Exam Papers Practice

10.1 Describing Fields

Mark Schemes

Course	DP IB Physics
Section	10. Fields (HL only)
Topic	10.1 Describing Fields
Difficulty	Medium

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

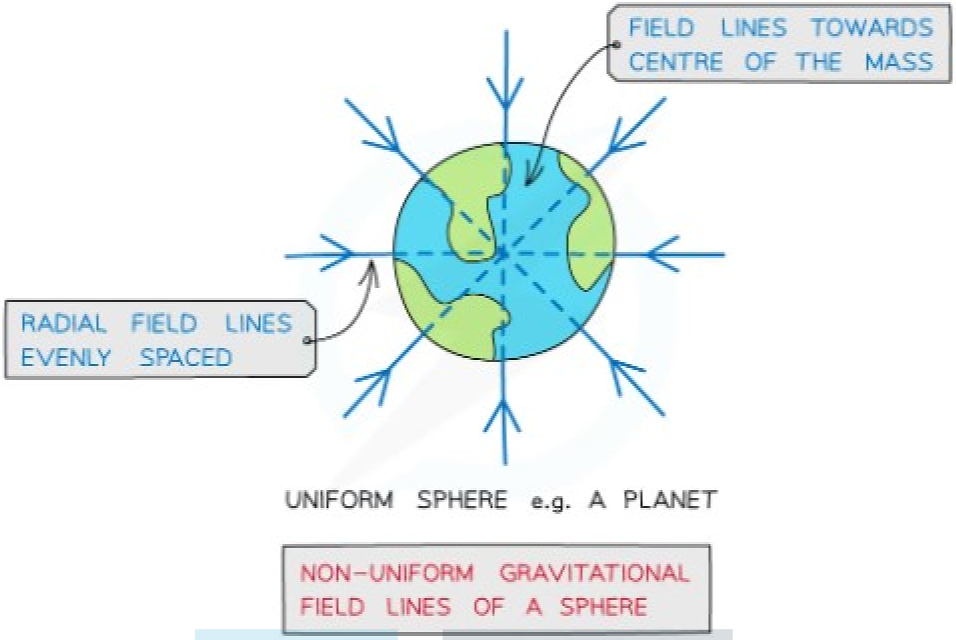
1

The correct answer is **D** because:

- The gravitational field around *M* is radial
- The path of the test mass *m* is parallel to a gravitational field line, and is in the same direction
  - Therefore, the gravitational field does (positive) work on the test mass
  - This is because work is defined as the product of force and distance moved in the same direction as the force

A is incorrect as	positive work is done by the gravitational field, since the gravitational force attracts *m* to *M*. In other words, the motion of *m* is in the same direction as the field line, therefore, energy is transferred to *m*
B is incorrect as	negative work would be done only if the test mass moved in the **opposite direction** to the field line, or in other words, if the test mass moved in the opposite direction to the gravitational force
C is incorrect as	gravitational equipotential lines are circles of constant radius from the centre of mass of *M*. The line AB is parallel to the gravitational field lines around *M*

A radial field around a planet consists of field lines that radiate out of the centre, as shown in the image below



2

The correct answer is **A** because:

- The metal plates are not parallel, therefore, the electric field strength should be stronger where they are closer together
  - This is because the electric field strength between parallel plates $E = \frac{V}{d}$ and so is inversely proportional to the distance d between the plates
- Therefore, the field lines should be more densely packed together where the plates are closer together
  - This rules out options B and C
- The metal plates are lines of equipotential
  - Therefore, the electric field lines should meet the plates at 90°
  - This rules out option D
- Therefore, the correct diagram is given by option A

B is incorrect as	the field lines are equally spaced, but the field strength is greater where the plates are closer together. Therefore, the field lines should be more densely packed here. Also, the field lines are not meeting the plates at 90°

C is correct as	the field lines meet the plates at 90° but they are equally spaced
D is correct as	the field lines are more densely packed where the plates are closer together, but the field lines do not meet the plates at 90°

