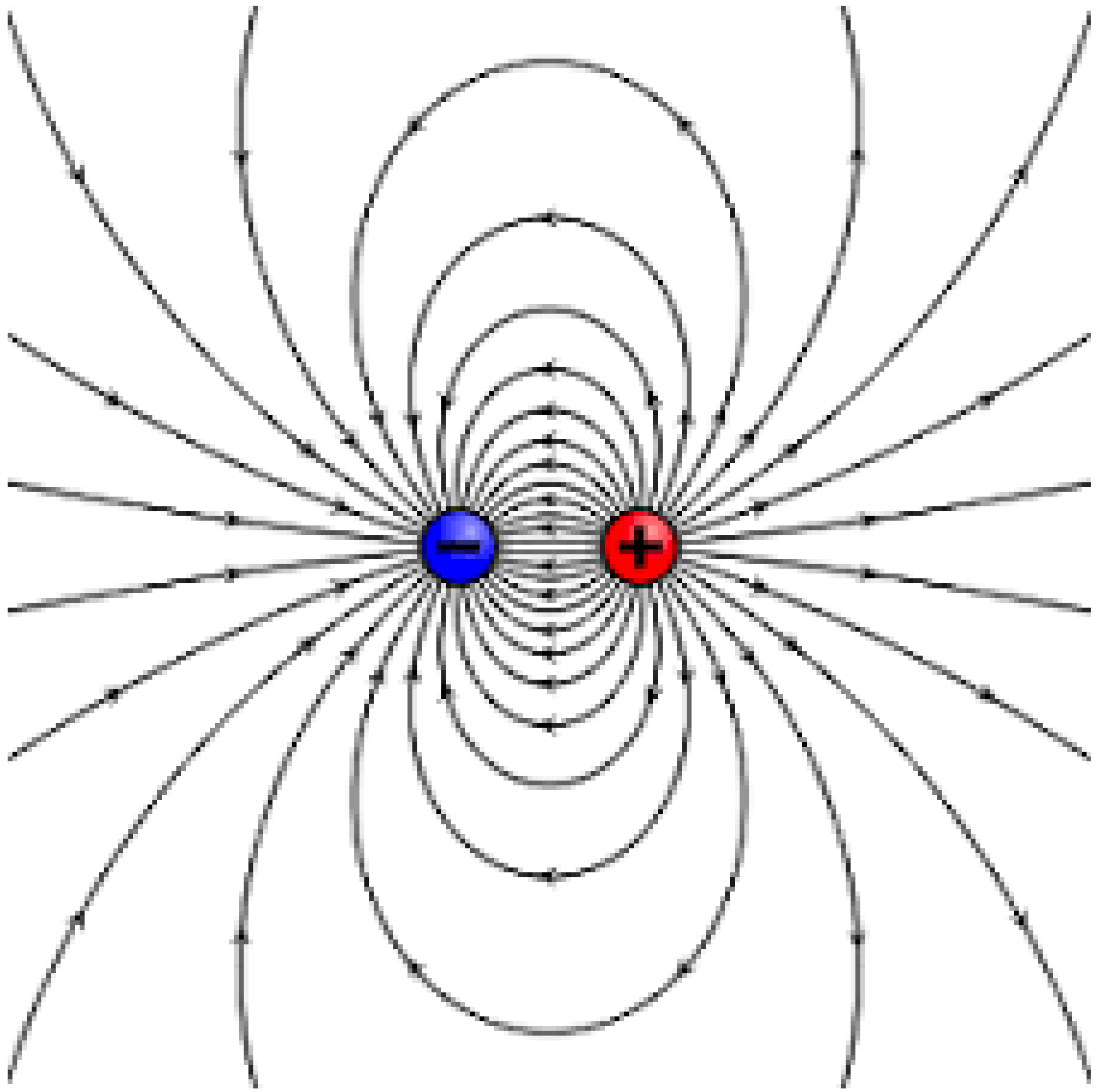
9702 C18 Electric fields



Electric Fields and Forces on Charges

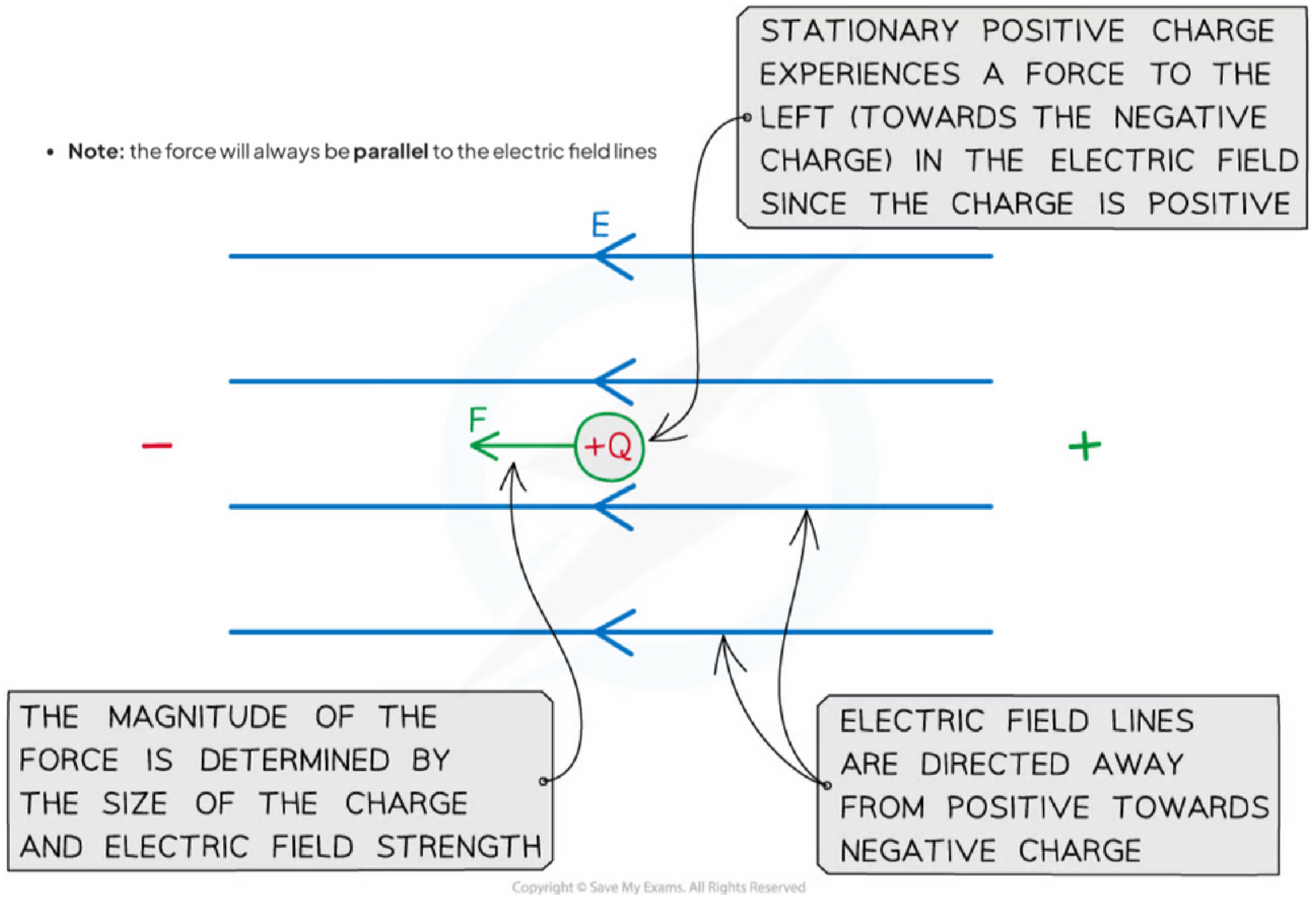
electric field = force per unit positive charge

(recall that opposite charges attract each other and like charges repel each other)

$$E = \frac{F}{Q}$$

Electric field strength is a **vector** quantity, it is always directed:
-away from a positive charge
