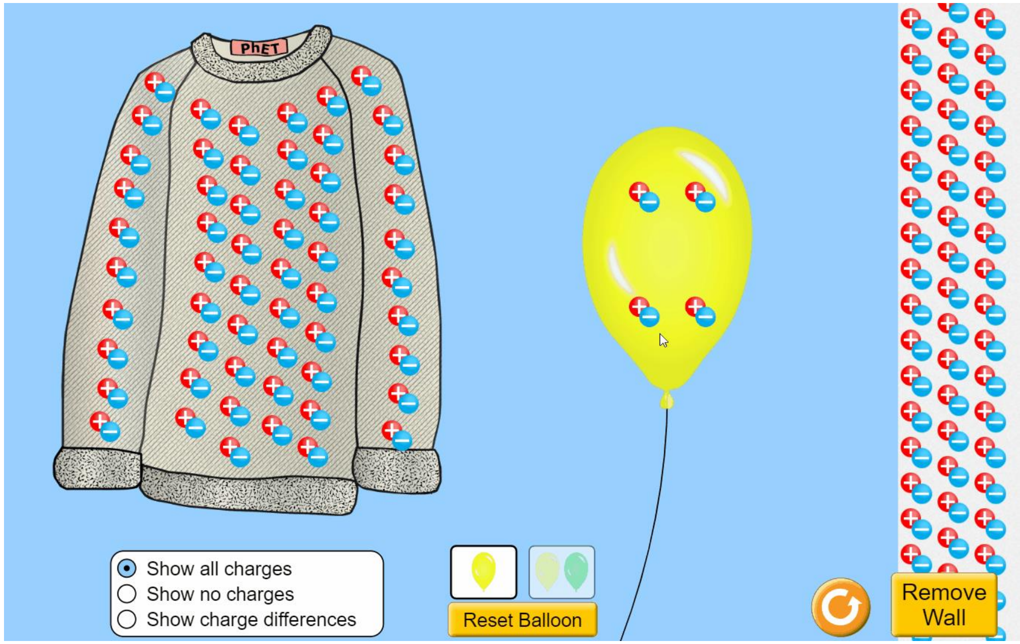
FORCE FIELDS

IB PHYSICS | COMPLETED NOTES

Static Electricity

IB PHYSICS | FORCE FIELDS

PhET Simulation



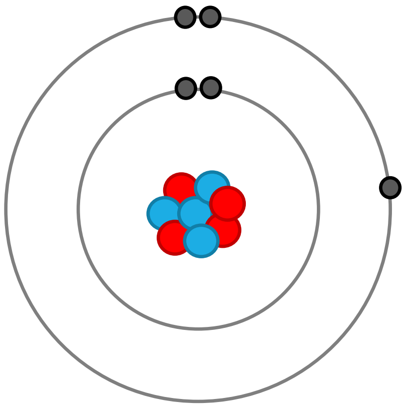
What happens when you rub the balloon on the sweater?

Electrons transfer from the sweater to the balloon

Click here for Simulation

Charge on an Atom

The protons and neutrons are buried deep in the nucleus and cannot easily be touched



electrons orbiting the nucleus are easily lost or gained

How do objects become charged?

Friction	Contact	Induction

Click here for Simulation

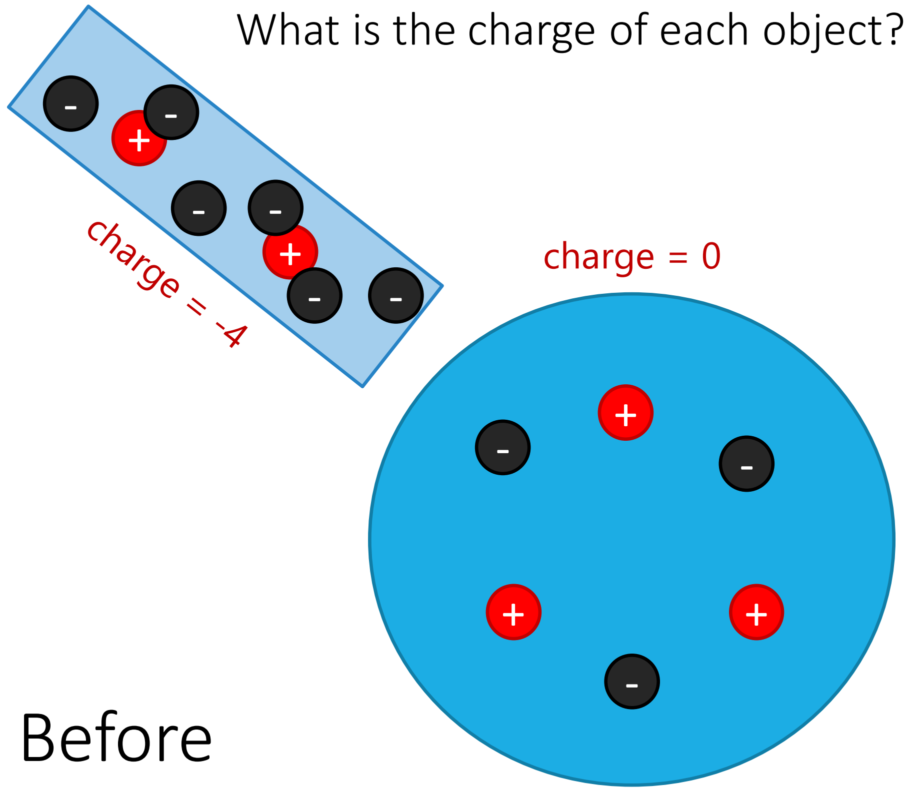
What happens when you rub John Travoltage's foot on the rug?

