electric charges, forces and fields
static electricity

(a) Interaction between plastic rods rubbed on fur
(b) Interaction between glass rods rubbed on silk
(c) Interaction between objects with opposite charges

→ like charges repel, unlike charges attract
atomic origin of charge

The charges of the electron and proton are equal in magnitude.

Proton: Positive charge
Mass = $1.673 \times 10^{-27}$ kg

Neutron: No charge
Mass = $1.675 \times 10^{-27}$ kg

Electron: Negative charge
Mass = $9.109 \times 10^{-31}$ kg

(a) Neutral lithium atom (Li):
- 3 protons (3+)
- 4 neutrons
- 3 electrons (3–)
Electrons equal protons: Zero net charge

(b) Positive lithium ion (Li⁺):
- 3 protons (3+)
- 4 neutrons
- 2 electrons (2–)
Fewer electrons than protons: Positive net charge

(c) Negative lithium ion (Li⁻):
- 3 protons (3+)
- 4 neutrons
- 4 electrons (4–)
More electrons than protons: Negative net charge
conductors and insulators

materials which permit the movement of charge through them are called **conductors**

- e.g. most metals

materials which resist the movement of charge through them are called **insulators**

- e.g. plastic, wood ...
**Charge Induction**

1. Uncharged metal ball
2. Negative charge on rod repels electrons, creating zones of negative and positive induced charge.
3. Wire lets electron buildup (induced negative charge) flow into ground.
4. Wire removed; ball now has only an electron-deficient region of positive charge.
5. Rod removed; positive charge spreads over ball.
Ball A’s (+) charge pulls on the (-) induced charge and pushes on the (+) induced charge. Because the (-) charge is closer to A, the pull is stronger than the push, so B is attracted to A.
induction

- inducing charge separation with a van der Graaf generator

Inducing Dipoles
With a Van de Graaff Generator

MIT Department of Physics
Technical Services Group
induction

→ inducing charge separation with a van der Graaf generator
polarization of insulators
polarization of insulators

Negatively charged comb

Molecules with induced charges

The comb’s (-) charge repels the electrons in each molecule in the paper, creating induced charges. The side of the paper facing the comb thus has a slight net positive charge.

Paper scrap (insulator)

Positively charged comb

A comb with a (+) charge also creates induced charges that attract the paper to the comb.
conservation of charge

- the total charge in a closed system is conserved
- we can move charge around, but we can’t create or destroy it

- the unit of electrical charge is the Coulomb
- 1 Coulomb is a lot of charge
- the charge of a proton (or electron) seems to be the minimum allowed unit of charge in nature, $e = 1.60217653(14) \times 10^{-19}$ C
the force between charges - Coulomb’s law

\[ F = k \frac{|q_1 q_2|}{r^2} \]

The negatively charged ball attracts the positively charged one; the positive ball moves until the elastic forces in the torsion fiber balance the electrostatic attraction.

(a) A torsion balance of the type used by Coulomb to measure the electric force

(b) Interaction of like and unlike charges
**the force between charges - Coulomb’s law**

\[ F = k \frac{|q_1 q_2|}{r^2} \]

\( k = 8.99 \times 10^9 \text{ Nm}^2/\text{C}^2 \)

(b) Interaction of like and unlike charges
Three charges are fixed in position on a line as shown.

What is the magnitude and direction of the total electrostatic force on the middle charge?
Three charges are fixed in position as shown.