-towards a negative charge

Where:
- E = electric field strength ($N\,C^{-1}$)
- F = electrostatic force on the charge (N)
- Q = charge (C)



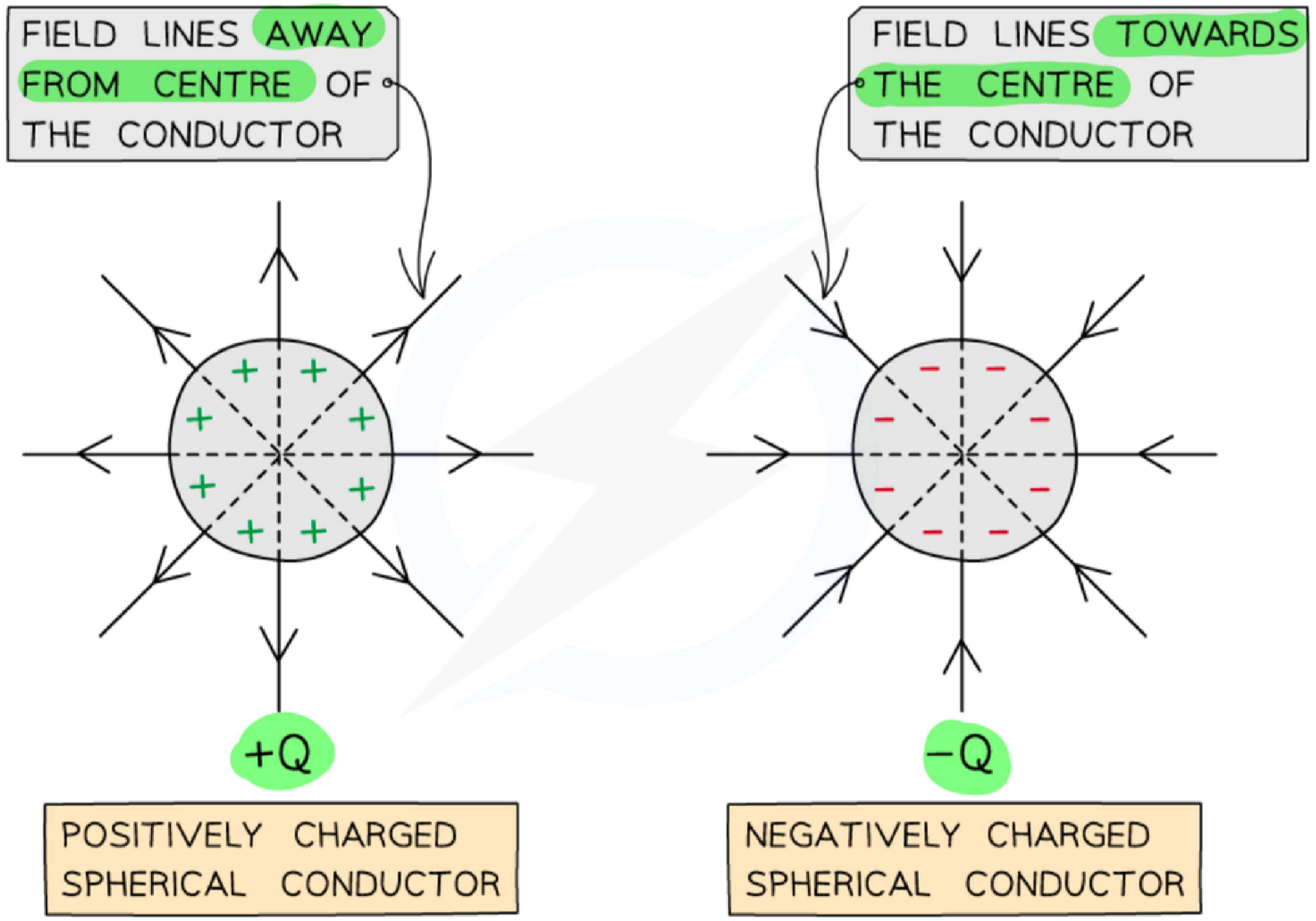
The direction of the force is determined by the charge:
-if **charge is +** , force(**accelerate**) is in the **same direction** as the E field
if **charge is -** , force(**decelerate**) is in the **opposite direction** to the E field

