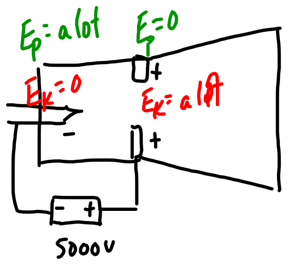
Example

In an electron gun, electrons are emitted by a hot filament in a process called thermionic emission. The electrons are then accelerated across a gap towards a positive electrode (the anode). The potential difference between the filament and the anode is 5000V.



Determine:

a) the electric potential energy of the electrons at the filament

$$V = \frac{\Delta E_p}{q}$$

$$\Delta E_p = Ve$$ elementary charge

$$\Delta E_p = (5000\ \text{J C}^{-1})(1.6 \times 10^{-19}\ \text{C})$$

$$\Delta E_p = 8.0 \times 10^{-16}\ \text{J}$$ ← electric potential energy.

b) the gain in kinetic energy of the electrons as they reach the anode.

loss in E_p = gain in E_K

$$\therefore \Delta E_K = 8.0 \times 10^{-16}\ \text{J}$$

c) the speed of the electrons as they pass through the hole in the anode (assuming they start from rest)

$$E_{K\,final} = 8.0 \times 10^{-16}\ \text{J} \quad (\text{since } E_{K\,initial} = 0)$$

$$E_K = \frac{1}{2}mv^2$$

$$v^2 = \frac{2E_K}{m}$$ mass of electron

$$v^2 = \frac{2(8.0 \times 10^{-16}\ \text{J})}{(9.1 \times 10^{-31}\ \text{kg})}$$

$$v = 4.2 \times 10^7\ \text{m s}^{-1}$$

Example

An alpha particle is a helium nucleus. It is stable and consists of 2 neutrons + 2 protons. The alpha particle is positively charged ($2e = 2(1.6\times10^{-19}C) = 3.2\times10^{-19}C$)

Recall Rutherford used alpha particles in his "Gold Foil Experiment" to investigate the structure of the gold atoms. He accelerated alpha particles across a large potential difference such that their kinetic energy was $3.6\times10^{-16}J$. The mass of the alpha particle is $6.7\times10^{-27}kg$.

Determine the speed of the alpha particles:

$$E_K = \frac{1}{2}mv^2$$

$$v^2 = \frac{2E_K}{m}$$

$$v^2 = \frac{2(3.6\times10^{-16}J)}{6.7\times10^{-27}kg}$$

$$v = 3.3\times10^5\ ms^{-1}$$

Determine the potential difference needed to accelerate them from rest to this speed.

$$\left.\begin{array}{l} E_{K\,initial} = 0 \\ E_{K\,final} = 3.6\times10^{-16}J \end{array}\right\} \Delta E_K = 3.6\times10^{-16}J$$

$$V = \frac{\Delta E_K}{q}$$

$$V = \frac{3.6\times10^{-16}J}{3.2\times10^{-19}C}$$

$$V = 1.1\times10^3\ V$$

potential difference (quantity)

volts (unit)

The electronvolt (eV)

The joule is not very convenient to use when working with very small objects. (like subatomic particles)

Atomic + Nuclear Physicists use the electronvolt

The electron volt is not an SI unit.

(The work done on a charge of "e" across a pot. diff. of 1 V)

$$V = \frac{\Delta W}{q}$$

$$\Delta W = Vq$$

V times e

$$\Delta W = V \cdot e$$

$$\Delta W = (1\,JC^{-1})(1.6\times10^{-19}C)$$

$$\Delta W = 1.6\times10^{-19} J$$

$$\therefore\ 1\,\underset{\text{unit}}{eV} = 1.6\times10^{-19} J$$

3.2eV

$3.2(1.6\times10^{-19}J)$

Example

An electron accelerates across a pot. diff of $1.0\times10^3 V$.

What is its KE in J?

$$\Delta E_K = Vq$$

$$\Delta E_K = (1.0\times10^3 JC^{-1})(1.6\times10^{-19} C)$$

$$\Delta E_K = 1.6\times10^{-16} J$$

What is its KE in eV?

$$\Delta E_K = 1.6\times10^{-16} J\left(\frac{1eV}{1.6\times10^{-19}J}\right)$$

$$\Delta E_K = 1.0\times10^3 eV$$

match

Recall $V = 1.0\times10^3 V$

If an electron accelerates across a pot. diff of $5.0\times10^3 V \Rightarrow E_K = 5.0\times10^3 eV$

§6.2 Electric Force + Field

Greeks → tried to explain the attraction/repulsion of objects that had been rubbed together.
→ proposed the idea of an electric charge.
→ positive and negative charges
→ like charges repel and unlike charges attract

Electrostatics → Study of the effect of stationary charges.