3

The correct answer is **C** because:

- The work done is perpendicular to equipotential lines
  - In other words, in the direction of the electric field caused by Q
- The electric potential difference ΔV_e is greater from P along path X
  - Path X starts at the outermost equipotential and finishes at the innermost equipotential
  - This potential gap is greater than path Y, which only crosses a potential difference to the middle equipotential
- Therefore, more work is done moving the test charge from P along path X towards Q

Remember that **no work is done** by electric field when a test charge moves **along** an equipotential surface. This is because the change in potential, $\Delta V_e = 0$. Hence, the work done, $W = q\Delta V_e = 0$.

4

The correct answer is **B** because:

- At position B:
  - The electric field E_7 due to the +7 μC charge has magnitude $\frac{7k}{r^2}$ where r is the distance between the charge and position B and k is the coulomb constant $k = \frac{1}{4\pi\varepsilon_0}$

- The electric field $E_{-3.5}$ due to the –3.5 μC charge has a magnitude $\frac{3.5k}{r^2}$ where r is the distance between the charge and position B
- Therefore, the resultant electric field $E = E_7 + E_{-3.5} = \frac{10.5k}{r^2}$

- By inspection, no combination of the fields due to both charges is greater than $\frac{10.5k}{r^2}$
  - This is because B is the only position at which the distance to each charge is r
  - For every other position, the distance to one of the charges is greater than r
  - Hence, the contributing electric field strength is weaker

A is incorrect as	the electric field strength due to the +7 μC charge has a magnitude $\frac{7k}{r^2}$ and the electric field strength due to the –3.5 μC charge has a magnitude $\frac{3.5k}{(3r)^2}$. In total, the sum is $\frac{7k}{r^2} + \frac{3.5k}{9r^2} = \frac{66.5k}{9r^2} \approx \frac{7.4k}{r^2}$ which is less than $\frac{10.5k}{r^2}$
C is incorrect as	the electric field strength due to the –3.5 μC charge has a magnitude $\frac{3.5k}{r^2}$ and the electric field strength due to the +7 μC charge has a magnitude $\frac{7k}{(far)^2}$ which is less than $\frac{7k}{r^2}$. Therefore, the sum will be less than $\frac{10.5k}{r^2}$

D is incorrect as	the electric field strength due to the –3.5 μC charge has a magnitude $\frac{3.5k}{r^2}$ and the electric field strength due to the +7 μC charge has a magnitude $\frac{7k}{(3r)^2}$ which is less than $\frac{7k}{r^2}$. Therefore, the sum will be less than $\frac{10.5k}{r^2}$

Make sure you are comfortable with applying the equation for electric field strength, $E = \frac{kQ}{r^2}$ and working out **resultant** electric fields, by adding the contribution from each charge present in the situation. In this case, the key is recognising that each position labelled is a distance *r* **from the nearest charge**. This enables you to determine resultant electric fields.

Of course, you could also do this question by inspection: the electric field is going to be strongest nearest to the larger magnitude of charge (+7 μC) but **not at position A**, because the electric field due to the –3.5 μC acts in the same direction.

5

The incorrect statement is **D** because:

- The gravitational potential $V_g = -\frac{GM}{r}$
- For constant radial distance *r*, the value of the potential V_g is proportional to mass *M*
    - Imagine an equipotential surface corresponding to –400 V, with some radius *r* from the centre of mass
    - The radius of this equipotential surface can only be varied by varying the mass of *M*, not its diameter