Point Charge Approximation

For a point outside a spherical conductor, the charge of the sphere may be considered to be a point chage at its centre

-->a uniform spherical conductor = charge is distributed evenely

the electric field lines around a spherical conductor are therefore **identical** to those **around a point charge**



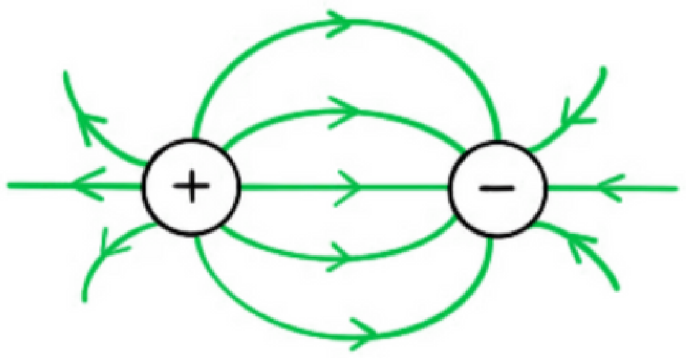
The field lines are **radial** and the direction depends on the charge of sphere:

-sphere conductor is **positively charged** = fields lines are directed **away from the centre of the sphere**

-sphere conductor is **negatively charged**, the field lines are directed **towards the centre of the sphere**

(gravitational force is always attractive, whilst electrostatic forces can be attractive or repulsive**)**

Electric Field Lines



Electric field lines are directed from positive to negative

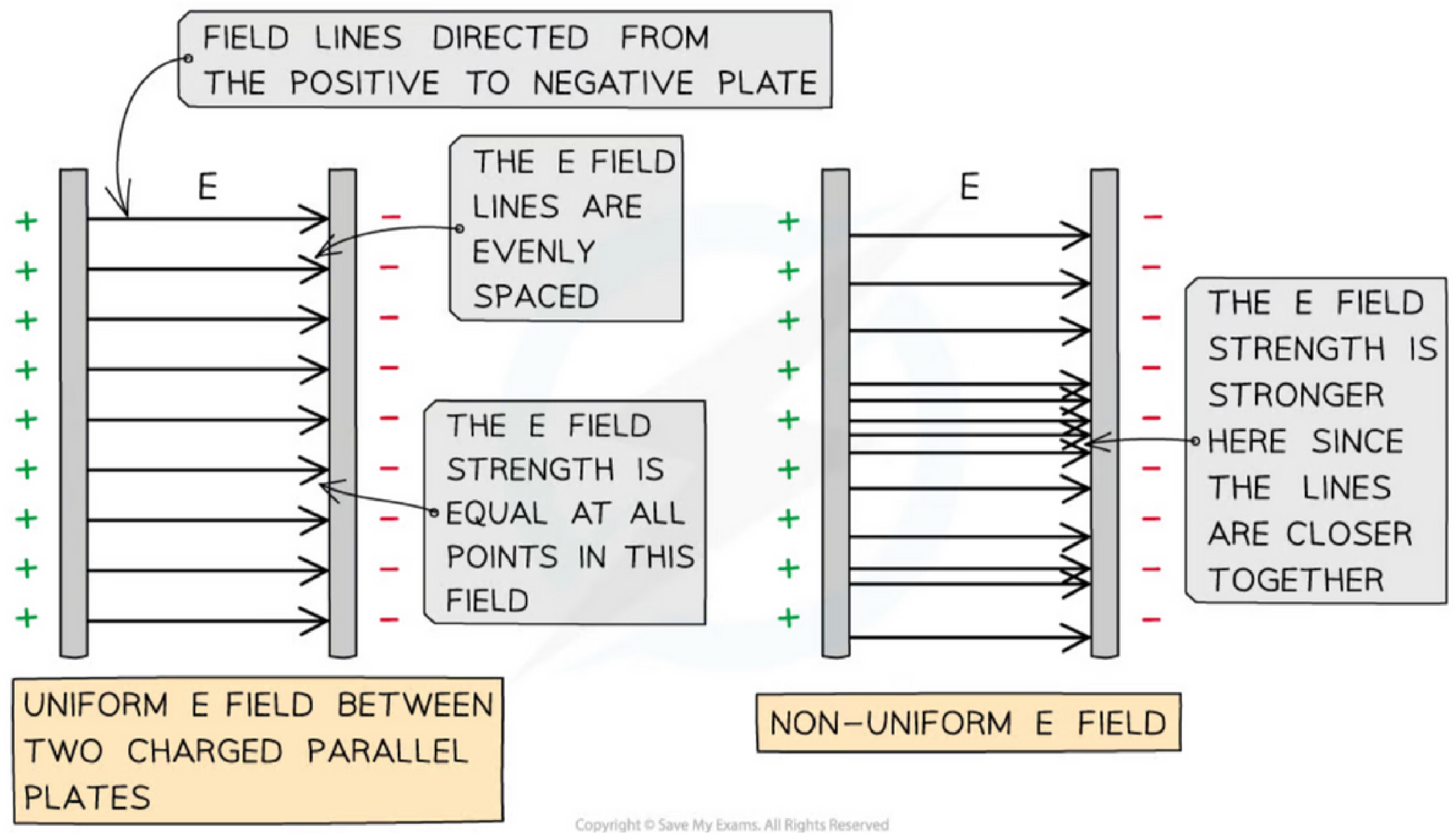
Therefore, the field lines must be pointed away from the positive charge and towards the negative charge