Law of Conservation of Charge

In any closed system, the algebraic sum of all the charges remains constant

Conductors

- a material that allows the flow of electric charge.
- charges must be free to move.
- metals, ionic solution, graphite.

carbon has 4 valence electrons
3 involved in bonding
1 electron is left and delocalized between the layers of atoms.

Insulators

- materials that do not have any free charges to move → they do not allow the flow of electric charge.
- nothing is a perfect insulator.
- a high enough potential difference can cause the charges to move.

Semi Conductor

- a material like Silicon in which a conduction band exists, but normally without any electrons.
- electrons can be excited (heat or light) into the conduction band and now the material is conducting.

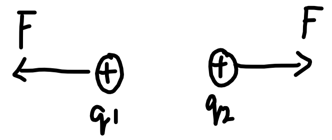
Coulomb's Law

- late 1700s
- Coulomb used a torsion balance to measure the force of attraction/repulsion between charged objects.
- Coulomb found:

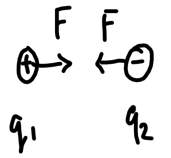
$$\left.\begin{array}{l} F \propto q_1 \\ F \propto q_2 \\ F \propto \dfrac{1}{r^2} \end{array}\right\} \quad F \propto \frac{q_1 q_2}{r^2}$$

Coulomb's Law

- applies to point charges.



- the forces on each object are relate by Newton's Third Law
- the force between the two charges is a mutual force.



- the magnitude of the force between the two charges depends on the medium in which the charges are located. We will worry about air or a vacuum.

$$F \propto \frac{q_1 q_2}{r^2}$$

$$F = \frac{k q_1 q_2}{r^2}$$

Where $k = \dfrac{1}{4\pi \varepsilon_0}$ and ε_0 is the permittivity of free space. (vacuum)

$(k = 8.99 \times 10^{9}\ N m^2 C^{-2})$ $\quad (8.85 \times 10^{-12}\ C^2 N^{-1} m^{-2})$

a fundamental constant.

Example

Determine the force between a +2.5nC charge and a −5.0nC charge placed 2.5 mm apart.

magnitude of force.

attractive → unlike charges

$$F = \frac{kq_1q_2}{r^2}$$

do not put signs on charges

$$F = \frac{(8.99\times10^{9}\,N\,m^2C^{-2})(2.5\times10^{-9}\,C)(5.0\times10^{-9}\,C)}{(2.5\times10^{-3}\,m)^2}$$

$$\boxed{F = 1.8\times10^{-2}\,N}$$

Example

The force between two point charges is 6.0×10^{-6} N. What is the force between them if the charge on one of is halved and the distance is doubled?

$$F = \frac{kq_1q_2}{r^2}$$

(new force) $$F' = \frac{k\left(\frac{q_1}{2}\right)q_2}{(2r)^2}$$

$$F' = \frac{\frac{1}{2}kq_1q_2}{4r^2}$$

$$F' = \frac{1}{8}\frac{kq_1q_2}{r^2}$$

F

$$F' = \frac{1}{8}F$$

$$F' = \frac{1}{8}(6.0\times10^{-6}\,N)$$

$$\boxed{F' = 7.5\times10^{-7}\,N}$$

Field

- a region in space where a force is experienced by:
  - a test mass → gravitational field
  - a test charge → electric field
  - a test pole
  - a test current element

  } → magnetic field

Electric Field

A region of Space throughout which an electric test charge experiences an electrical force.

The direction of the field is the direction of the force on a positive test charge

Electric Field Strength

The electric field strength $\vec{E}$ at a point in space is defined as the force per unit charge on a small positive test charge placed at That point.

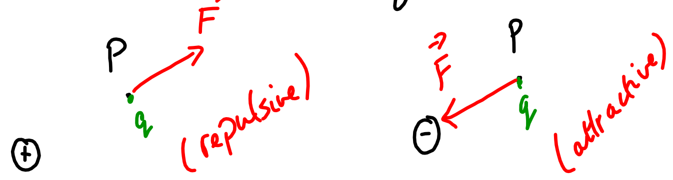
$$\vec{E} = \frac{\vec{F}}{q}$$ ← do not put a sign on q.

Where $\vec{E}$ is the electric field strength $(N\,C^{-1})$

$\vec{F}$ is the force on the test charge due to the field at P. (N)

q is the charge on the small positive test charge (C)

$\vec{E}$ is a vector quantity

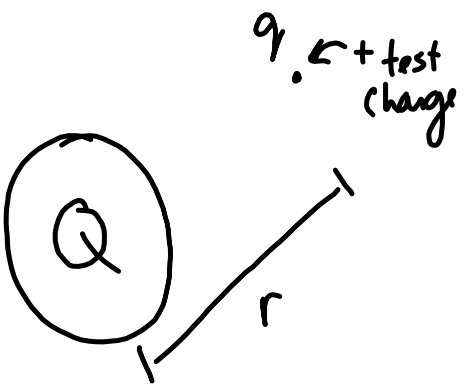


	Gravitational	Electric
Force	$F = \frac{Gm_1m_2}{r^2}$	$F = \frac{kq_1q_2}{r^2}$
Field Strength	$g = \frac{F}{m}$	$E = \frac{F}{q}$