A is correct as	equipotentials are lines or surfaces corresponding to constant gravitational potential. For a spherical mass *M*, points of constant gravitational potential would be joined by a sphere around *M*
B is correct as	the gravitational field strength *g* is proportional to the **gradient** of the potential, $\frac{\Delta V}{\Delta r}$. Since *g* decreases with distance by the inverse square law, or $g \propto \frac{1}{r^2}$, then equal changes in potential ΔV should happen over greater distances Δr further away from *M*. This corresponds to a shallower potential gradient
C is correct as	work is only done by the gravitational field if a test mass moves parallel to the direction of gravitational force - i.e., along a gravitational **field line**. Equipotential surfaces are **perpendicular** to field lines; hence, no work is done by the gravitational field along an equipotential surface

6

The correct answer is **C** because:

- The work done ΔW (or energy transferred) by the electric field on the helium nucleus as it moves across the potential difference ΔV_e is given by $\Delta W = q\Delta V_e$
  - The energy is transferred to the particle's kinetic energy, given by $\frac{1}{2}mv^2$
  - Therefore, $\frac{1}{2}mv^2 = q\Delta V_e$
  - Hence, $v = \sqrt{\frac{2q\Delta V_e}{m}}$

- The known quantities are:
  - $\Delta V_e = 5\text{ kV} = 5000\text{ V}$
  - $m = 2m_p + 2m_n$ (where m_p is the mass of a proton and m_n is the mass of a neutron)
  - $q = 2e$ (where e is the elementary charge)
- Hence:
  - $v = \sqrt{\frac{2 \times (2e) \times 5000}{(2m_p + 2m_n)}} = \sqrt{\frac{4 \times 5000e}{2(m_p + m_n)}} = \sqrt{\frac{10\,000e}{m_p + m_n}} = 100\sqrt{\frac{e}{m_p + m_n}}$

You are expected to know that a helium nucleus is an **alpha particle**, and that alpha particles comprise of **two protons and two neutrons.**

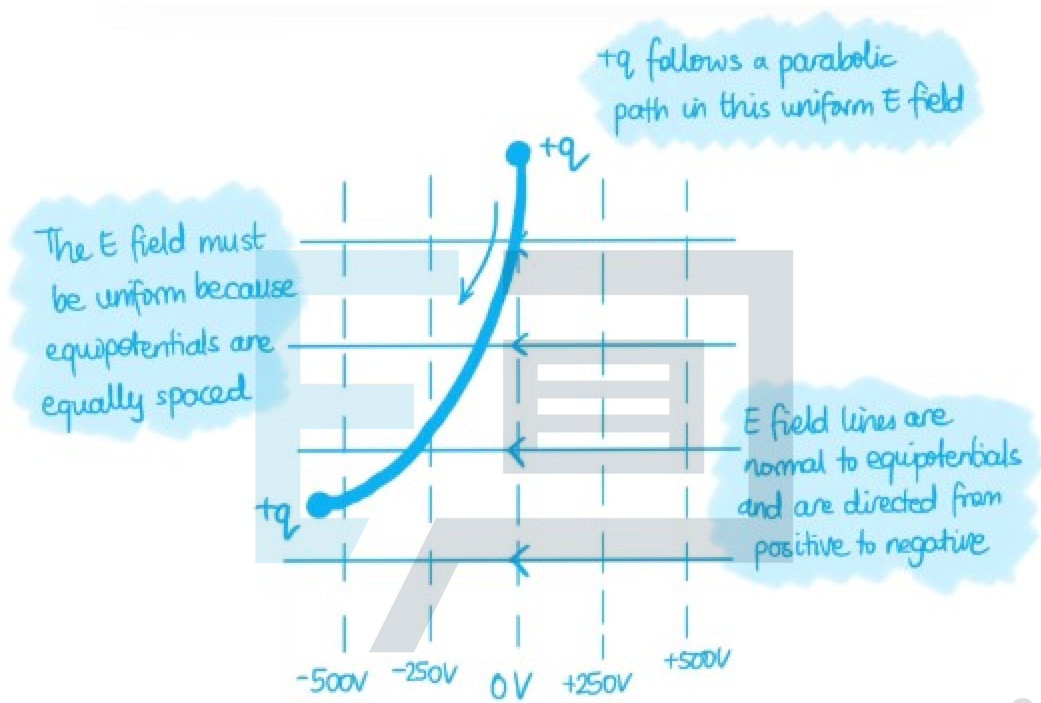
7

The correct answer is **A** because:

- The small point charge $+q$ is positively charged, therefore it will move toward areas of negative charge
  - Negative charge creates a negative potential
  - Therefore, the point charge should move **toward** negative potential in the image
  - Only options **A** or **B** could be correct
- The equipotentials are equally spaced, which means the electric field strength is constant
  - This is because the gradient of the potential is constant
  - Therefore, the point charge will follow a **parabolic** path, because the electric force is constant
  - Hence, the correct path shown is path **A**

Electric field lines are always directed from areas of positive charge to areas of negative charge. Recognising that you can visualise the shape and direction of the electric field - because you are given information about the equipotentials - is crucial for this question.

Since the equipotentials are uniformly spaced (more specifically, the change in potential ΔV is **constant** for equal changes in distance), then the **gradient** of the potential is constant; which means the **electric field strength** is constant. Thus, this electric field must be **uniform.** A vertically falling charged particle will therefore follow a parabola, as shown in the image below:



Note that this is exactly analogous to a projectile of mass m "falling" into a uniform gravitational field. You should remember that such projectile motion is parabolic, for the same reasons as above.

8

The correct answer is **D** because:

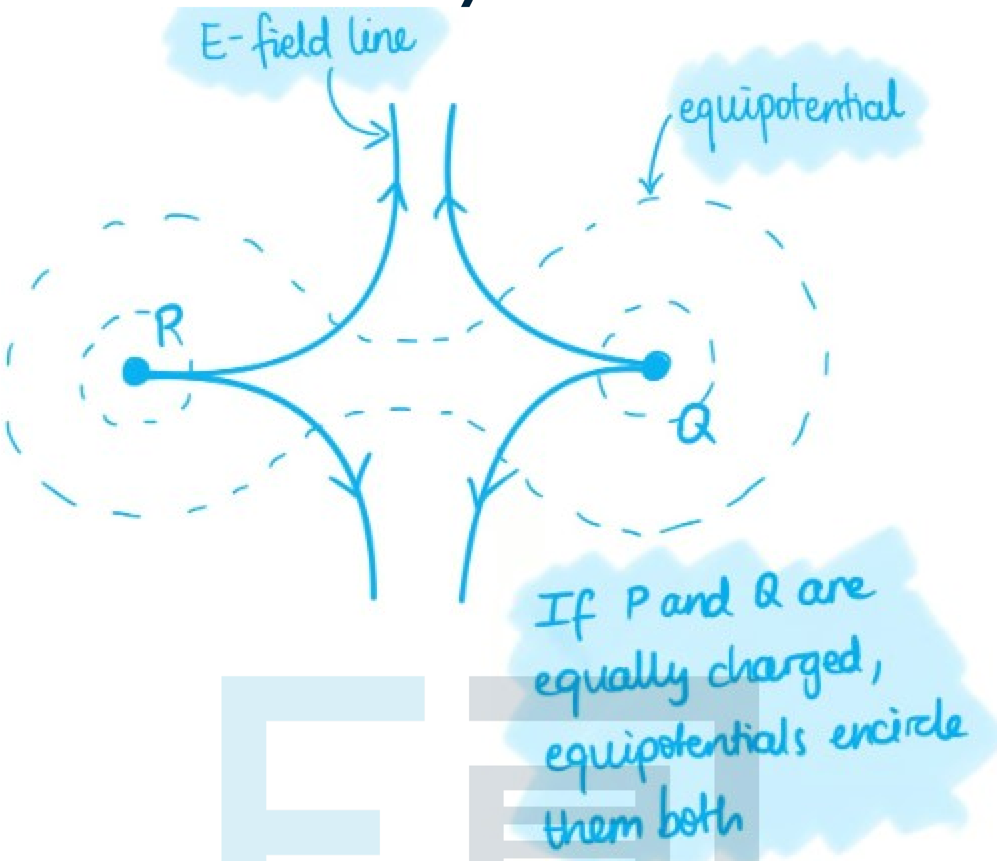
- Since the equipotential encircles both charges, the electric field lines must be radial to them
  - This is as expected, since the electric field and equipotentials must intersect at 90°