A radial fields(non-uniform fields) spreads evenly in all directions

Around a point chage:

-if charge is + , field lines are radially outwards

-if charge is - , field lines are radially inwards



uniform electric field = same electric field strength throughout the field(represented by **equally spaced** field lines)

non-uniform electric field = varying electric field strength throughout

-stronger field = field lines closer together

-weaker field = field lines further apart

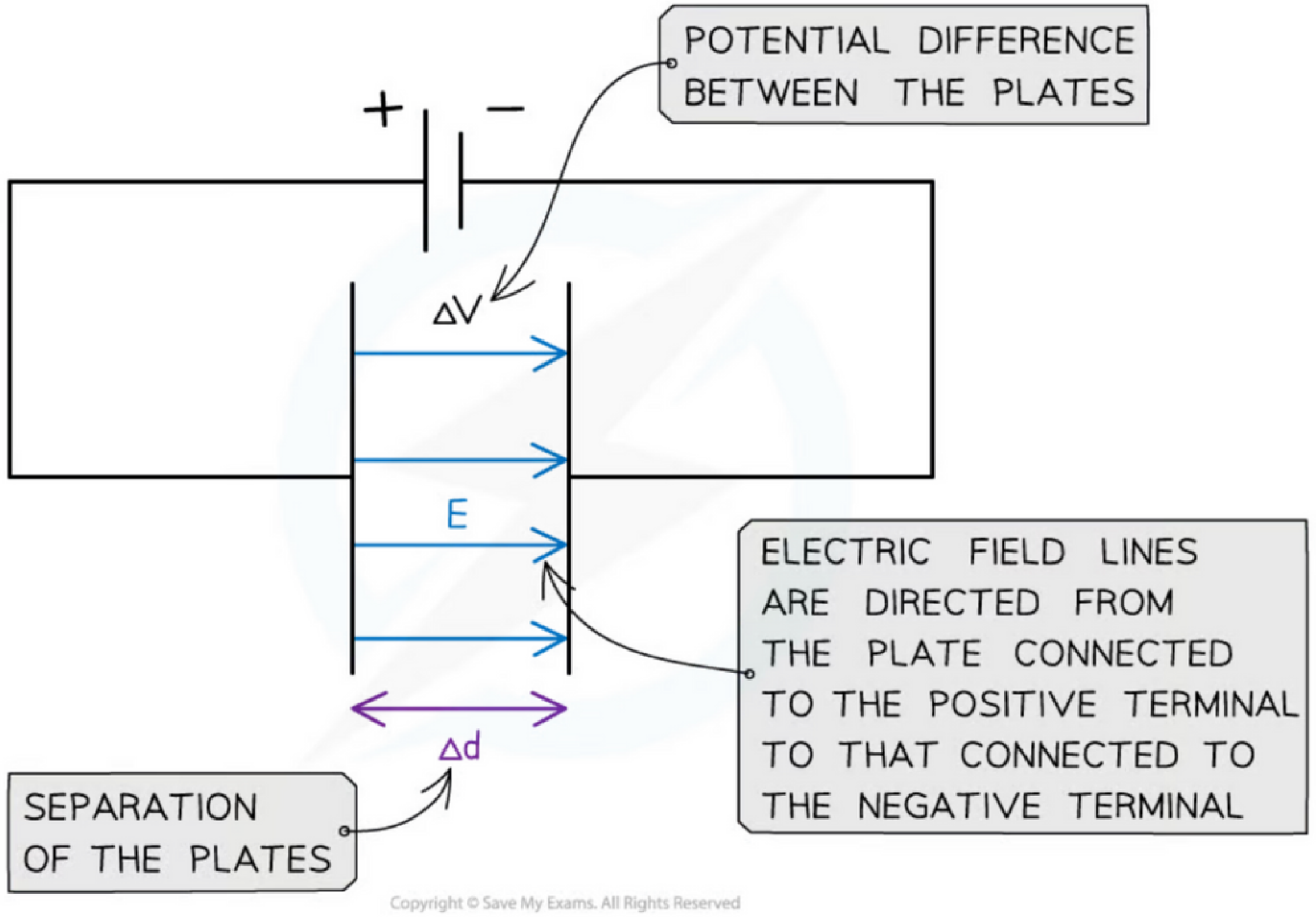
Electric Field Strength

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

(this equation can be used to calculate E of a **uniform field between two charged parallel plates. Cannot be used to find the E around a point charge(since this would be a radial field=non-uniform field)**

Where:

- E = electric field strength ($V\ m^{-1}$)
- ΔV = potential difference between the plates (V)
- Δd = separation between the plates (m)



(if one parallel plates is earthed, it has a voltage of 0v)

Electric Field of a Point Charge in free space

$$k = \frac{1}{4\pi\varepsilon_0} = 8.99 \times 10^9 \ \mathrm{F\,m^{-1}}$$

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

- Where:
  - Q = the charge producing the electric field (C)
  - r = distance from the centre of the charge (m)
  - ε_0 = permittivity of free space ($\mathrm{F\,m^{-1}}$)

