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# 7.5 Electric Potential


# PHYSICS

## AQA A Level Revision Notes

# A Level Physics AQA

## 7.5 Electric Potential

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## 7.5.1 Electric Potential

# Electric Potential

- In order to move a positive charge closer to another positive charge, work must be done to overcome the force of repulsion between them
  - Similarly, to move a positive charge away from a negative charge, work must be done to overcome the force of attraction between them

- Energy is therefore transferred to the charge that is being pushed upon
  - This means its **potential energy** increases

- If the positive charge is free to move, it will start to move away from the repelling charge
  - As a result, its potential energy decreases back to 0

- This is analogous to the gravitational potential energy of a mass increasing as it is being lifted upwards and decreasing as it falls
- The electric potential at a point is defined as:

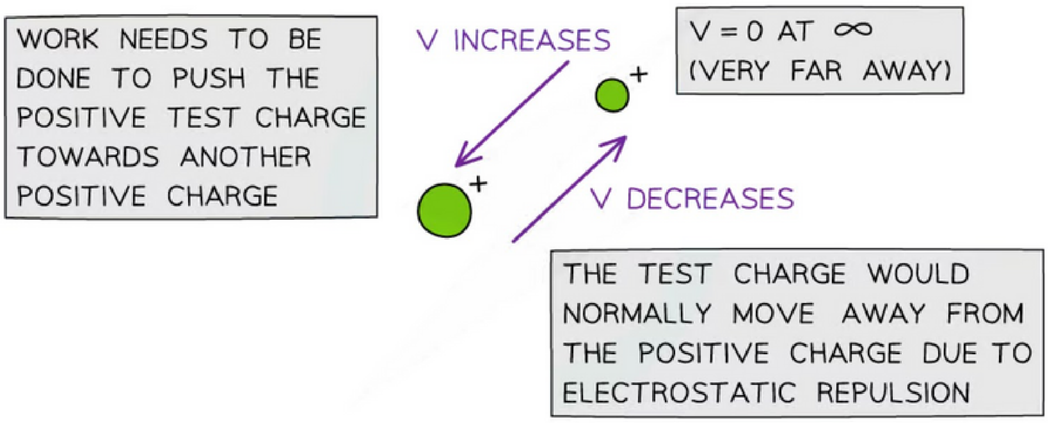
  **The work done per unit positive charge in bringing a point test charge from infinity to a defined point**

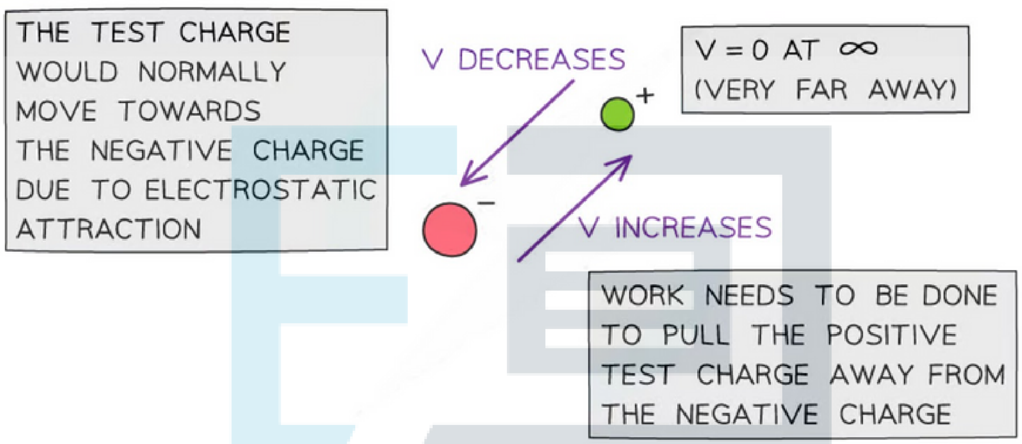
- Electric potential is a **scalar** quantity
  - This means it doesn't have a direction