What is the magnitude and direction of the total electrostatic force on the -1.0 nC charge?
The electric field

Suppose we set up the two charges as shown:

\[ -q \quad +q \]
the electric field

suppose we set up the two charges as shown

![Diagram of two charges and a third charge in between](image)

a third charge placed in between feels a force

how does it know the other charges are there?

the charges produce an ‘electric field’
the electric field

suppose we set up the two charges as shown

![Diagram showing two charges, -q and +q, and an electric field vector E.]

a third charge placed in between feels a force

how does is know the other charges are there?

the charges produce an ‘electric field’

at every point in space there is a vector $\vec{E}$

a charge $q$ placed at that position feels a force $\vec{F} = q\vec{E}$
the electric field

suppose we set up the two charges as shown

![Diagram showing two charges with an electric field](image)

the charges produce an ‘electric field’

at every point in space there is a vector $\vec{E}$

$$\vec{E} = \lim_{q \to 0} \frac{\vec{F}}{q}$$

*put a ‘test charge’ at each point, measure the force it feels and divide out its charge*
the electric field

electric field line diagram

arrows show direction of E-field, density of lines shows magnitude of E-field
the electric field

electric field line diagram

arrows show direction of E-field, density of lines shows magnitude of E-field

lines only begin and end on charges
the electric field from a point charge

\[ F = k \frac{|qQ|}{r^2} \]

\[ \vec{E} = \lim_{q \to 0} \frac{\vec{F}}{q} \]

\[ E = k \frac{|Q|}{r^2} \]

\[ k = 8.99 \times 10^9 \text{ Nm}^2/\text{C}^2 \]
superposition of electric fields

The total electric field at any point is the vector sum of the electric fields from all the point charges around it

\[ \vec{E} = \vec{E}_1 + \vec{E}_2 + \ldots \]

e.g.

\[ Q_1 = -1.0 \text{ nC} \]
\[ Q_2 = +1.0 \text{ nC} \]
superposition of electric fields

the total electric field at any point is the vector sum of the electric fields from all the point charges around it

\[ \vec{E} = \vec{E}_1 + \vec{E}_2 + \ldots \]

e.g.

\[ Q_1 = -1.0 \text{ nC} \]

\[ Q_2 = +1.0 \text{ nC} \]
superposition of electric fields

the total electric field at any point is the vector sum of the electric fields from all the point charges around it

\[ \vec{E} = \vec{E}_1 + \vec{E}_2 + \ldots \]

-\[ Q_1 = -1.0 \text{ nC} \]
-\[ Q_2 = +1.0 \text{ nC} \]
the electric field

electric field line diagram

arrows show direction of E-field, density of lines shows magnitude of E-field
the electric field

two equal positive charges
Two charges are separated by a distance of 1.40 m. The electric field produced by the two charges is found to be zero a distance of 0.40 m from the left charge along the line joining the two charges. Find $Q_2$.

\[ Q_1 = -1.0 \mu C \]
large charged parallel plates cause an almost uniform field in the gap between them
An electron escapes from the negative plate of a capacitor producing a uniform electric field of magnitude $2.00 \times 10^3$ N/C.

Starting from rest, the electron takes $2.00 \times 10^{-8}$ seconds to travel to the positive plate. How far apart are the capacitor plates?
electric field in a conductor

inside a conducting material, the electric field must be zero in an electrostatic situation

imagine it wasn’t - the electric field would cause forces on the ‘free’ charges and they’d accelerate, so the situation wouldn’t be static

the ‘free’ charges will always rapidly rearrange themselves to produce zero $E$-field inside the conductor
electric dipole in a uniform electric field

A dipole is shown - it is easy to see that the total force on the dipole is zero.
electric dipole in a uniform electric field

a dipole is shown - it is easy to see that the total force on the dipole is zero

but there is a torque on the dipole that’ll cause it to rotate

\[ \tau = 2qEd \sin \theta \]
electric dipole in a uniform electric field

but there is a torque on the dipole that’ll cause it to rotate

\[ \tau = 2qEd \sin \theta \]

two orientations feel zero torque:
an insulating material made from ‘polar’ molecules which behave like electric dipoles can thus be polarized
electric dipole in an electric field

- use induction to form a dipole
- watch how it lines up in the electric field from the vdG sphere
electric dipole in an electric field

- use induction to form a dipole
- watch how it lines up in the electric field from the vdG sphere