The foot gains electrons from rubbing on the carpet and the electrons spread out

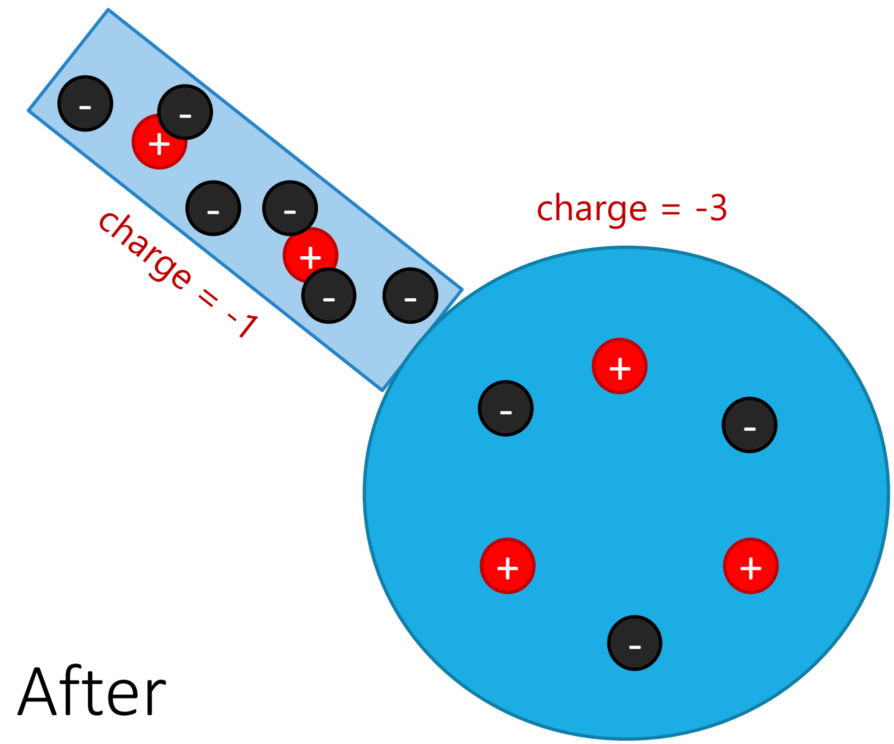
How do objects become charged?

Friction	Contact	Induction

What is the charge of each object?

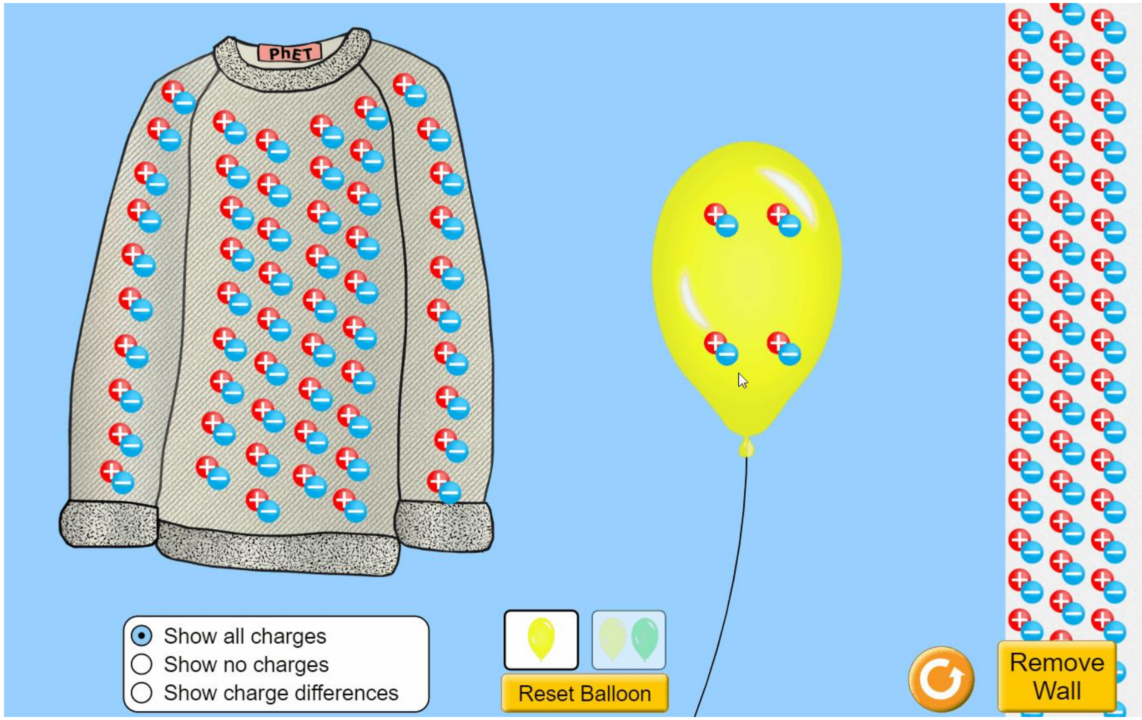


Draw in the Electrons



How do objects become charged?

Friction	Contact	Induction



What happens when you bring the balloon over to the wall?

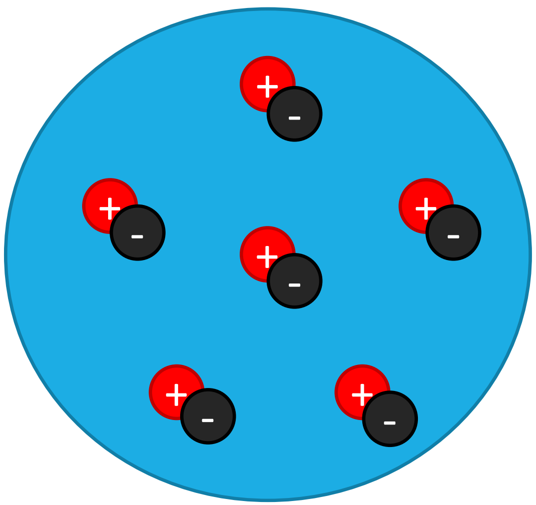
The electrons in the wall redistribute and move away from the negative source

Click here for Simulation

How do objects become charged?

