5.1 Electric Fields

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Course	DP IB Physics
Section	5. Electricity & Magnetism
Topic	5.1 Electric Fields
Difficulty	Medium

To be used by all students preparing for DP IB Physics HL
Students of other boards may also find this useful

1

The correct answer is **C** because:

- When the conducting spheres X and Y are brought into contact, they end up with the same charge, because they are identical
  - Therefore, at the point of contact, the total charge –8 μC + 12 μC = +4 μC is distributed equally across them
  - This means each sphere is charged with +2 μC after being separated again

The underlying principle that will help you understand this question is the conservation of charge. Charge is always carried in units of the elementary charge ($e = \pm 1.6 \times 10^{-19}$ C) so since the conducting spheres in this question are identical, when they are brought into contact a **finite** amount of charge will spread evenly across them. The total charge is therefore distributed symmetrically.

2

The incorrect answer is **C** because:

- The work done (or energy transferred) on or by an electron as it moves across a potential difference is independent of the path taken
  - The potential difference, and hence the energy transferred, is only dependent on the initial and final position of the electron

A is incorrect as	a potential difference occurs whenever there is a separation of charge. If charge is separated, an electric field is set up, directed from positive to negative
B is incorrect as	$V = \frac{W}{q}$ therefore $W = qV$, so if the charge q = e (the elementary charge on an electron), then $W = eV$ is the work on or by an electron across a potential difference V
D is incorrect as	the electric field has both magnitude and direction

3

The correct answer is **A** because:

- The kinetic energy transferred to the proton as it crosses the potential difference is the work done by the electric field, W:
  - $W = qV$
  - So, we can write $\frac{1}{2} m_p v_p^2 = W = qV$
- Therefore:
  - $\frac{1}{2} m_p v_p^2 = qV$
  - So, $m_p v_p^2 = 2qV$
  - and $v_p^2 = \frac{2qV}{m_p}$
  - So, $v_p = \sqrt{\frac{2qV}{m_p}}$

B is incorrect as	the equation for kinetic energy is $\frac{1}{2} m_p v_p^2$ and not $\frac{1}{2} m_p v_p$ so the square root of $\frac{2qV}{m_p}$ must be found to obtain the value of final proton velocity
C is incorrect as	the equation for kinetic energy is equal to work done $\frac{1}{2} m_p v_p^2 = qV$. When rearranged instead of dividing by 2 on the right hand side the equation should be multiplied by 2 on the right hand side. It should give $m_p v_p^2 = 2qV$ and not $m_p v_p^2 = \frac{qV}{2}$
D is incorrect as	the kinetic energy is equal to the work done $\frac{1}{2} m_p v_p^2 = qV$ and not just the final velocity

There is a lot of information provided to help you in this question. Make sure you use it and show all your working clearly, so you do not make any mistakes in your numerical calculations.

4

The incorrect statement is **D** because:

- The potential difference created by accelerating the metal was measurable and found to be consistent with a model of negative charge carriers in the metal

A is incorrect as	the inertia of free electrons meant they momentarily gathered in an area of excess negative charge

B is incorrect as	fixed positive ions (protons) accelerated with the conductor, while the free electrons were 'left behind' due to their inertia. Hence, a momentary area of excess positive charge was created in the conductor
C is incorrect as	electrons have a (tiny!) mass; therefore, they too will experience inertia, which is the opposition to changes in a body's motion. In this case, the change in motion is acceleration, which would cause them to 'gather' at the opposite end of the conductor's motion

5

The correct answer is **A** because:

- The magnitude of force experienced by both charges is equal
  - This is a consequence of Newton's third law, which says that if body A (say, Q) exerts a force on body B (say, q), then body B exerts an equal and opposite force on body A
- The electric field strength is defined as the magnitude of the electric force per unit of charge experienced by a positive test charge
  - This can be expressed as $\frac{F}{q}$

B is incorrect as	the magnitude of the force experienced by both charges is equal
C is incorrect as	the magnitude of E created by Q at q is $\frac{F}{q}$ and not $\frac{F}{Q}$ because it is at q so this gives the magnitude of the field at this point

D is incorrect as	the magnitude of the force experienced by both charges is equal AND the magnitude of E created by Q at q is $\frac{F}{q}$ and not $\frac{F}{Q}$ because it is at q so this gives the magnitude of the field at this point

It is important to recognise that an electric field is generated by a larger charge on a smaller charge moving within the field. In this question, the field is generated by charge Q and charge q is the test charge within it.

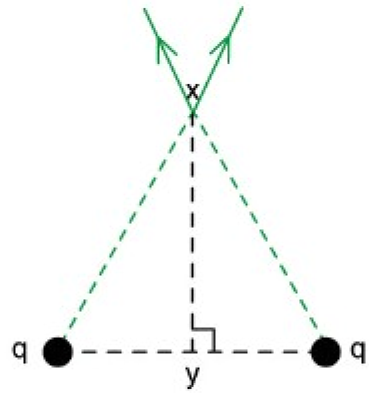
The realisation that, regardless of the magnitude of the charges on q and Q, they exert an **equal** force on each other (in opposite directions) is critical. You should be able to apply Newton's third law in a variety of contexts. You might imagine the 'larger' charge Q exerts a larger force on the 'smaller' charge q, but this is not the case.