- However, you will still see the electric potential with a positive or negative sign. This is because the electric potential is:
  - **Positive** around an isolated positive charge
  - **Negative** around an isolated negative charge
  - **Zero** at infinity

- Positive work is done by the mass from infinity to a point around a positive charge and negative work is done around a negative charge. This means:
  - When a positive **test charge** moves closer to a **negative** charge, its electric potential **decreases**
  - When a positive test charge moves closer to a **positive** charge, its electric potential **increases**

- To find the potential at a point caused by multiple charges, the total potential is the sum of the potential from each charge




***The electric potential V decreases in the direction the test charge would naturally move in due to repulsion or attraction***

## Electric Potential Difference



- Two points at different distances from a charge will have different electric potentials
  - This is because the electric potential increases with distance from a negative charge and decreases with distance from a positive charge
- Therefore, there will be an **electric potential difference** between the two points
  - This is represented by the symbol $\Delta V$
- $\Delta V$ is normally given as the equation

$$\Delta V = V_f - V_i$$

- Where:
  - $V_f$ = final electric potential (J C$^{-1}$)
  - $V_i$ = initial electric potential (J C$^{-1}$)
- A difference in electric potential will give a difference in electric potential energy, which can also be calculated

## Electric Potential in Radial Field

- The **electric potential** in the field due to a **point charge** is defined as:

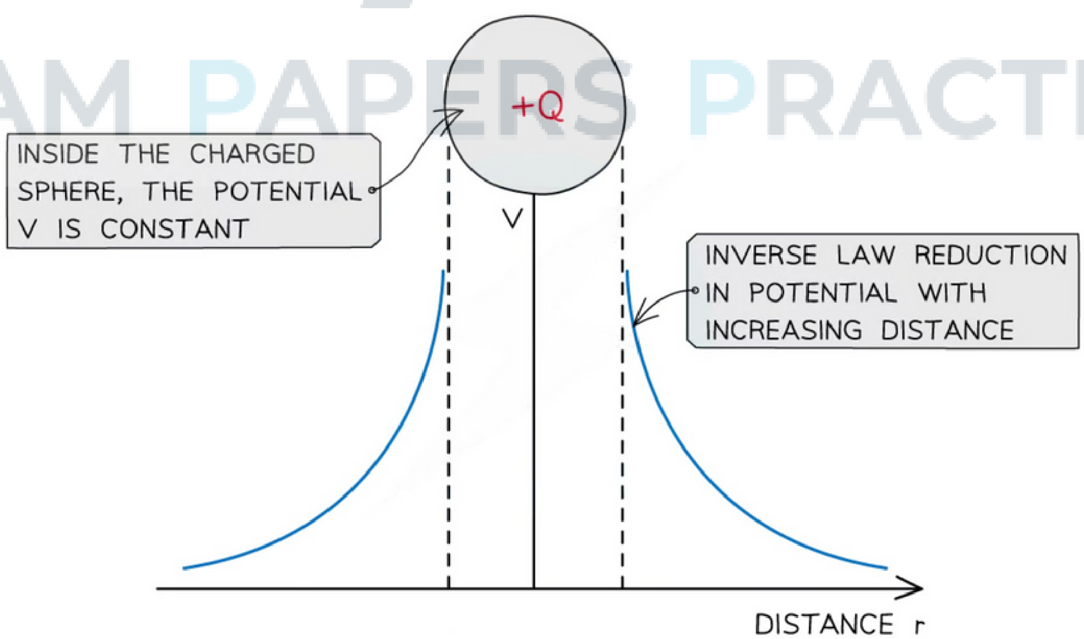
$$V = \frac{Q}{4\pi\varepsilon_0 r}$$

- Where:
  - $V$ = the electric potential (V)
  - $Q$ = the point charge producing the potential (C)
  - $\varepsilon_0$ = permittivity of free space (F $m^{-1}$)
  - $r$ = distance from the centre of the point charge (m)