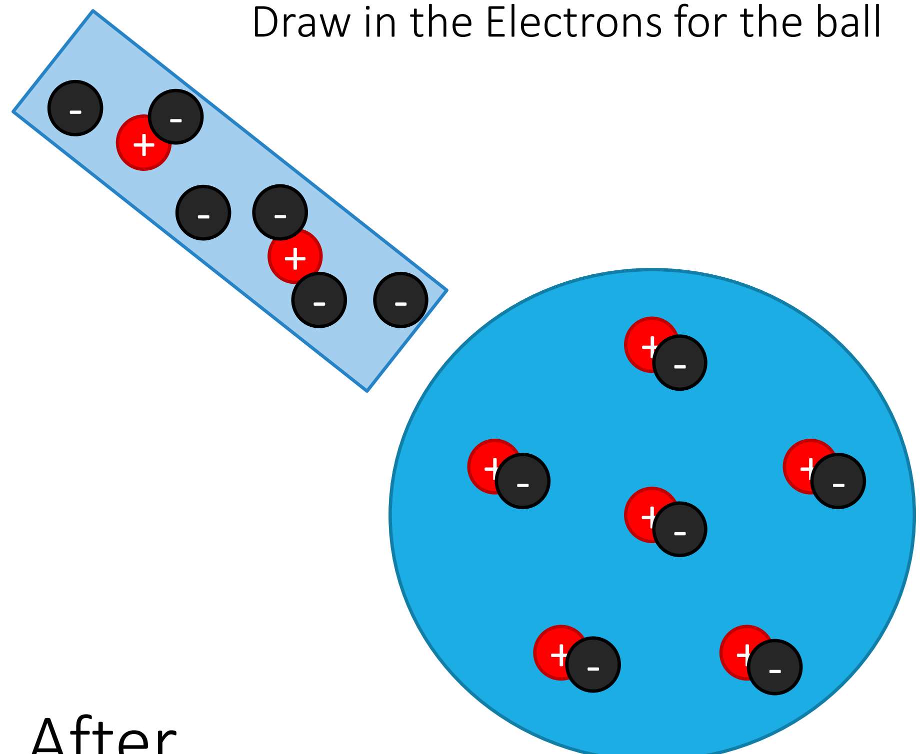
Friction	Contact	Induction

What is the charge of this object?



Before

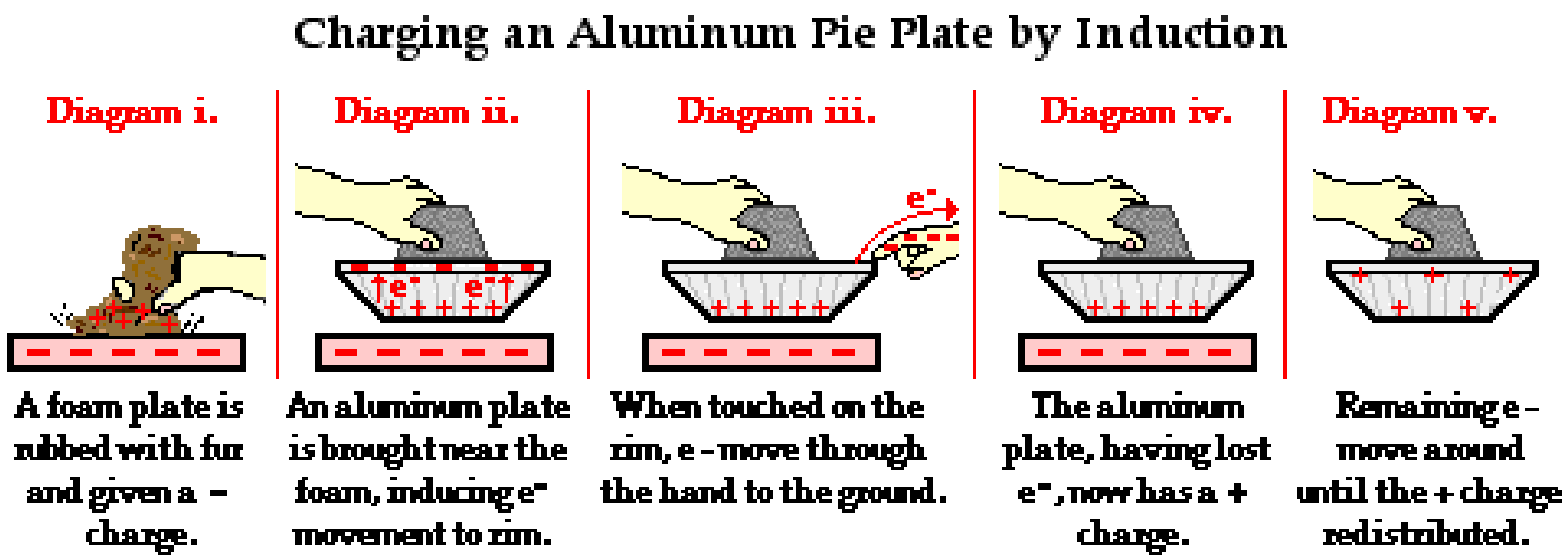
Draw in the Electrons for the ball



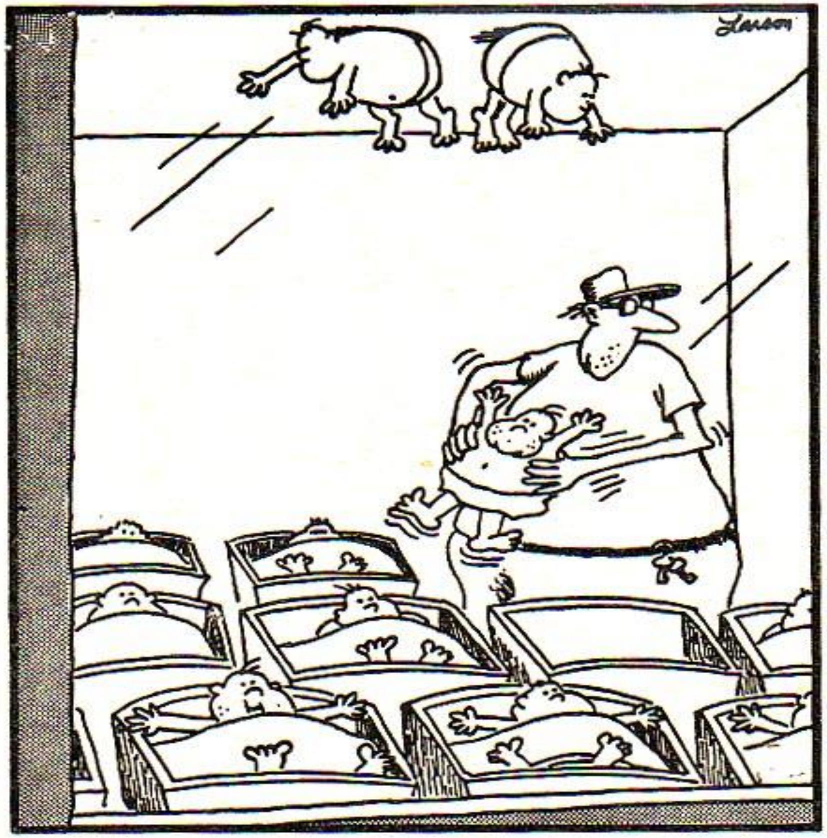
After

How do objects become charged?

