AQA

A-LEVEL

PHYSICS

7408/3BD Turning Points in Physics

Report on the Examination

7408/3BD

June 2023

Version: 1.0

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Question 1

01.1

Most students had some idea of the processes involved; however, just over half were unable to express this clearly enough. In order to score the mark here it needed to be clear that electrons were in the filament and that they were given enough energy by heating the filament to allow them to escape the metal.

Common mistakes which did not receive credit were:

- failure to reference energy
- attributing the gain in energy to the accelerating pd rather than the heating of the filament.

When students referred to the electrons being accelerated after they left the metal, this was ignored unless it was linked to the electrons being “pulled” out of the metal by the accelerating pd.

01.2

Around two-thirds of students were able to complete this calculation successfully. However, some students were unable to gain the mark because they did not give the answer to one more significant figure (s.f.) than the value in the question; this is required in “show that” questions. Some students misunderstood the circuit by adding or subtracting the 6.3 V from the 500 V.

01.3

This question was an assessment objective (AO) 3 question which required more than an acknowledgement that diffraction demonstrates wave behaviour. Around one-third of students were able to score at least one mark, with a further third scoring two marks. However, only a small number were able to score the full three marks.

In order to score here, students needed to appreciate that for diffraction to be significant the wavelength must be approximately the size of the gap. Some students stated that the gap must be equal or smaller or larger than the wavelength and were not awarded this mark as the key to observing a diffraction pattern is to have the same order of magnitude – a fact not captured by these answers. The most commonly scored mark was the calculation of the de Broglie wavelength of the electron, either from the velocity given or the accelerating pd. Finally, students had to realise that the size required was smaller than the diameter of an atom and was therefore too small to create. This was the hardest mark to gain, with most students missing this crucial point.

Some students missed the part of the question which referred to a gap and instead assumed this was referring to a diffraction through a crystal. They were able to score the first two marks, but could not access the third. Those who answered that the apparatus was sound in principle but the hole could not be made small enough in practice were able to score all three marks.

01.4

This question allowed students to show their knowledge of a technique to measure the specific charge of the electron. There was a free choice as to which method was used which allowed a wide range of answers.

Students were asked to write about three areas, giving details of the experimental setup and the measurements required, how the specific charge was calculated from these measurements, and the significance of the results.

The most accessible area was the significance, although many students were able to gain at least one mark from an experimental description. Those students who were familiar with the experiment to measure the specific charge of the electron were able to score well. However, there were a significant minority who either did not attempt the question or who did not refer to a suitable experiment. Around 80% of students were able to score at least one mark with just over half scoring at least three marks. Nearly 40% were able to score four marks.

For the experimental setup, students had to give in diagrammatic or written form enough information to describe the setup and to ensure that all the quantities specified were actually directly measurable. In line with the specification, no details of either the creation or measurement of the magnetic field were required. It was enough for students to state that a perpendicular magnetic field of known or measured flux density was used. Students who referred to quantities that were not directly measurable such as the velocity of the electrons, the kinetic energy of the electrons, or the electric field were only able partially to address this area.

The calculation could be given as either a series of steps (provided these steps did not involve the use of either the charge or the mass of the electron) or with the steps combined algebraically to produce an expression for the specific charge. Either route was acceptable for full credit. In order to address this area fully, the students had to present a calculation or a series of calculations leading to $\frac{e}{m}$ using only measurable quantities.

In dealing with the significance of the results, students needed to refer to the very large specific charge of the electron compared to the hydrogen ion which implied that it either has a very small mass or a very large charge.

The most common method used was to accelerate the electron beam through a potential difference into a region with a perpendicular magnetic field. In order to measure the radius of the electron beam, it is necessary for the beam to pass through a low-pressure gas in order to make the beam visible. This detail was required to gain full credit for the experimental description. In this case there is no route to the specific charge in steps. Any use of steps required the value for the electron charge and mass and was therefore only able to gain partial credit. To address the determination of $\frac{e}{m}$ completely required $\frac{1}{2}mv^2 = eV$ and $\frac{mv^2}{r} = Bev$ to be combined algebraically.

The next most common approach was to balance electric and magnetic forces to produce an undeflected beam. The key concepts which were required for the experimental description were the horizontality of the electron beam and the distinction between the accelerating potential difference and the potential difference across the parallel plates. Those who stated that the electric field was measured directly were unable to address the measurements fully but were able to address the determination of $\frac{e}{m}$ completely. Those who stated that the velocity was measured were only able to address partially both the experimental description and the determination of $\frac{e}{m}$.

