taken to fall a measured distance, many responses failed to state how the velocity was determined from these values using $\frac{s}{t}$. The details about using lines marked on the microscope to determine the distance was missing from nearly all responses and was not insisted upon, although it is a vital part of how Millikan was able to carry out the experiment. Most students were able to partially address this area, but few were able to address it fully. Most responses mentioned measuring the distance and time for the droplet to fall but lacked the calculation or a statement that the electric field had to be off.

Most responses had some idea of the determination. In order to fully address this area, in addition to the correct equation for r students had to identify that ρ was the density of the oil or η was the viscosity of the air. Many either missed this out or wrongly identified which symbol referred to the oil and which to the air. Some responses gave an equation for r^2 which did not fully address how to calculate r . A small number of students just listed the equation and then said you should rearrange and solve for r ; this was not enough to address this area.

The principles and assumptions section proved to be the most accessible area to address. The most common response was that the oil droplet was a sphere. The next most common idea was that when the droplet falls at terminal velocity the weight was equal in magnitude and opposite in direction to the drag force. To balance the precision insisted on in 01.1 for a balanced-forces argument, the detail required here was reduced, which meant that statements such as '*weight was equal to the drag force*' were accepted. However, this had to be linked to the concept of terminal velocity. Other responses included the fact that air acted like a viscous fluid allowing Stoke's law to be applied or that upthrust or buoyancy was negligible.

There was some confusion in this section with some students going from one sentence writing about terminal velocity and viscous drag force to the next which stated that air resistance was negligible. Others incorrectly referred to Stoke's law or $6\pi\eta rv$ as the buoyancy force.

- 02.2 This question asked for a determination of the charge on the oil droplet. This was well answered with most responses scoring well. However, some responses did not score as well as they could have due to misunderstanding what is required for a 'show that' question. The response to any 'show that' question should include the equations used, a substitution and the answer given to at least one more significant figure than the approximate value in the question. In this case the answer was expected to at least 2 significant figures (sf).
- 02.3 This question addressed the uncertainties in the experimental data typically given to students to analyse. The most accessible mark was given for converting a percentage uncertainty to an absolute uncertainty, again as the question gave a 1 sf approximate value, 2 sf were required in the answer. A significant number of students were not able to determine the percentage uncertainty in the charge, despite knowing the calculation. Most commonly responses subtracted the percentage uncertainty for the potential difference rather than adding it.

The last mark was for relating the uncertainty to the quantisation of charge. This question was designed to test the understanding of quantisation, rather than a mere statement about charge being quantised. Some students did recognise that as the uncertainty was larger than half of the charge of the electron this meant that it is impossible to state where that quantity was an integer multiple of this charge. The most common approach to answering this correctly was to calculate maximum and minimum values for the charge and to point out that while the mean value was

approximately an integer multiple of 1.60×10^{-19} , the maximum and minimum values were not. In order to make this argument it was expected that 1.60×10^{-19} was quoted along with the max and min values. Incorrect answers here often confused the uncertainty with the quantity to be quantised, or just referred to 8.0×10^{-19} being a multiple of 1.60×10^{-19} .

Question 03

Question 3 was about Hertz's determination of the speed of radio waves. While many students were familiar with this experiment, there was a large number of students who did not seem to know how Hertz was able to make this measurement. Some of these students were able to gain a mark for describing or naming the equipment Hertz used to create and detect radio waves. These students were obviously familiar with Hertz's work but did not know how he measured the speed.

There were two marks for describing Hertz's experimental setup; generally students who were familiar with Hertz's work were able to score here. Common mistakes were calling the reflector a mirror or placing the reflector between the transmitter and the detector. As Hertz did many experiments over a number of years, any reference to equipment that could have been used by Hertz was credited here, with either a spark-gap transmitter or a dipole aerial used to create radio waves and a dipole aerial or loop with a small gap used to detect radio waves being accepted. This detail could be provided in a labelled diagram or the text.

The method marks were more challenging although many who knew the experiment were able to gain three marks. In order to score here, there had to be a setup which could allow the measurements to be made. So, answers which did not include some form of reflector could only score the third marking point since maxima and minima did not exist and could not therefore be measured. The third marking point was for correctly identifying the wavelength; in this case answers had to refer to the distance between adjacent nodes, not just nodes. The fourth marking point was for establishing what was measured; many students missed this point by just describing a detection of the maxima and minima but not measuring the distance between them. The last mark was only awarded when there was an experimental setup which allowed the wavelength to be determined. This did not need to be described in detail for this mark and answers which failed to score either the third or fourth marking point could gain this mark if the correct experiment could be identified but was poorly described.

Some answers required a measurement of the radio wave intensity at the transmitter and reflector, which is impossible due to the size of the equipment given. Answers of this type, including those which stated that the first harmonic was used, were not able to gain the fourth marking point, since this referred to the measurements made, but were able to access the other four marking points.