Friction	Contact	Induction

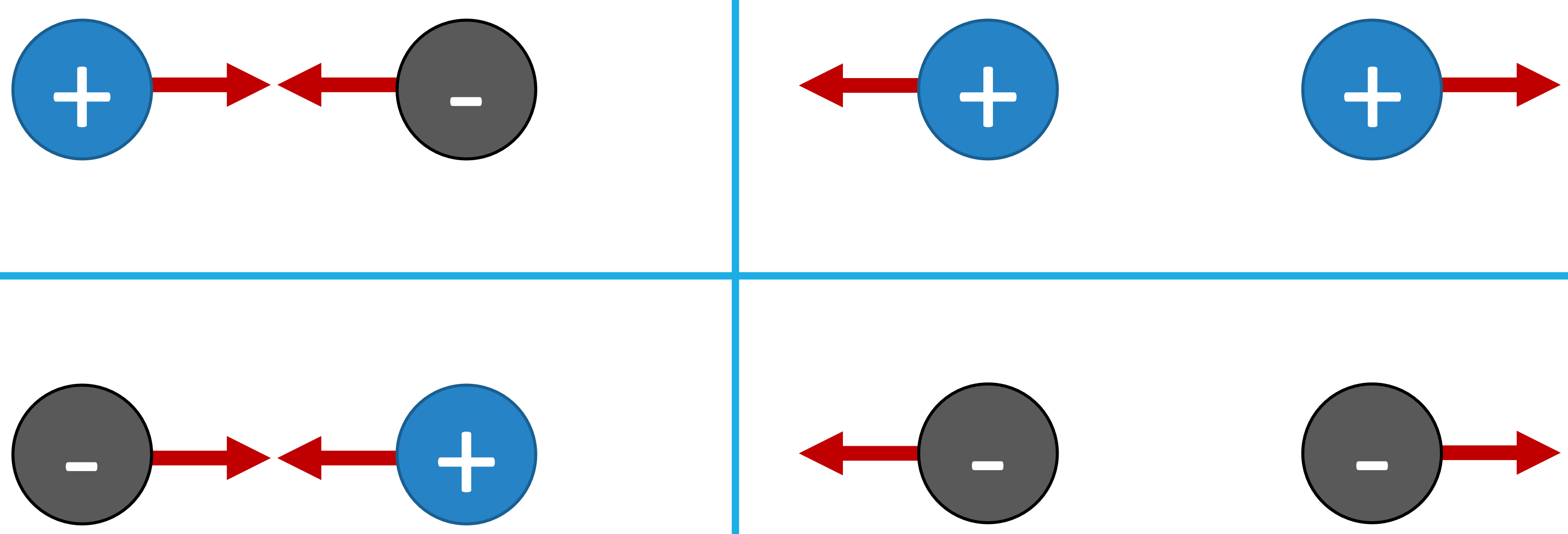


Use your knowledge responsibly



Late at night and without permission, Reuben would often enter the nursery and conduct experiments in static electricity.

Charge Interactions

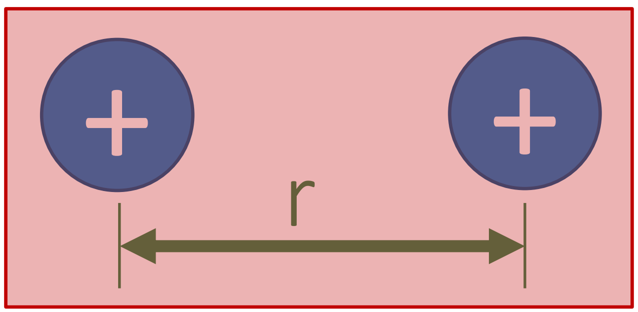


Opposite Charges
Attract

Like Charges
Repel

Which one has more force?

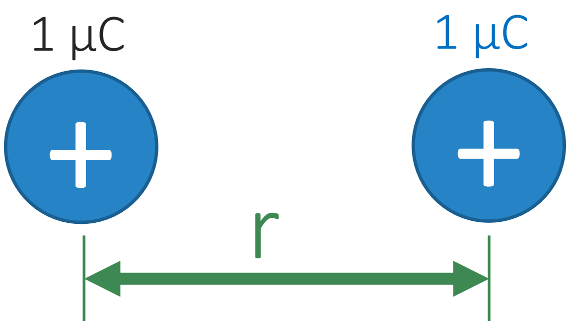
Which charged pair has larger electrostatic forces acting?

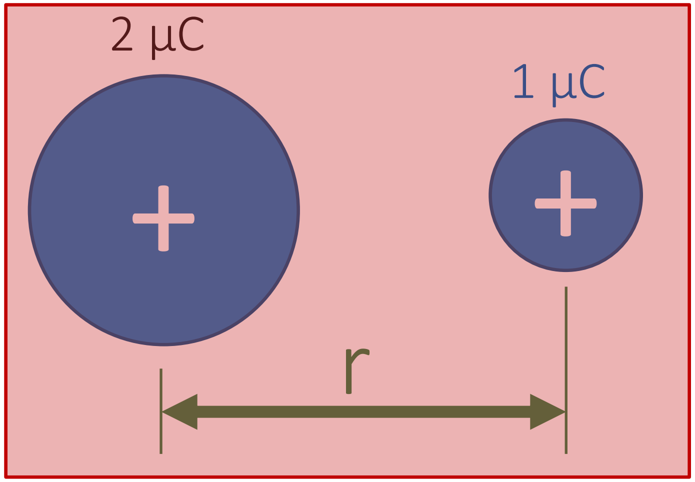


smaller distance = greater force

Which one has more force?

Which charged pair has larger electrostatic forces acting?



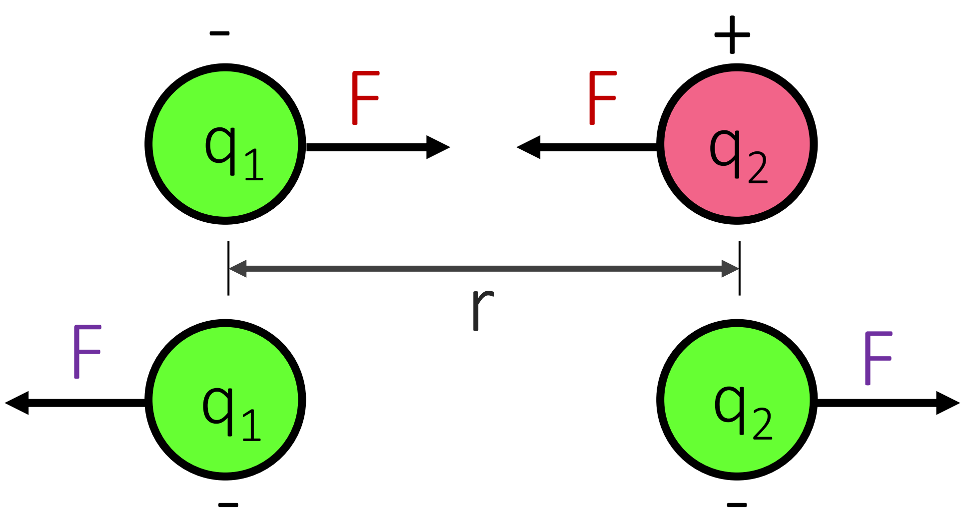


greater charge = greater force

Coulomb's Law

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

The force of attraction or repulsion between two point charges is directly proportional to the product of the two charges and inversely proportional to the square of the distance between them.