For a determination of $\frac{e}{m}$ most students showed how the velocity could be determined from $\frac{V_P}{dB}$, which could then be used with $\frac{e}{m} = \frac{v}{2V_A}$. Combining these two equations was also acceptable but not required. However, those who did combine them had to ensure they did not confuse velocity and potential difference or accelerating and plate potential differences.

Only a few students used the method where the magnetic field was switched off and the deflection of the electron measured. The vast majority of students who used this route directly measured the vertical deflection of the electron beam. Hardly any students used Thomson's method of measuring the deflected angle.

Some students did not give a correct method. However, when the experiment they described could be used to calculate e or m or as a part of an experiment to determine the specific charge, then they could gain partial credit for the experimental description – providing that they gave some details of the experiment, some measurements, and some relevant calculations. However, to gain credit for the significance, it had to refer to the significance of Thomson's determination of $\frac{e}{m}$. Therefore, references to Millikan's oil-drop experiment could gain a partial credit for a good description but could not get credit for writing about the charge being a multiple of the electron charge.

Question 2

02.1

This question was very accessible with around 80% of students scoring at least two marks. Over half of the students scored full marks.

Students had to measure the terminal velocity of the oil drop for the first mark, having to determine that the line was between 0.052 and $0.054\ \mathrm{m\ s^{-1}}$. There were a few misreads due to reading the wrong section of the graph, missing the units on the velocity access and reading it as $\mathrm{m\ s^{-1}}$ instead of $\mathrm{mm\ s^{-1}}$ or misinterpreting the scale on the velocity axis. Those making a power-of-ten error in reading the graph were able to gain the first mark but were penalised in the final answer.

The second mark was for recognising that weight had to balance the viscous drag force. This could be shown by writing $mg = 6\pi\eta rv$ or by substitution. The final mark was for the answer to the calculation. An error was carried forward for a misread of the terminal velocity but not for invalid working, e.g. using the gradient to calculate the speed of the oil drop.

02.2

This question was also accessible to most students, with over 60% scoring at least two marks and just under half scoring full marks. However, around a quarter were unable to score at all.

Students had to calculate the value of the charge on the oil droplet and then deduce whether this was consistent with the accepted value of the electron charge. To calculate the charge students had to realise that the electric field given was equal to $\frac{V}{d}$ in the equation $\frac{eV}{d} = mg$. The first mark was given for evidence of this. The second mark was for the correct result for the calculation. Students who used $8.85\ \mathrm{kV\ m^{-1}}$ as V in the equation were unlikely to score here.

The final mark was for realising that the charge of the oil drop was four times the electron charge and to state that this was consistent with the accepted value of the electron charge as four electrons were removed from the oil drop. Stating that the charge was four times the electron charge was not enough by itself, particularly as some went on to state that this was not consistent with the accepted value for the electron charge. The answer to $\frac{Q}{e}$ should have been given to at least one decimal place to show how close to an integer this value was. However, since the answer was 4.0 this was not insisted on, on this occasion.

Those students who looked for an equation with electric field in it and used the radius of the oil droplet in the equation for a radial electric field $E = \frac{Q}{4\pi\varepsilon_0 r^2}$ gained no marks for the calculation of Q. However, this did produce an answer which was approximately six times the charge on the electron and answers which stated this were able to gain the last marking point.

Incorrect calculations of Q which lead to $\frac{Q}{e}$ being greater than 100 were not allowed as an error carried forward since the precision of the answer based on a 2 s.f. electric field was not enough to determine whether the answer was in fact a multiple of the electron charge.

Question 3

03.1

This question proved to be very challenging, with only just over a third of students gaining the mark. While most students had the correct idea, they lacked the detail required.

In order to score the mark here, the electric field had to be drawn perpendicular and in phase with the magnetic field. An arrow showing the direction of propagation of the wave was required as was at least one label of either the direction of propagation or the electric field. It was disappointing to see the number of responses where the diagram was not labelled, despite the clear instruction to do so.

In addition to missing labels, the mark was not awarded if the electric field did not cross the 0 line in the same place as the magnetic field or if the electric field was drawn in the same plane as the electric field. As the question was about drawing the electric field, the mark was determined by the drawing alone and any comments about what the student had intended to draw were ignored.

03.2

Nearly two-thirds of students knew that Maxwell proposed the electromagnetic wave model of light.

03.3

Most students were able to score at least one mark (around 80%). However, just under half were able to provide the detail for two marks, with only around 10% gaining full marks.

Students had to state that Newton proposed that light was made of particles called corpuscles for the first mark. The second mark was for showing some understanding of how this theory was used to explain diffraction. Two points were needed from:

- component of velocity/momentum parallel to surface unchanged
- component perpendicular to surface increases
- (short range) force of attraction (to surface)
- light travels faster in glass.