- This equation shows that for a positive (+) charge:
  - As the distance from the charge *r* **decreases**, the potential *V* **increases**
  - This is because more work has to be done on a positive test charge to overcome the repulsive force

- For a negative (–) charge:
  - As the distance from the charge *r* **decreases**, the potential *V* **decreases**
  - This is because less work has to be done on a positive test charge since the attractive force will make it easier

- Unlike the **gravitational potential** equation, the minus sign in the electric potential equation will be included in the charge
- The electric potential varies according to 1 / r
  - Note, this is different to electric field strength, which varies according to $1 / r^2$




***The potential changes as an inverse law with distance near a charged sphere***

- **Note:** this equation still applies to a conducting sphere. The charge on the sphere is treated as if it concentrated at a point in the sphere from the point charge approximation

## Worked Example

A Van de Graaf generator has a spherical dome of radius 15 cm. It is charged up to a potential of 240 kV.

Calculate:

a) The charge stored on the dome

b) The potential at a distance of 30 cm from the dome

Part (a)

**Step 1: Write down the known quantities**

- Radius of the dome, $r$ = 15 cm = $15 \times 10^{-2}$ m
- Potential difference, $V$ = 240 kV = $240 \times 10^{3}$ V

**Step 2: Write down the equation for the electric potential due to a point charge**

$$V = \frac{Q}{4\pi\varepsilon_0 r}$$

**Step 3: Rearrange for charge Q**

$$Q = V4\pi\varepsilon_0 r$$

**Step 4: Substitute in values**

$$Q = (240 \times 10^{3}) \times (4\pi \times 8.85 \times 10^{-12}) \times (15 \times 10^{-2}) = 4.0 \times 10^{-6}\ \text{C} = 4.0\ \mu\text{C}$$



Part (b)

**Step 1: Write down the known quantities**

- $Q$ = charge stored in the dome = 4.0 μC = $4.0 \times 10^{-6}$ C
- $r$ = radius of the dome + distance from the dome = 15 + 30 = 45 cm = $45 \times 10^{-2}$ m

**Step 2: Write down the equation for electric potential due to a point charge**

$$V = \frac{Q}{4\pi\varepsilon_0 r}$$

**Step 3: Substitute in values**

$$V = \frac{(4.0 \times 10^{-6})}{(4\pi \times 8.85 \times 10^{-12}) \times (45 \times 10^{-2})} = 79.93 \times 10^{3} = \mathbf{80\ kV}\ (2\ \text{s.f.})$$

## 7.5.2 Graphical Representation of Electric Potential

### Graphical Representation of Electric Potential

- **Electric field strength**, *E* and the **electric potential**, *V* can be graphically represented against the distance from the centre of a charge, *r*
- *E, V* and *r* are related by the equation:

$$E = \frac{\Delta V}{\Delta r}$$

- Where:
  - *E* = electric field strength ($V\,m^{-1}$)
  - $\Delta V$ = change in potential (V)
  - $\Delta r$ = displacement in the direction of the field (m)