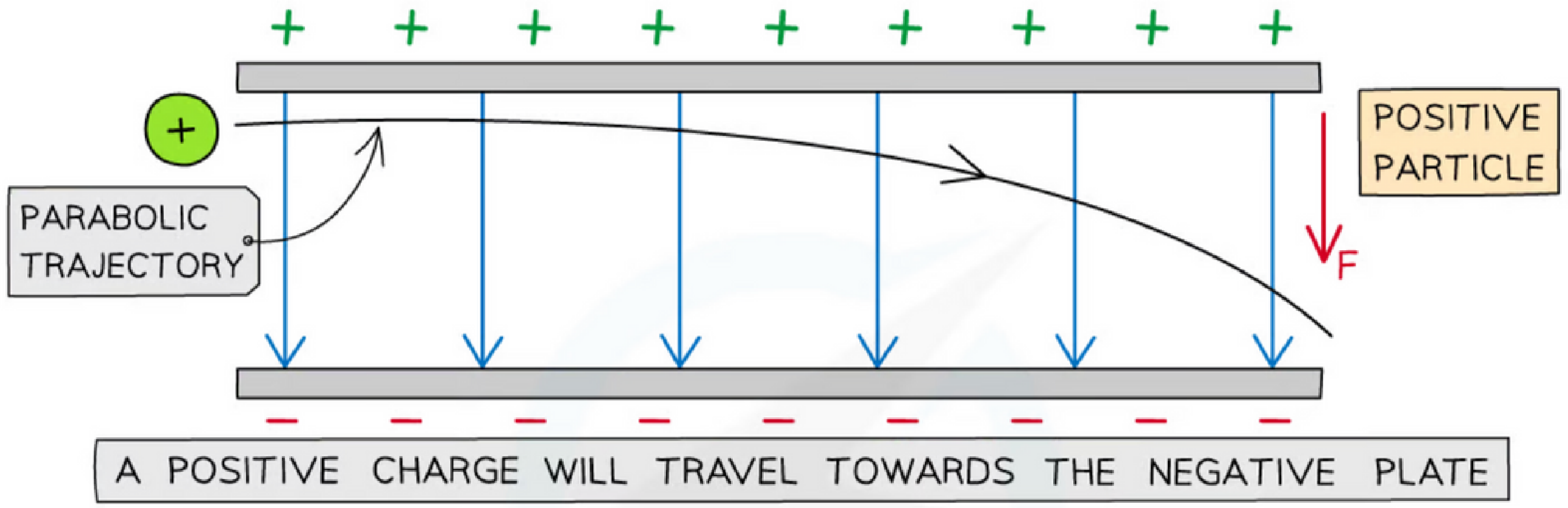
- As the distance from the charge *r* increases, *E* decreases by a factor of $1/r^2$

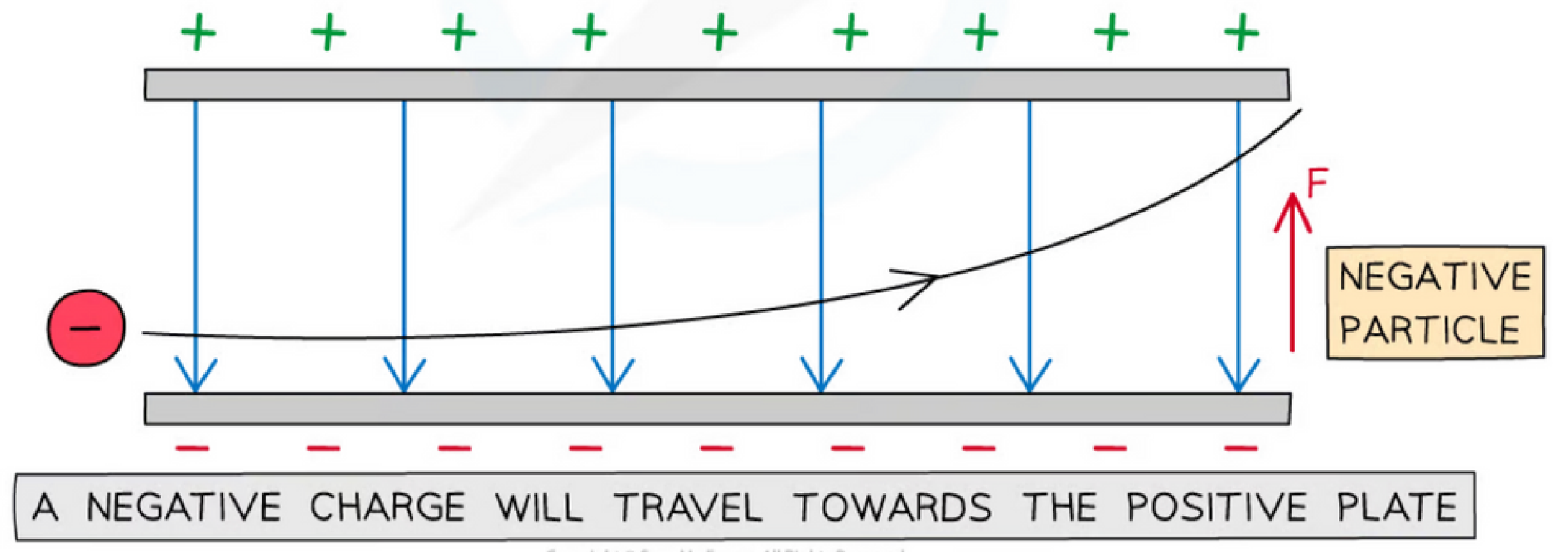
(inverse square law relationship)

Motion of Charged Particles

If a charged particle remains still in a uniform electric field, it will move parallel to the electric field lines)