Most students who scored two marks were able to state that there was a short-range force of attraction which meant light travelled faster in glass than air. Responses that discussed horizontal and vertical components were able to score here, but not for the third marking point unless there was an accompanying diagram to clarify these directions in terms of the boundary between air and glass. No credit was given for a force of attraction towards the normal or referring to the force of attraction as gravity, although the mark could be gained from the other bullet points.

For the third mark students had to identify that it was the component of velocity perpendicular to the surface which increased while the component of velocity parallel was unaffected, resulting in the light bending towards the normal. This could be stated in the text or shown in a suitably labelled diagram.

Some responses stated that Newton predicted that light would bend away from the normal. This could not gain the third mark although the other two marks were still accessible.

03.4

This question proved challenging with only around 60% of students scoring anything. However, around two-thirds of those who gained one mark were able to score at least two. Only a few were able to score full marks.

The first mark was given for a description of an experiment involving diffraction and/or interference. For this mark some description either in the text or a labelled diagram was required; simply naming an experiment, e.g. Young's double slits, was not enough.

For the second mark, it was required to describe or sketch the results of the experiment, e.g. a description of the diffraction pattern. It was not enough to refer to a diffraction pattern; a description of what was observed was required. It was also not enough to refer to maxima alone but rather maxima and minima or a series of fringes, since the particle model also predicted (two) maxima.

For the third mark, responses need to link diffraction or interference to wave behaviour and give a description in either writing or a diagram of what Newton's model would have predicted.

Most students described a variation of the double-slit experiment; however, a single slit or diffraction grating was also accepted. Although not on the specification, references to Poisson's spot were accepted as the idea that the wave theory predicted a bright fringe in the centre of the double-slit pattern. Producing a spectrum from a diffraction grating was accepted, but not from a prism.

Any response in terms of refraction did not score, as Newton's theory was able to explain this phenomenon.

Question 4

04.1

The majority of students (around 80%) were able to score one mark; however, only around 20% were able to score two.

The other postulate required was that the speed of light was invariant in free space. This was consistent with the equation since only constants which did not depend on the reference frame were included and therefore the speed of light did not depend on the reference frame.

Very few students were able to articulate this fully. It was common for students to omit the idea that it is only the speed of light in a vacuum or free space that is invariant while almost none referred to the constants being independent of reference frame. Only one of these two details was required for full marks, while one mark was given for referring either to the invariance of the speed of light or the equation only containing constants.

Stating that the speed of light was only constant in inertial reference frames instead of all reference frames was accepted for one mark but not as part of a two-mark answer.

Simply substituting the constants into the equation to calculate the speed of light did not gain credit.

04.2

Again, most students (over 80%) were able to score at least one mark, with just under half able to get full marks.

In order to score full marks here it was necessary to recognise that the distance in the reference frame of the target was the proper length l_0. Students who recognised this were mostly able to calculate the distance as $69\ \mathrm{m}$. Those who forgot to square $\frac{v}{c}$ arrived at $93\ \mathrm{m}$ and were able to score one mark.

Responses which confused l and l_0 but which had full working leading to $21\ \mathrm{m}$ were also able to score one mark – this was the most common way to score one mark.

04.3

Many students were unable to recall or use the relativistic equation for kinetic energy being the total energy – rest energy, with around 40% failing to score. A simple statement of this in words or equation form was required for the first mark. A full substitution was also accepted for this mark. Since this was a “show that” question, the working was required for the first and second marks and the answer to one more s.f. than that given in the question was required for the third mark. Most students who knew the relativistic kinetic energy equation were able to score at least one more mark.

Students who calculated either the total or the rest energy were able to score one mark.

Those who used $\frac{1}{2}mv^2$ or mv^2 (often stating mc^2 but using the speed of the electron rather than the speed of light) were not able to score, including those who calculated the relativistic mass.

04.4

Many students struggled with drawing the graph, with around 40% failing to score. Only around a third were able to gain two marks, with only a small number gaining full marks.

The first mark was for following the $\frac{1}{2}mv^2$ line up to around $0.1c$; the acceptable range of divergence was from 0.3×10^8 to 1.1×10^8 m s^{-1}. The second mark was for going through the point established in question 04.3, $(2.5 \times 10^8, 122 \times 10^{-12})$ to within one square. In order to score this mark, the curve drawn had to show an increasing gradient, straight lines drawn through this point did not score.

The third mark for was showing that the speed of the particle could not exceed 3.0×10^8 m s^{-1}. Lines which clearly would exceed 3.0×10^8 just off the graph paper did not gain this mark.

Mark Ranges and Award of Grades

Grade boundaries and cumulative percentage grades are available on the Results Statistics page of the AQA Website.