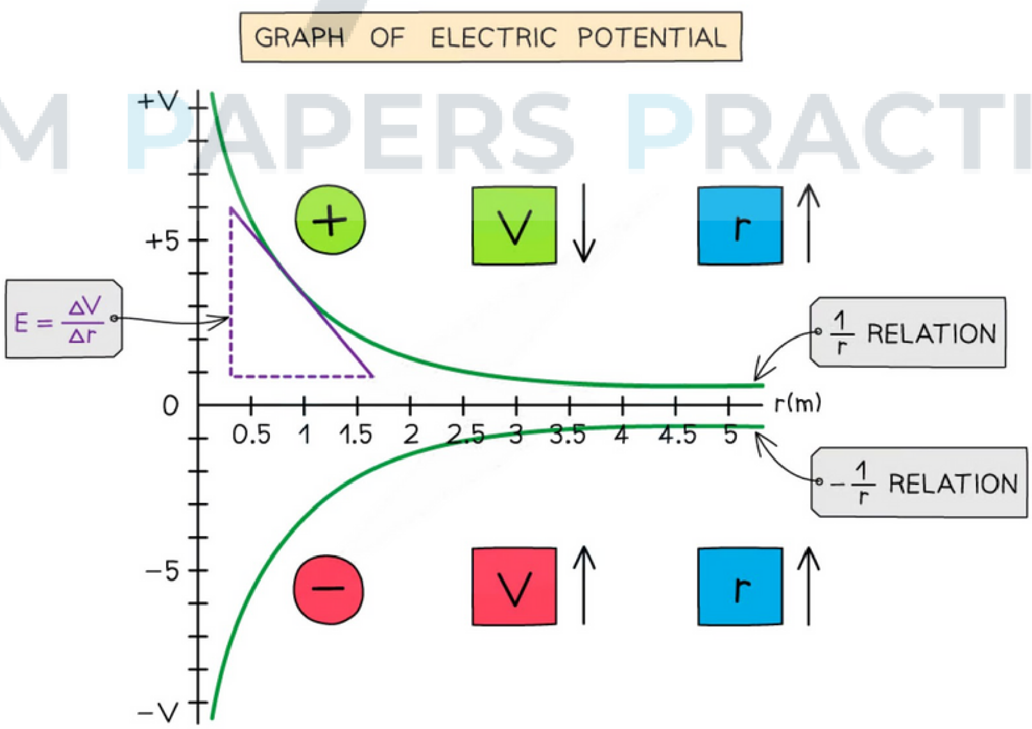
- An electric field can be defined in terms of the variation of **electric potential** at different points in the field:

  **The electric field at a particular point is equal to the gradient of a potential-distance graph at that point**

- The potential gradient in an electric field is defined as:

  **The rate of change of electric potential with respect to displacement in the direction of the field**

- The graph of potential *V* against distance *r* for a negative or positive charge is:



*The electric potential around a positive charge decreases with distance and increases with distance around a negative charge*

- **The key features of this graph are:**
  - The values for *V* are all negative for a negative charge
  - The values for *V* are all positive for a positive charge
  - As *r* increases, *V* against *r* follows a 1/*r* relation for a positive charge and -1/*r* relation for a negative charge
  - The **gradient** of the graph at any particular point is the value of *E* at that point
  - The graph has a shallow increase (or decrease) as *r* increases

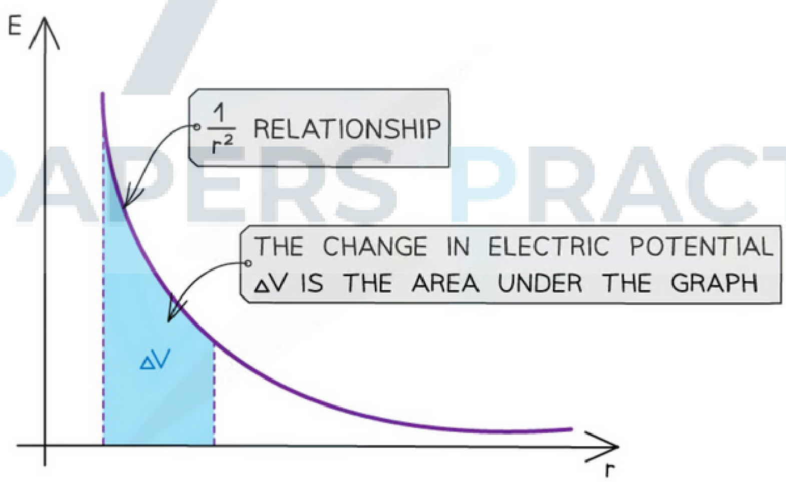
- The electric potential changes according to the charge creating the potential as the distance *r* increases from the centre:
  - If the charge is **positive**, the potential **decreases** with distance
  - If the charge is **negative**, the potential **increases** with distance