However, the electric field strength, here, is **due to the charge Q,** which we can imagine as 'creating the field' (in reality, both charges have an electric field around them). Therefore, the electric field strength due to charge Q is the force experienced per unit of charge **at that point in the field,** i.e., $E = \frac{F}{q}$ and **not** $E = \frac{F}{Q}$.

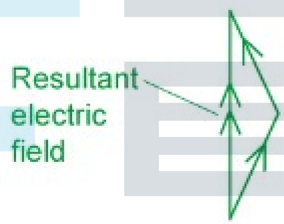
6

The correct answer is **B** because:

- The electric field from each charge q is radially outward, such that the two electric field vectors at point **X** is shown as below:



- The vector sum of these gives a resultant vector that is vertically upward, shown by the double headed arrow below:



A, C & D are incorrect as	according to the vector triangle the resultant force is along the line YX away from the point charges.

You should remember the electric field due to a point charge is **radial**. That means, it is directed outwards, in all directions, from the point charge – therefore, in this question, there are two 'outward' vectors from both point charges at the point **X**. These should be added, 'tip-to-tail', to work out the direction of the resultant electric field vector.

7

The correct answer is **C** because:

- The cross-sectional area A of a wire is the area of a circle, therefore:
  - $A = \pi r^2 = \pi \times \left(\frac{2.0 \times 10^{-3}}{2}\right)^2 = \pi \times 10^{-6}$ m^2
- The current $I = nAvq$ where n is the number of charge carriers per unit volume, v is the drift speed and q is the charge on each charge carrier
  - The charge q is the elementary charge $e = 1.6 \times 10^{-19}$ C
  - $v = 3 \times 10^{-4}$ m s^{-1}
- Therefore,
  - $I = 10^{28} \times (\pi \times 10^{-6}) \times (3 \times 10^{-4}) \times (1.6 \times 10^{-19})$
  - $I = \pi \times 3 \times 1.6 \times 10^{28} \times 10^{-6} \times 10^{-4} \times 10^{-19} \approx 4.8\pi \times 10^{-1} = 0.48\pi$ A

A is incorrect as	the cross-sectional area of the wire is given by $A = \pi r^2 = \pi \times \left(\frac{2.0 \times 10^{-3}}{2}\right)^2 = \pi \times 10^{-6}$ m^2 and not just $A = \pi r = \pi \times \frac{2.0 \times 10^{-3}}{2} = \pi \times 10^{-3}$ m^2
B is incorrect as	the cross-sectional area of the wire is given by $A = \pi r^2 = \pi \times \left(\frac{2.0 \times 10^{-3}}{2}\right)^2 = \pi \times 10^{-6}$ m^2 so the final value of 0.48 must be multiplied by π
D is incorrect as	the cross-sectional area of the wire is given by $A = \pi r^2 = \pi \times \left(\frac{d}{2}\right)^2$ and not by $A = \pi r^2 = \pi \times d^2$

Remember to use the rules for multiplying indices to simplify the powers of ten in this question. Also remember that the area of a circle, the cross-sectional area of the wire is given by $A = \pi r^2$

8

The incorrect statement is **B** because:

- The current, given by $I = nAvq$ at **X** and **Y** is equal, since charge is conserved
- The charge density per unit volume n, and the charge of each charge carrier q is constant
- Therefore, the cross-sectional $A \propto \frac{1}{v}$ where v is the drift speed
  - Hence, since A increases at **Y**, the drift speed decreases
  - Therefore, statement **B** is incorrect

A is incorrect as	current is equal at **X** and **Y**, due to conservation of charge (there are no junctions)
C is incorrect as	charge density is a constant property of the metal, therefore, it does not change between **X** and **Y**
D is incorrect as	electric charge is always conserved

The key to this question is finding the equation all the quantities relate to and then figure out how this changes certain values.

9

The correct answer is **C** because:

- The force between two charges $F = \frac{kQ_1Q_2}{r^2}$ where k is a constant
  - Therefore, the force between the two charges Q_1 and Q_2 when separated by a distance r is given by $F = \frac{k(q)(4q)}{r^2} = \frac{4kq^2}{r^2}$
- If $Q_1 \rightarrow 2Q_2 = 2q$ and $r \rightarrow 3r$, then $F \rightarrow F'$, where:
  - $F = \frac{k(2q)(4q)}{(3r)^2} = \frac{2 \times 4kq^2}{9r^2} = \frac{2}{9} \times \frac{4kq^2}{r^2} = \frac{2}{9}F$

A is incorrect as	the charge on q doubles, so q becomes $2q$ so the fraction becomes $\frac{2}{9}$ and not $\frac{2}{3}$
B is incorrect as	the equation is $F = \frac{kQ_1Q_2}{r^2}$ and not $F = \frac{kQ_1Q_2}{r}$ so the fraction becomes $\frac{2}{9}$ and not $\frac{2}{3}$
D is incorrect as	the distance between the charges is also trebled, so this needs to be considered

This question requires you to find an equation in terms of the original variables, then an equation in terms of the new variables and use the multiplication of fractions to find the difference between them.

10

The correct answer is **B** because:

- Current $I = \frac{\Delta q}{\Delta t}$
  - This is read as the rate of flow of electric charge

A is incorrect as	while current $I = \frac{V}{R}$, this does not **define** the electric current (it **quantifies** it, since resistance R is defined as the ratio $\frac{V}{I}$)
C is incorrect as	this is the definition of the potential difference across a component, $V = \frac{W}{q}$
D is incorrect as	this is the definition of the electromotive force ϵ of a cell