	Symbol	Unit
Electrostatic Force	F	[N]
Object 1 Charge	q_1	[C]
Object 2 Charge	q_2	[C]
Separation Distance	r	[m]

Coulomb's Constant

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

$k = 8.99 \times 10^9\ N\ m^2\ C^{-2}$

Use unit analysis to prove the units of k:

$$k = \frac{Fr^2}{q_1 q_2} = \frac{Nm^2}{CC} = Nm^2C^{-2}$$

Solve for k | Plug in units | Simplify

IB Physics Data Booklet

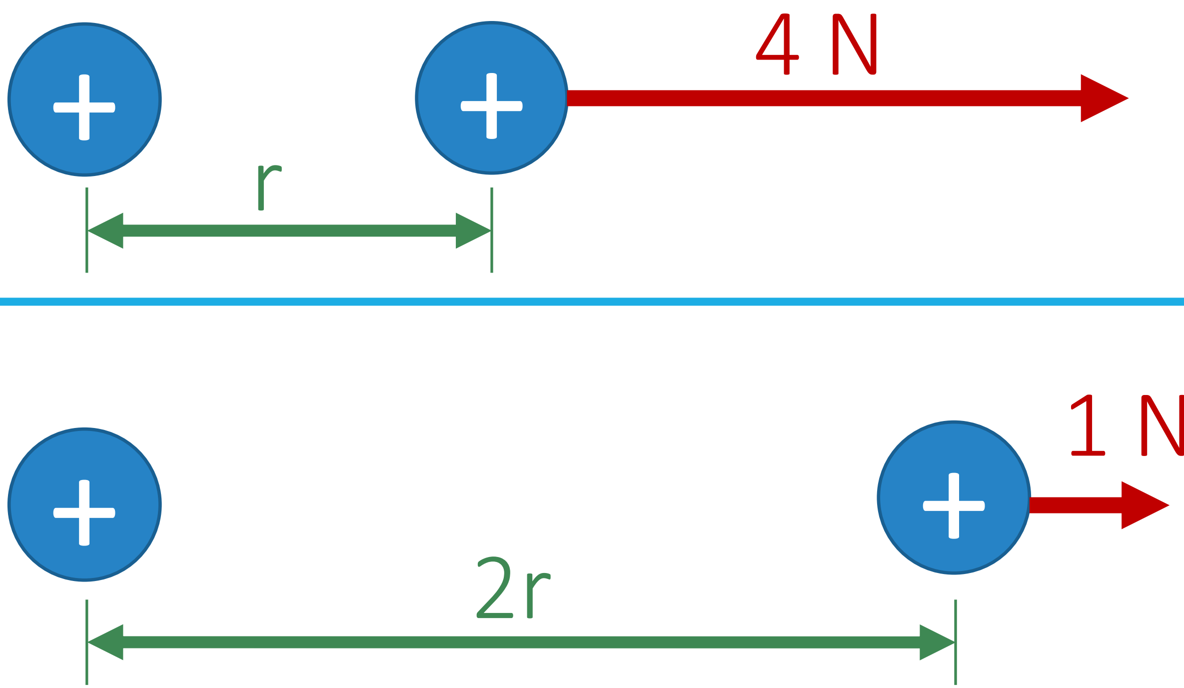
Sub-topic 5.1 – Electric fields	Sub-topic 5.2 – Heating effect of electric currents
$I = \frac{\Delta q}{\Delta t}$	Kirchhoff's circuit laws:
$F = k\frac{q_1 q_2}{r^2}$ **Coulomb's Law*	$\Sigma V = 0$ (loop)
$k = \frac{1}{4\pi\varepsilon_0}$	$\Sigma I = 0$ (junction)
$V = \frac{W}{q}$	V
$E = \frac{F}{q}$	
$I = nAvq$	

Sub-topic 5.3 – Electric cells
$\varepsilon = I(R + r)$

Quantity	Symbol	Approximate value
Acceleration of free fall (Earth's surface)	g	9.81 m s^{-2}
Gravitational constant	G	$6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$
Avogadro's constant	N_A	$6.02 \times 10^{23} \text{ mol}^{-1}$
Gas constant	R	$8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
Boltzmann's constant	k_B	$1.38 \times 10^{-23} \text{ J K}^{-1}$
Stefan–Boltzmann constant	σ	$5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$
Coulomb constant	k	$8.99 \times 10^{9} \text{ N m}^2 \text{ C}^{-2}$
Permittivity of free space	ε_0	$8.85 \times 10^{-12} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2}$
Permeability of free space	μ_0	$4\pi \times 10^{-7} \text{ T m A}^{-1}$
Speed of light in vacuum	c	$3.00 \times 10^{8} \text{ m s}^{-1}$

Conceptual Math

What is the repulsion force on the positive charge below?