- To calculate *E*, draw a tangent to the graph at that point and calculate the gradient of the tangent
- This is a graphical representation of the equation:

$$V = \frac{Q}{4\pi\varepsilon_0 r}$$

where Q and $4\pi\varepsilon_0$ are constants

- The graph of *E* against *r* for a charge is:




*The electric field strength E has a 1/r² relationship*

- **The key features of this graph are**:
  - The values for *E* are all positive
  - As *r* increases, *E* against *r* follows a $1/r^2$ relation (inverse square law)
  - The **area** under this graph is the change in electric potential Δ*V*
  - The graph has a steep decline as *r* increases

- The area under the graph can be estimated by counting squares, if it is plotted on squared paper, or by splitting it into trapeziums and summing the area of each trapezium
- The inverse square law relation means that as the distance *r* doubles, *E* decreases by a factor of **4**
- This is a graphical representation of the equation:

$$E = \frac{Q}{4\pi\varepsilon_0 r^2}$$

where Q and $4\pi\varepsilon_0$ are constants

### Exam Tip

One way to remember whether the electric potential increases or decreases with respect to the distance from the charge is by the direction of the electric field lines. The potential always **decreases** in the **same** direction as the field lines and vice versa.Drawing, interpreting or calculating from either of these graphs are common exam questions.The graph of *E* against *r* should start off **steeper** and decrease **rapidly** compared to that of *V* against *r*, to distinguish it as an inverse square law ($1/r^2$) relation instead of just $1/r$.

## 7.5.3 Work Done on a Charge

# Work Done on a Charge

- When a mass with charge moves through an electric field, work is done
- The work done in moving a charge q is given by:

$$\Delta W = q\Delta V$$

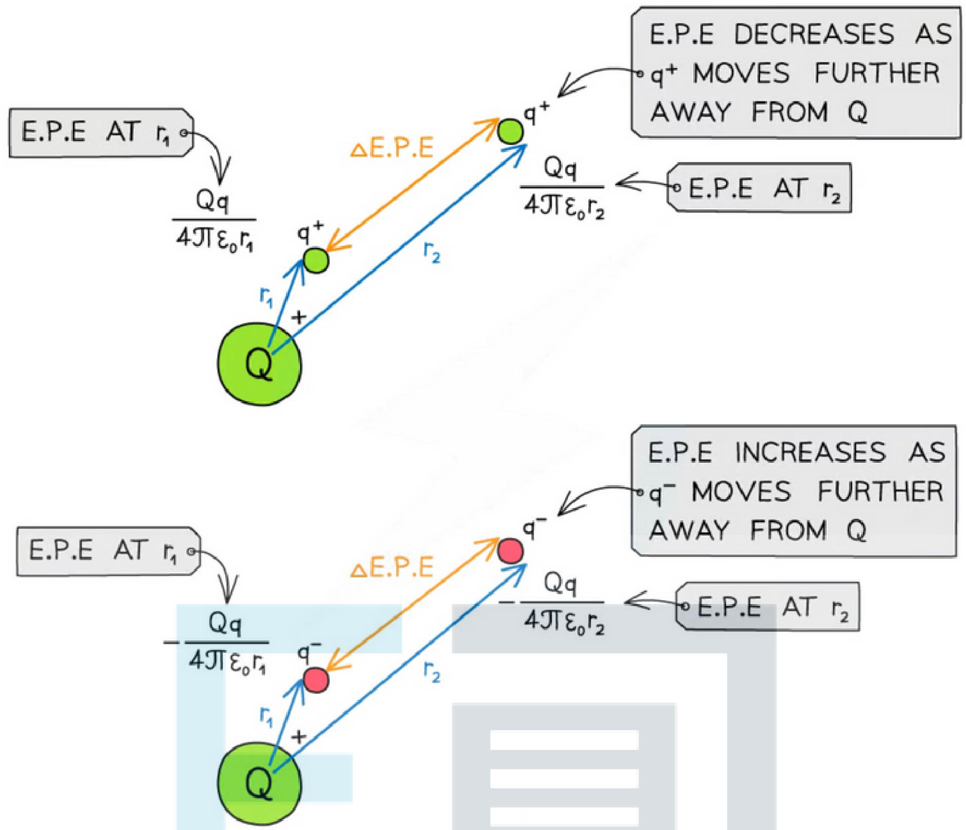
- Where:
  - $\Delta W$ = change in work done (J)
  - $q$ = charge (C)
  - $\Delta V$ = change in electric potential (J $C^{-1}$)