If a charged particles is in motion through a <u>uniform electric field</u>(between two charged parallel plates), it will experience a constant electric force and travel in a **<u>parabolic trajectory</u>**





(note that neutron(no charge) experiences no force in an electric field and therefore travel straight through the plates undeflected)

Factor affect deflection:

1.Mass - the greater the mass = the smaller the deflection vice versa

2.Charge - the greater the magnitude of charge = the greater the deflection vice versa

3.Speed - the greater the speed of particle = the smaller the deflection vice versa

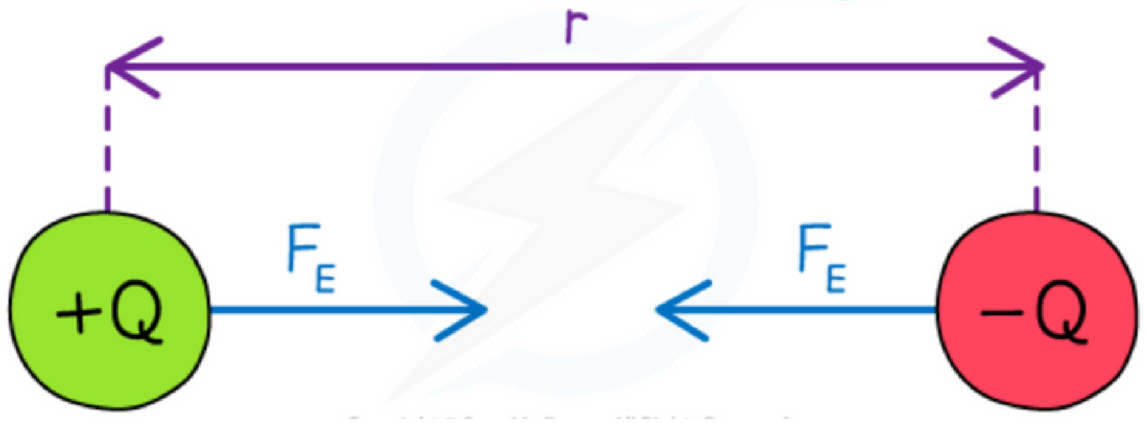
Coulomb’s Law

-all charged particles produce an E-field around it

Coulomb’s Law = the electrostatic force between two point charges is proportional to the product of the charges and inversely proportional to the square of their seperation

Coulomb equation

$$F_E = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2} = \frac{kQ_1Q_2}{r^2}$$



the 1/r^2 is called the inverse square law:
this means when a charge is x2 as far as away from another, the F between them reduced by 1/4

Where:

- F_E = electrostatic force between two charges (N)
- Q_1 and Q_2 = two point charges (C)
- ε_0 = permittivity of free space
- r = distance between the centre of the charges (m)

if F is + = repulsive force
if F is - = attractive force

Electric Potential

Electric potential at a point = work done per unit positive charge in bringing a small test charge from infinity to the point

Electric potential is scalar(so no direction)

However, you will still see electric potential with a positive or negative sign. This is because the **electric potential is:**

-positive when near an isolated positive charge
-negative when near an isolated negative charges
-zero at infinity

When a test charge moves closer to a negative charge, its electric potential decreases
When a test charge moves closer to a positive charge, its electric potential increases

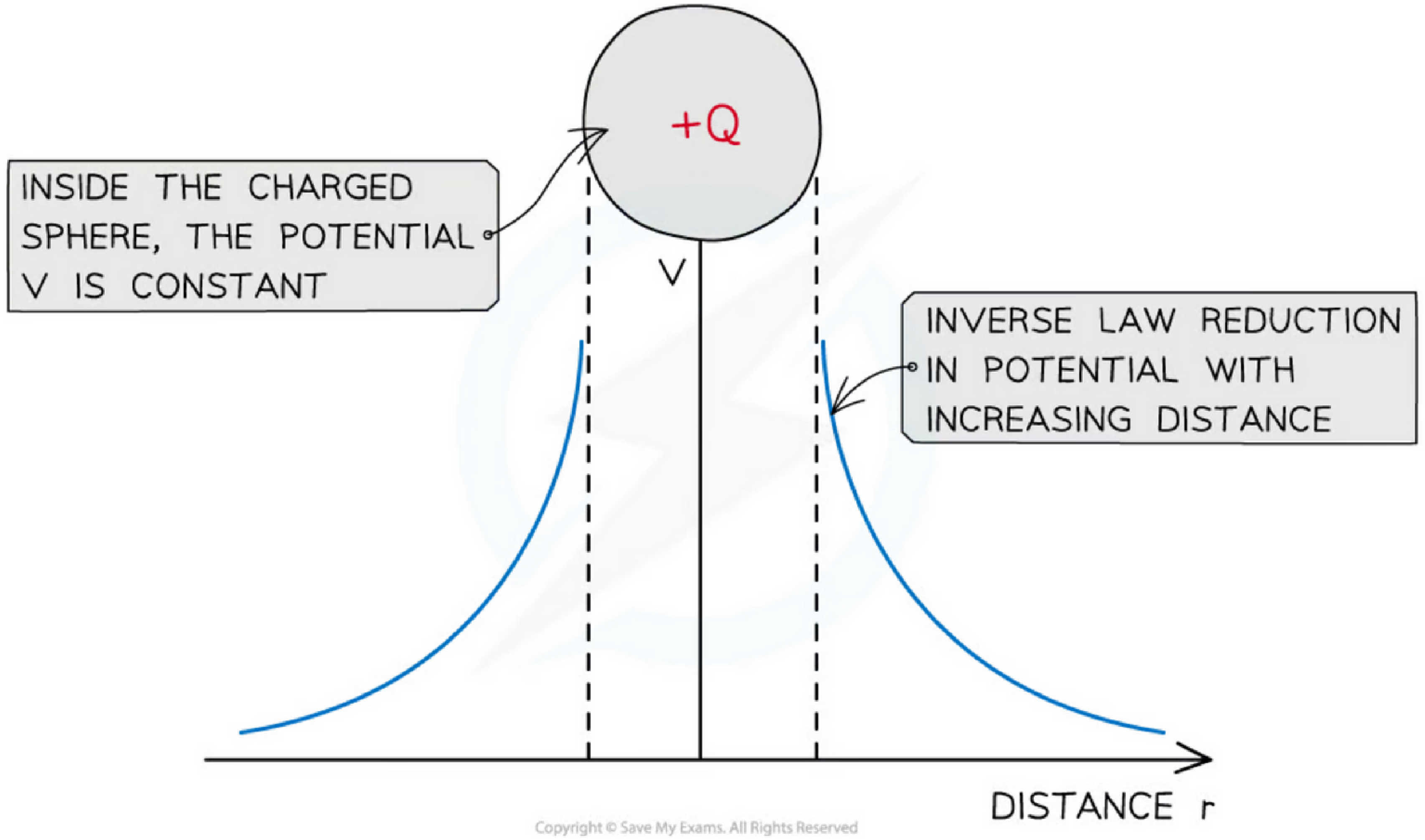
-->To find the potential at a pint caused by multiple charges, add up each potential seperately