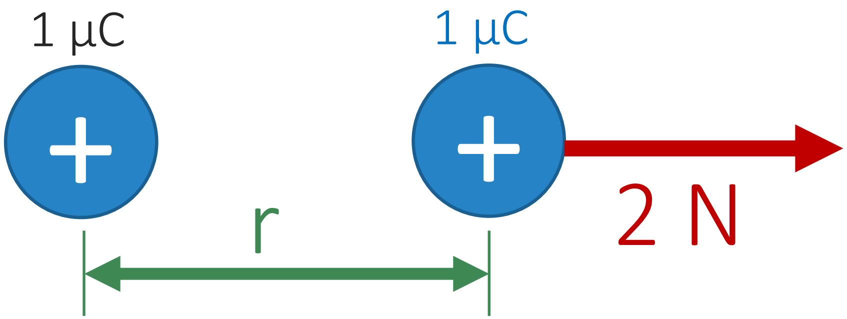


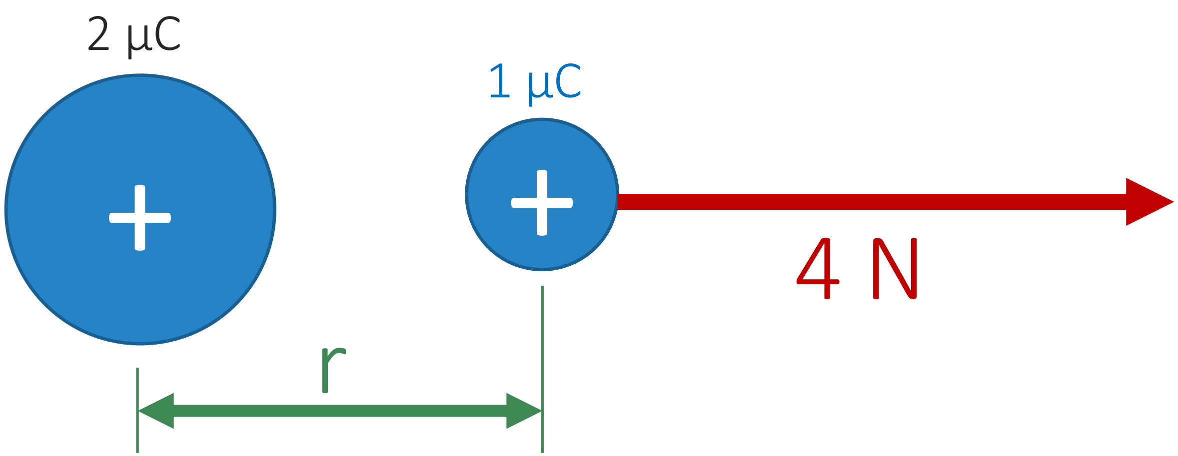
$$F = k\frac{q_1 q_2}{(2r)^2}$$

$$F = k\frac{q_1 q_2}{4r^2}$$

Conceptual Math

What is the repulsion force on the positive charge below?

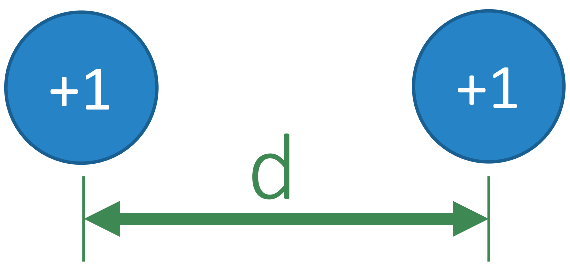




$$F = k\frac{2q_1q_2}{r^2}$$

Conceptual Math

Which pair has the greater electrostatic force? **Same!**

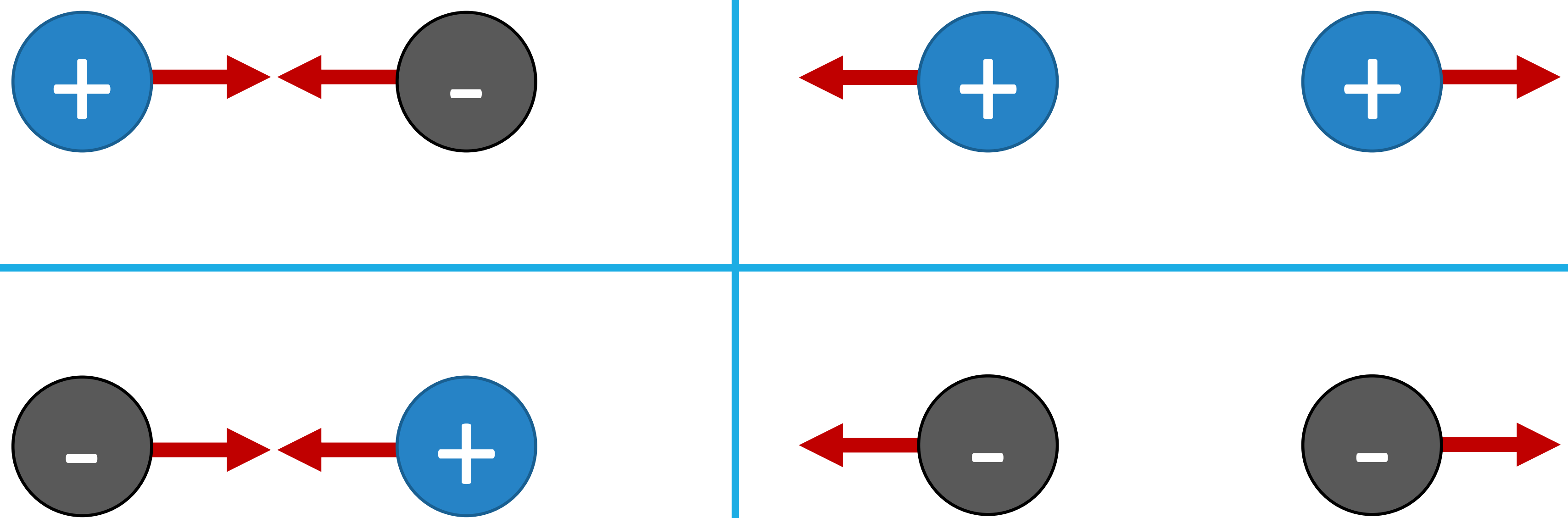


$$F = k\frac{2q_1 2q_2}{(2r)^2} = k\frac{4q_1 q_2}{4r^2} = k\frac{q_1 q_2}{r^2}$$

Electrostatic and Gravitational Force

IB PHYSICS | FORCE FIELDS

Review of Charges



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Attract

Like Charges
Repel

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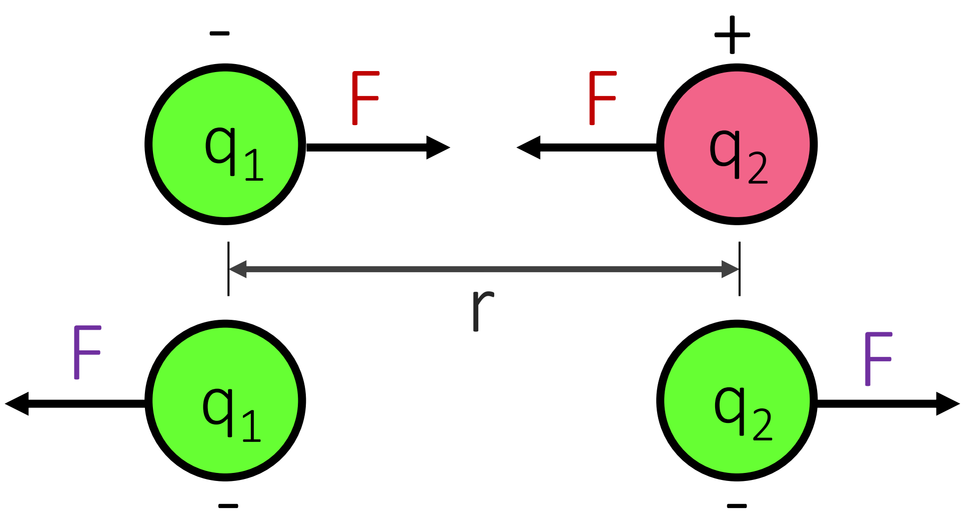