- This change in work done is equal to the change in **electric potential energy** (E.P.E)
  - When $V = 0$, then the E.P.E = 0

- The change in E.P.E, or work done, for a point charge $q$ at a distance $r_1$ from the centre of a larger charge Q, to a distance of $r_2$ further away can be written as:

$$\Delta E.P.E = \frac{Qq}{4\pi\varepsilon_0}\left(\frac{1}{r_2} - \frac{1}{r_1}\right)$$

- Where:
  - Q = charge that is producing the electric field (C)
  - $q$ = charge that is moving in the electric field (C)
  - $r_1$ = first distance of $q$ from the centre of Q (m)
  - $r_2$ = second distance of $q$ from the centre of Q (m)



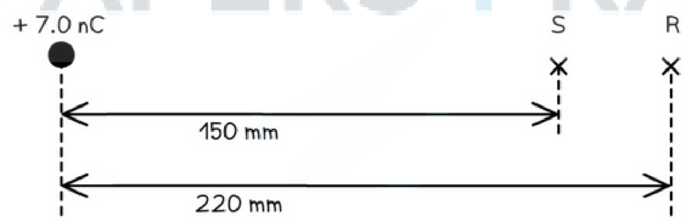

***Work is done when moving a point charge away from another charge***

- Work is done when a positive charge in an electric field moves **against** the electric field lines or when a negative charge moves **with** the electric field lines



## Worked Example

The potentials at points **R** and **S** due to the +7.0 nC charge are 675 V and 850 V respectively.




Calculate how much work is done when a +3.0 nC charge is moved from **R** to **S**.

**Step 1: Write down the known quantities**

- p.d. at **R**, $V_1 = 675$ V
- p.d. at **S**, $V_2 = 850$ V
- Charge, $q = +3.0$ nC $= +3.0 \times 10^{-9}$ C