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

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

Where:

- V = the electric potential (V)
- Q = the point charge producing the potential (C)
- ε_0 = permittivity of free space ($F\,m^{-1}$)
- r = distance from the centre of the point charge (m)



<u>For a positive charge:</u>

-r decreases = v increases

-this is because more work has to be done on a positive test charge to overcome the repulsive force

<u>For a negative charge:</u>

-r decreases = v decreases

-this is because less work has to be done on a positive test charge since the attractive force will make it easier

Electric Potential Gradient

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

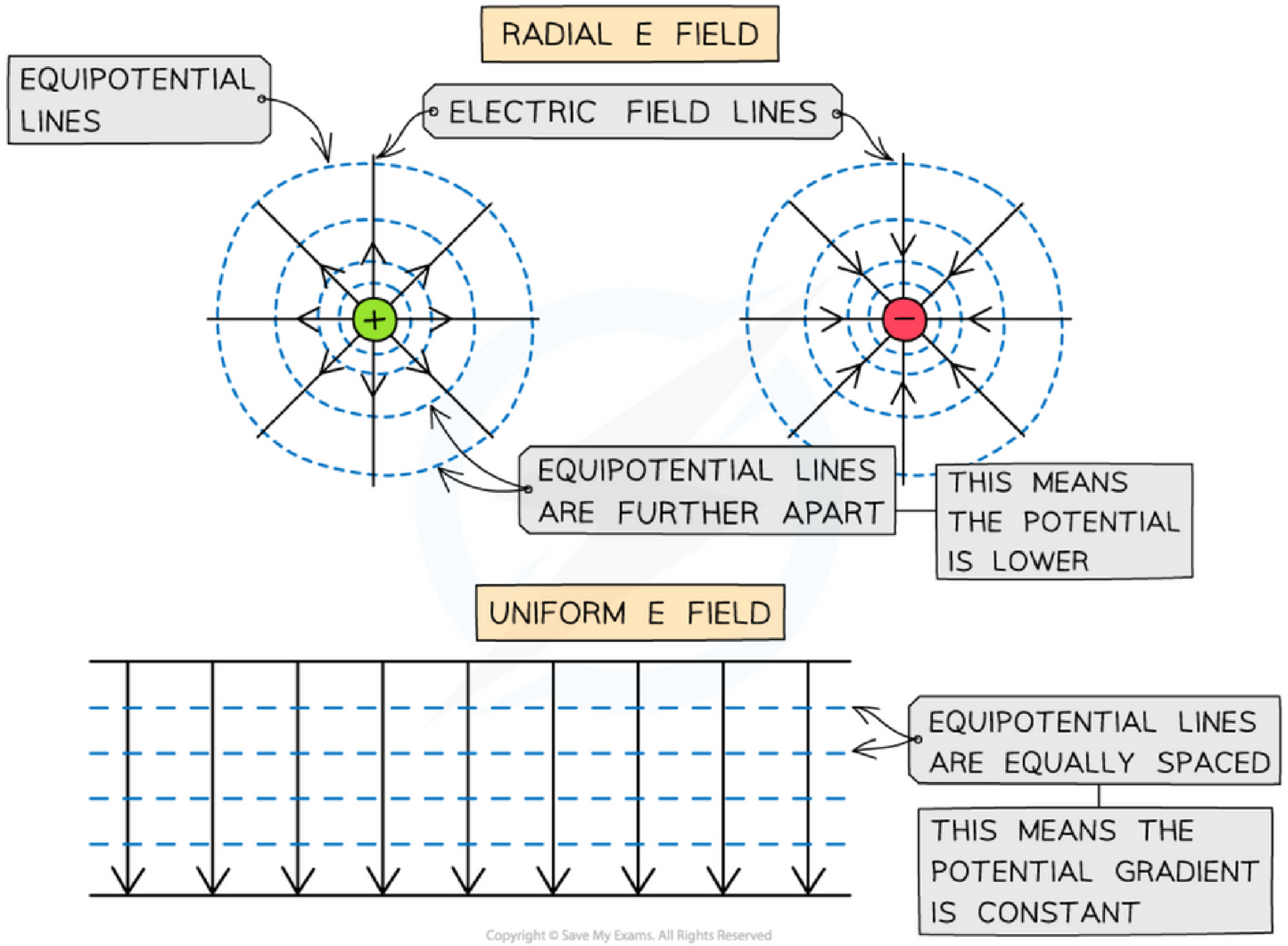
Where:

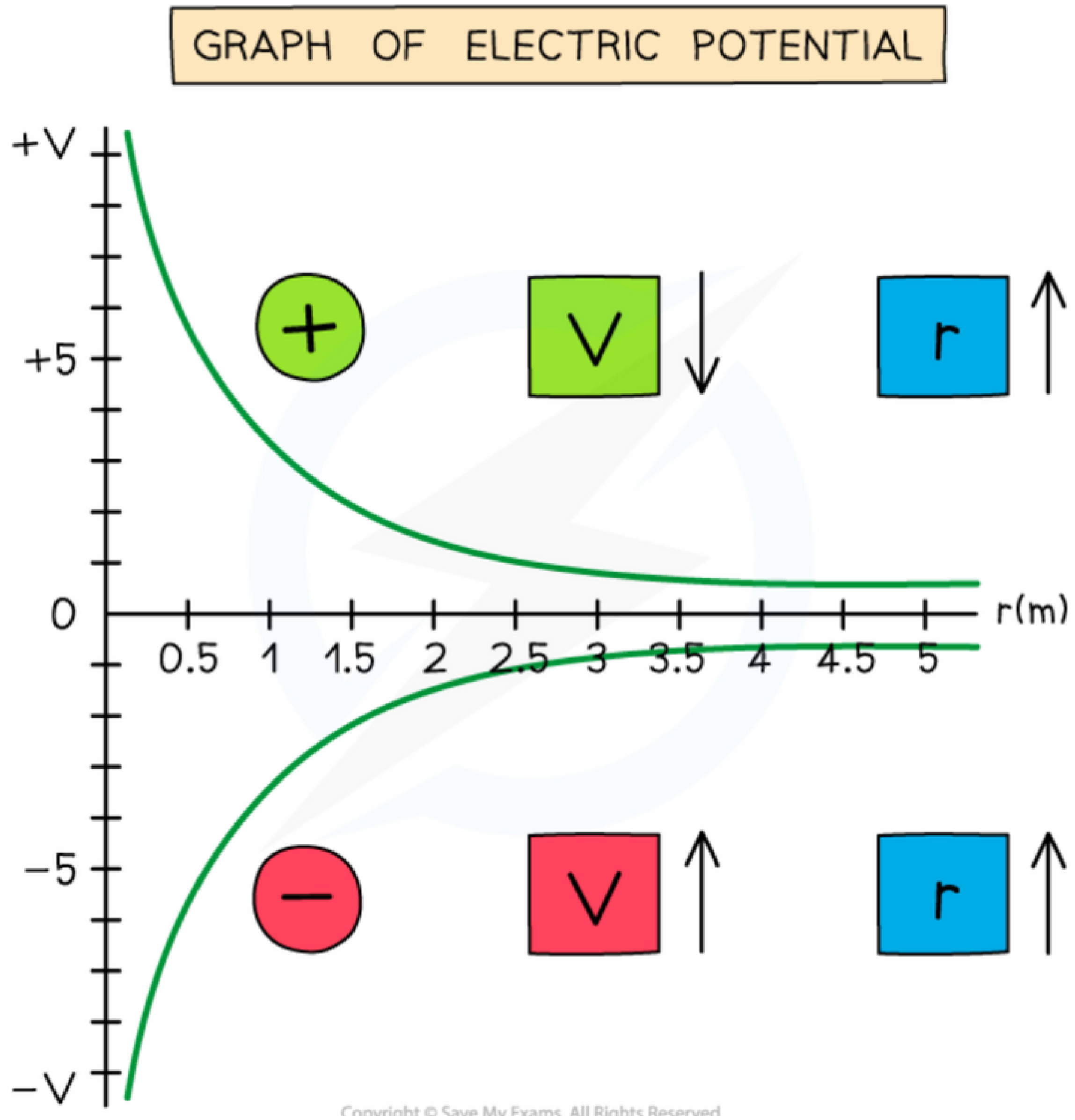
- E = electric field strength ($V\,m^{-1}$)
- ΔV = change in potential (V)
- Δr = displacement in the direction of the field (m)

recall that **electric field = force per unit positive charge**

also electric field at a point = negative of electric potential gradient at that point

The **potential gradient** is defined by the **equipotential lines**: these demonstrate the **electric potential in an E-field and are always drawn perpendicular to the field lines**





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

Electric Potential Energy of Two Point Charges

Electric potential energy, Ep = work done in bringing a charge from infinity to that point

The electric potential energy of a pair of point charges Q_1 and Q_2 is defined by:

$$E_p = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r} = \frac{kQ_1Q_2}{r}$$

Where:

- E_p = electric potential energy (J)
- r = separation of the charges Q_1 and Q_2 (m)
- ε_0 = permittivity of free space (F m^{-1})

This equation is defined by the work done in moving point charge Q2 from infinity towards a point charge Q1.

The work done is equal to:

$$W = VQ$$

Where:

- W = work done (J)
- V = electric potential due to a point charge (V)
- Q = Charge producing the potential (C)

recall that at infinity, V=0 so Ep=0

The change in potential energy from a charge Q_1 at a distance r_1 from the centre of charge Q_2 to a distance r_2 is equal to:

$$\Delta E_p = \frac{Q_1 Q_2}{4\pi\varepsilon_0}\left(\frac{1}{r_1} - \frac{1}{r_2}\right) = kQ_1Q_2\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

The change in electric potential ΔV is the same, without the charge Q_2

$$\Delta V = \frac{Q}{4\pi\varepsilon_0}\left(\frac{1}{r_1} - \frac{1}{r_2}\right) = kQ\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$