Those students who attempted to measure the distance between the transmitter and the time delay between sparks being produced by the transmitter and receiver did not score any of the last three marks.

Some students were aware that stationary waves were involved but described waves on a string. These were not able to gain credit; only answers which involved radio waves were able to score.

Some students did attempt to describe a different experiment to determine the speed of light. That did not score here. This part of the specification is about historical experiments and so setups which were able to measure the speed of radio waves were only able to score marks where they described situations

that were accessible to Hertz. References to data logging, computers and oscilloscopes did not gain credit, although they did not prevent marks being scored in the rest of the answer.

Question 04

04.1 As in other ‘show that’ questions, the answer must be given to more significant figures than the approximate value given in the question, in this case a minimum of 2 sf. A full substitution including the correct powers of ten was required to gain the mark. Most students were able to score here.

04.2 This question was also very accessible with most students scoring. Correct answers had to complete two calculations with a comparison to realise that this decrease in temperature was consistent with the accelerating potential difference given. Answers which noticed a small difference or made a calculation error and said they were inconsistent were not able to gain full marks.

The most straightforward way to do this question was to calculate the energy required to raise the temperature of the aluminium by 68.0 K and then calculate the energy of the beam by multiplying the kinetic energy of one electron by the number of electrons. However, any valid comparison could be used, and some compared the energy per electron, the rise in temperature or the mass of aluminium.

04.3 As is usually the case, students found the calculation of relativistic kinetic energy difficult. Most commonly students confused the total energy mc^2 with the kinetic energy $mc^2 - m_0c^2$. However, there was also a significant minority who could not calculate the non-relativistic kinetic energy; instead of calculating $\frac{1}{2}mv^2$ they tried to use mc^2 using the velocity of the particles instead of the speed of light.

Students were expected to compare the two kinetic energies with their answer to 04.1 and comment that the relativistic equation was correct. In order to score this mark students needed to have calculated values using the correct equation, although minor rounding or calculation errors were tolerated.

However, some students opted instead to calculate the speed using the two equations route and could also gain full marks. A small minority of students used the energy here to calculate either a rise in temperature for the aluminium block or an accelerating pd. This again could gain full marks.

Those who did not recall the relativistic kinetic energy could still get two marks for the correct use of $\frac{1}{2}mv^2$ and a calculation of the relativistic mass, $\sqrt{1 - \frac{v^2}{c^2}}$, $\frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$ or the total energy with a suitable

comment about their significance, for example “the total energy is significantly different from the rest energy and therefore relativity applies”.

Some answers gained one mark by calculating the speed as a fraction of the speed of light and saying that this was close enough to the speed of light to require relativity.

04.4 Nearly two-thirds of students gave the correct response.

04.5 Students found this question to be very challenging, although most students were able to gain some marks. Only a few students were able to gain full marks, although some students gave very well explained answers.

The fact that the increase in kinetic energy was fixed, due to $E_k = eV$, proved to be the most challenging part of the question. Very few answers scored these marks. The idea that the increase in speed was greater in the first stage was more widely recognised but often lacked the correct physics to explain this.

Many students were able to recognise that the mass increased with speed. However, fewer were able to apply this successfully to this scenario. Most thought that a constant change in speed leads to larger increase in E_k rather than a constant increase in E_k leading to a smaller increase in speed. Some stated that it would take more energy to increase the speed by the same amount. While this would be true for a small increase in speed, most who took this route did not appreciate that the speed could not be increased by the same amount no matter how much energy was used, since this would exceed the speed of light.

Some students tried to explain with a reference to the E_k against v graph. However, while many could recall the shape of the graph, they struggled to apply the graph to this question. Many who referred to the graph said that as E_k tended to infinity the increase in E_k must get bigger, incorrectly implying that in each stage it moved the same distance along the line of the graph. Some who referred to the graph, referred to the larger increase in E_k for the same increase in v , not realising that it was the same increase in E_k which produced a smaller increase in v .

Some stated that the acceleration would be the same in all stages, since the potential difference was the same. While the field and therefore the force and acceleration would be the same assuming the distance was constant and relativity did not apply, this does not mean they would produce the same change in speed, since the acceleration would apply for a shorter time when the electron was travelling faster. While the rules of special relativity can be applied to the acceleration of the electron, especially in the non-accelerating reference frame of the lab, to do so is beyond the scope of this course and was not required.

A few were let down by their ability to describe motion correctly, the increase in speed was reduced, however the *increase* did not get slower. A smaller group confused the change in speed with the speed.

Mark Ranges and Award of Grades

Grade boundaries and cumulative percentage grades are available on the [Results Statistics](#) page of the AQA Website.