**Step 2: Write down the work done equation**

$$W = q\Delta V$$

**Step 3: Substitute in the values into the equation**

$$W = (3.0 \times 10^{-9}) \times (850 - 675) = 5.3 \times 10^{-7} \text{ J}$$

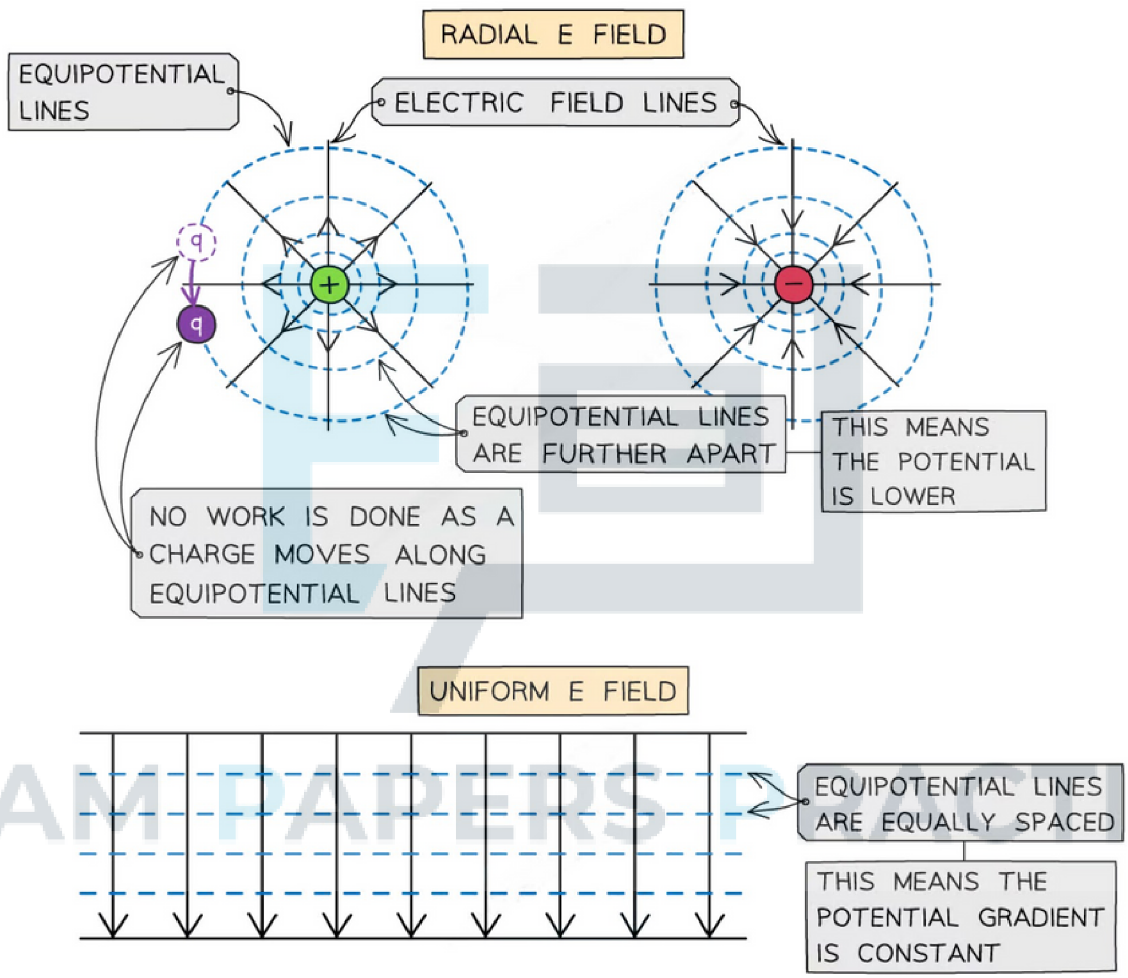
### Exam Tip

Remember that $q$ in the work done equation is the charge that is being moved, whilst Q is the charge which is producing the potential. Make sure not to get these two mixed up, as both could be given in the question (like the worked example) and you will be expected to choose the correct one

## Electrostatic Equipotential Surfaces

- Equipotential lines (2D) and surfaces (3D) join together points that have the **same electric potential**
- These are always:
  - **Perpendicular** to the electric field lines in both radial and uniform fields
  - Represented by **dotted** lines (unlike field lines, which are solid lines with arrows)

- The potential gradient is defined by the **equipotential lines**




***Equipotential lines around a radial field or uniform field are perpendicular to the electric field lines***

- In a **radial field** (eg. a point charge), the equipotential lines:
  - Are concentric circles around the charge
  - Become further apart further away from the charge

- In a **uniform field** (eg. between charged parallel plates), the equipotential lines are:
  - Horizontal straight lines
  - Parallel
  - Equally spaced

- **No work is done** when moving along an equipotential line or surface
- Work is only done when moving **between** equipotential lines or surfaces
  - This means that an object travelling along an equipotential doesn't lose or gain energy and $\Delta V = 0$