- Since P and Q are of the same sign, there can be no resultant electric field between them
    - This is indicated correctly by a space between horizontal equipotentials

A is incorrect as	a vertical equipotential between two charges indicates that the charges are oppositely charged. This is because field lines connect oppositely charged particles
B is incorrect as	equipotential lines cannot join charges because this would indicate the electric field is parallel to them at their surface (since the equipotential intersects them at 90°). This is not the case
C is incorrect as	the equipotential lines intersect the charges at 90°. This is not true of equipotential lines, because this would indicate the electric field is parallel to the surface of the charge (which is not the case)

Take great care not to mix up electric field lines and equipotentials!

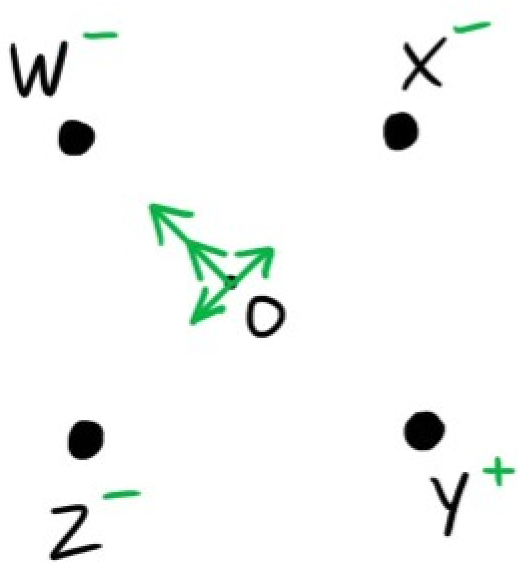
A diagram of the electric field superimposed on top of the equipotentials in option **D** should convince you that this is correctly drawn for two charges of equal sign:



9

The correct answer is **A** because:

- Drawing the electric field due to each of W, X, Y and Z in turn gives a diagram as shown below:



- Each electric field line is directed from positive charge toward negative charge
- There is no resultant field due to charges Z and X, because they are equal and in opposite directions at position O
- Therefore, the resultant field is only due to charge Y and W
  - Since these charges are oppositely charged, their electric field acts in the same direction
  - Therefore, the resultant electric field is directed from Y, towards charge W
  - Hence, the correct answer is **A**

You should be able to analyse diagrams like this "by inspection", and spot symmetries (like the resultant field due to Z and X being zero, because they are the same charge and O is the midpoint between them). This skill will drastically simplify similar problems; this is a popular exam question, so even if you have to do a bit of trial and error, practice drawing field lines is worthwhile!

10

The correct answer is **B** because:

- If equipotentials encircle two sources, they must correspond (i.e., be point masses or charges of the same sign)
  - Field lines and equipotentials are always perpendicular to each other
  - Hence, if equipotentials encircle sources of a field, this must mean field lines never connect the sources (otherwise, they would not intersect at 90°)

A is incorrect as	while the equipotentials would be correct for two equal point masses, they would not be correct for two equal charges that are oppositely charged. There is a field line connecting two opposite charges: hence, the equipotential between them is vertical

C is incorrect as	the equipotentials are valid for two equal point masses (and invalid for two equal opposite charges). This is because the field lines for equal point masses oppose each other, therefore, the equipotentials encircle the sources
D is incorrect as	the equipotential lines are valid for two equal charges of the same sign, but are also valid for two equal point masses. Point masses in this case are equivalent to charged bodies of the same sign (since field lines, in both contexts, oppose each other)