	Symbol	Unit
Electrostatic Force	F	[N]
Object 1 Charge	q_1	[C]
Object 2 Charge	q_2	[C]
Separation Distance	r	[m]

IB Physics Data Booklet

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$F = k\frac{q_1 q_2}{r^2}$ **Coulomb's Law*	$\Sigma V = 0$ (loop)
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$V = \frac{W}{q}$	V
$E = \frac{F}{q}$	
$I = nAvq$	

Sub-topic 5.3 – Electric cells

$\varepsilon = I(R + r)$

Quantity	Symbol	Approximate value
Acceleration of free fall (Earth's surface)	g	$9.81\ \text{m s}^{-2}$
Gravitational constant	G	$6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2}$
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Gas constant	R	$8.31\ \text{J K}^{-1}\ \text{mol}^{-1}$
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Permeability of free space	μ_0	$4\pi \times 10^{-7}\ \text{T m A}^{-1}$
Speed of light in vacuum	c	$3.00 \times 10^{8}\ \text{m s}^{-1}$

Sign is important!

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

$k = 8.99 \times 10^9\ N\ m^2\ C^{-2}$

+ F → Repel (+)(+) or (-)(-)

- F → Attract (+)(-) or (-)(+)

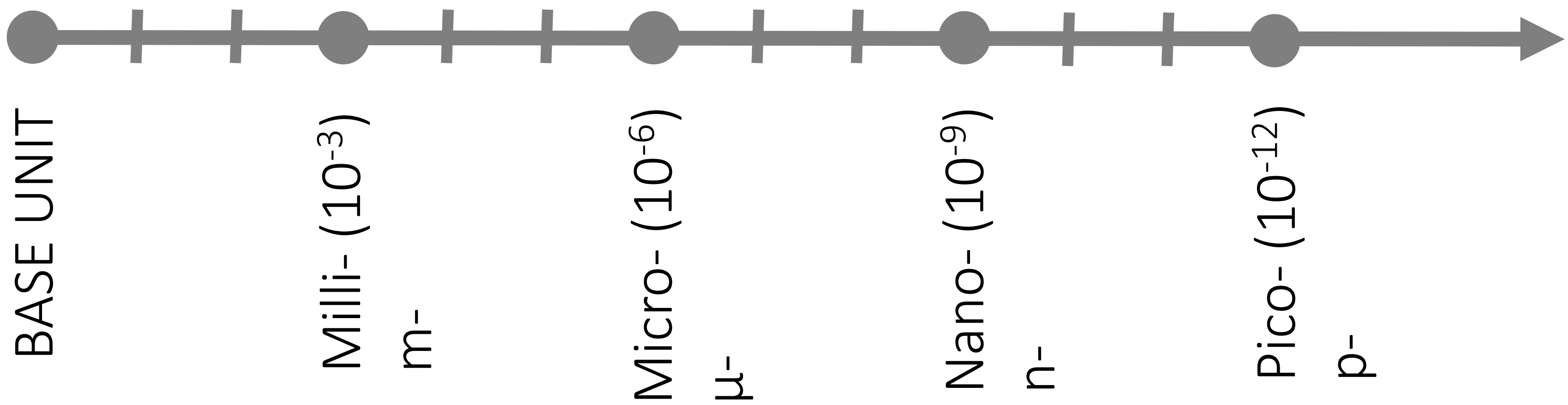
Quantifying Charge

The total charge in Coulombs can be related to the number of electrons

Speed of light in vacuum	c	$3.00 \times 10^{8}\ \mathrm{m\,s^{-1}}$
Planck's constant	h	$6.63 \times 10^{-34}\ \mathrm{J\,s}$
Elementary charge	e	$1.60 \times 10^{-19}\ \mathrm{C}$
Electron rest mass	m_{e}	$9.110 \times 10^{-31}\ \mathrm{kg} = 0.000549\ \mathrm{u} = 0.511\ \mathrm{MeV\,c^{-2}}$
Proton rest mass	m_{p}	$1.673 \times 10^{-27}\ \mathrm{kg} = 1.007276\ \mathrm{u} = 938\ \mathrm{MeV\,c^{-2}}$
Neutron rest mass	m_{n}	$1.675 \times 10^{-27}\ \mathrm{kg} = 1.008665\ \mathrm{u} = 940\ \mathrm{MeV\,c^{-2}}$
Unified atomic mass unit	u	$1.661 \times 10^{-27}\ \mathrm{kg} = 931.5\ \mathrm{MeV\,c^{-2}}$

Quantifying Charge

The coulomb was selected to use with electric currents which makes it a very large unit for static electricity. **Get your metric prefixes ready**



Conversion Check

$7\ \mu C \rightarrow C$

7×10^{-6} C

kilo	k	10^{3}
hecto	h	10^{2}
deca	da	10^{1}
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	µ	10^{-6}
nano	n	10^{-9}

Try This

A small cork with an excess charge of +7.0 μC is placed 14 cm from another cork, which carries a charge of −3.2 μC. What is the magnitude of the electric force between the corks?

$$F = k\frac{q_1 q_2}{r^2} = (8.99 \times 10^9)\frac{(7 \times 10^{-6})(-3.2 \times 10^{-6})}{(0.14)^2}$$

$$F = -10.3\ \mathrm{N}$$

attract

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

k = 8.99 × 10^9 N m^2 C^{-2} Elementary Charge = 1.60 × 10^{-19} C

How many electrons??

A small cork with an excess charge of +7.0 μC is placed 14 cm from another cork, which carries a charge of −3.2 μC. What is the magnitude of the electric force between the corks?

How many excess electrons on the second cork??

$$-3.2 \times 10^{-6}\ \mathrm{C} \times \frac{1\ electron}{-1.60 \times 10^{-19}\ \mathrm{C}} = 2 \times 10^{13} electrons$$

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

k = 8.99 × 10^9 N m^2 C^{-2} Elementary Charge = 1.60 × 10^{-19} C

Gravity

What is Gravity?