Data Booklet

Field Strength (at a certain point due to a source)	$g = \frac{GM}{r^2}$	$E = \frac{kQ}{r^2}$

Electric Field Strength due to a single point charge:



$$F = \frac{kQq}{r^2}$$

$$E = \frac{\frac{kQ\cancel{q}}{r^2}}{\cancel{q}}$$

$$E = \frac{kQ}{r^2}$$

where Q is the source charge.

Acceleration of a charged body in an electric field

Consider an object of mass m and carrying a charge q which is placed in an electric field strength $\vec{E}$:

$$\vec{E} = \frac{\vec{F}}{q} \qquad \vec{F}_{net} = m\vec{a}$$

$$\vec{F} = q\vec{E} \qquad q\vec{E} = m\vec{a}$$

(the force experienced by charge q)

$$\vec{a} = \frac{q\vec{E}}{m}$$

Example

Calculate the acceleration of an electron in an electric field of strength $100\,NC^{-1}$

$q = 1.60 \times 10^{-19}\,C$

$m = 9.11 \times 10^{-31}\,kg$

$$a = \frac{qE}{m}$$

$$a = \frac{(1.60\times10^{-19}\,\cancel{C})(100\,N\cancel{C^{-1}})}{(9.11\times10^{-31}\,\cancel{kg})}$$

$\cancel{kg}\cdot ms^{-2}$

HUGE! $\boxed{a = 1.76 \times 10^{13}\,ms^{-2}}$

Example

A small oil droplet carries a positive charge of 3.0×10^{-9} C

When the oil droplet is placed in an electric field there is a force on the droplet of 1.5×10^{-5} N to the right.

What is the strength of the electric field at this point?

What is the acceleration of the oil droplet if its mass is 1.5 mg?

$$\vec{E} = \frac{\vec{F}}{q}$$

$$\vec{E} = \frac{1.5 \times 10^{-5}\ \text{N}\ [R]}{3.0 \times 10^{-9}\ \text{C}}$$

$$\vec{E} = 0.50 \times 10^{4}\ \text{NC}^{-1}\ [R]$$

$$\vec{E} = 5.0 \times 10^{3}\ \text{NC}^{-1}\ [R]$$

$$\vec{F} = m\vec{a}$$

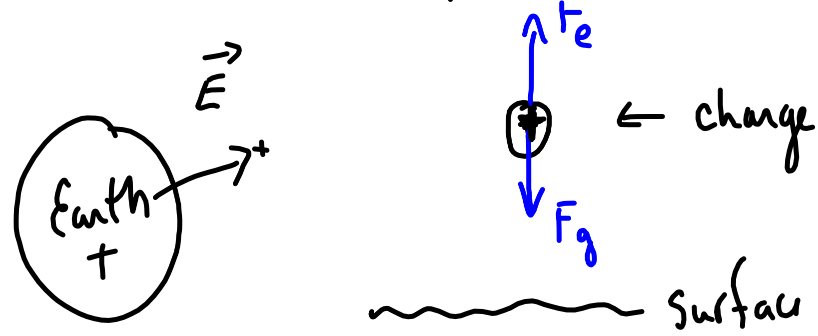
$$\vec{a} = \frac{\vec{F}}{m}$$

$$\vec{a} = \frac{1.5 \times 10^{-5}\ \text{N}\ [R]}{1.5 \times 10^{-6}\ \text{kg}}$$

$$\vec{a} = 10\ \text{ms}^{-2}\ [R]$$

Example

Delicate measurements indicate that the Earth has an electric field surrounding it similar to that around a positively charged sphere. It's magnitude at the Earth's surface is about $100\,NC^{-1}$. What charge would an oil drop of mass 2.0×10^{-15} kg have to have, in order to remain suspended by the Earth's electric field?



← charge must be positive in order to be suspended

$$F_e = F_g$$

$$qE = mg$$

$$q = \frac{mg}{E}$$

$$q = \frac{(2.0\times10^{-15}\,kg)(9.81\,ms^{-2})}{100\,NC^{-1}}$$

$$q = 2.0\times10^{-16}\,C$$

Drift Speed of Charge Carriers

$$I = nAvq$$

$$v = \frac{I}{nAq}$$

Where v is the drift speed (ms^{-1})

I is the current (A or Cs^{-1})

n is the density of charge carriers (free electron density) (electrons/m^3)

q is the charge on the charge carrier (C)

$q = 1.6 \times 10^{-19}$ C for electron

A is the cross-sectional area of the wire (m^2)