Idea #1: A downward force that stops you from flying away

Idea #2: An attraction towards larger objects

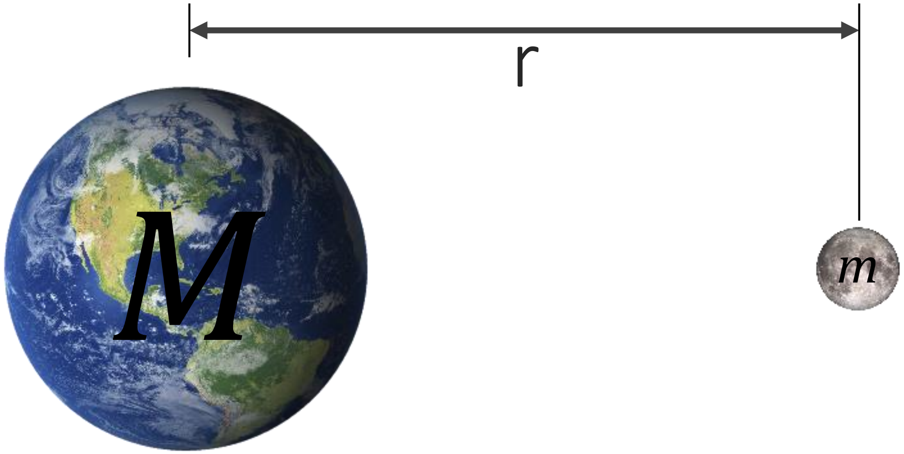
Idea #3: All mass attracts all other mass

Circle the answer that you agree with most

Universal Law of Gravitation

$$F = G\frac{Mm}{r^2}$$

The force of attraction between bodies with mass is directly proportional to the product of the two masses and inversely proportional to the square of the distance between them.



	Symbol	Unit
Gravitational Force	F	[N]
Object 1 Mass	M	[kg]
Object 2 Mass	m	[kg]
Separation Distance	r	[m]

Universal Law of Gravitation

$$F = G\frac{Mm}{r^2}$$

G → Universal Gravitational Constant

$G = 6.67 \times 10^{-11}\ N\ m^2\ kg^{-2}$

IB Physics Data Booklet

Sub-topic 6.2 – Newton's law of gravitation

$$F = G\frac{Mm}{r^2}$$

*Universal Law of Gravitation

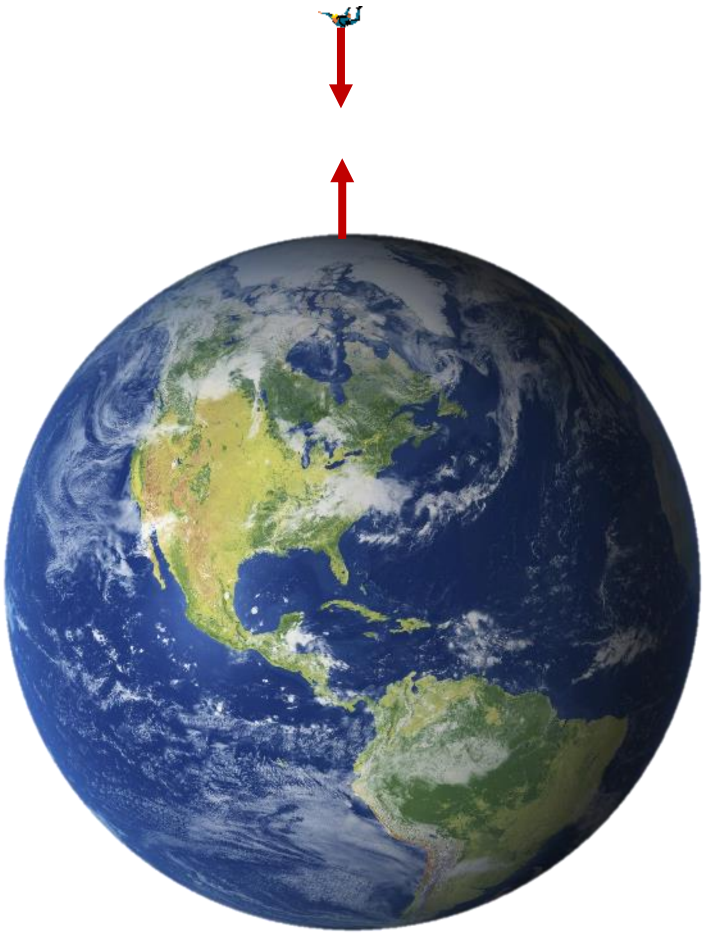
$$g = \frac{F}{m}$$

$$g = G\frac{M}{r^2}$$

Fundamental constants

Quantity	Symbol	Approximate value
Acceleration of free fall (Earth's surface)	g	$9.81\ \text{m s}^{-2}$
Gravitational constant	G	$6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2}$

Gravity – Equal and Opposite

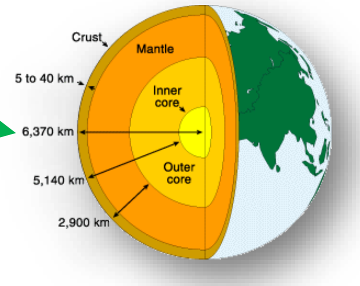


The force on the skydiver is the same as the force on the earth but the earth's huge mass means that there is hardly any acceleration

Measuring the proper distance

Technically Newton's Law of Gravitation defines how to calculate the gravitational force between two **point masses**

(Not a point mass)



Fortunately, Newton's shell theorem states that:

"A spherically symmetric shell of mass M acts as if all of its mass is located at its center."

Try This

Determine the force of gravitational attraction between the earth (m = 5.98 x 10^{24} kg) and a 70-kg physics student if the student is in an airplane at 40000 feet above earth's surface. This would place the student a distance of 6.39 x 10^6 m from earth's center.

$$F = G\frac{Mm}{r^2} = (6.67 \times 10^{-11})\frac{(5.98 \times 10^{24})(70)}{(6.39 \times 10^6)^2}$$

$$\boxed{F = 684\ \mathrm{N}}$$

Comparison

Electrostatic Force

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

$k \rightarrow Coulomb\ Constant$

$q_1, q_2 \rightarrow$ Charges [C]

Gravitational Force

$$F = G\frac{Mm}{r^2}$$

$G \rightarrow Gravitational\ Constant$

$M, m \rightarrow$ Masses [kg]

Permittivity

Coulomb's Constant is sometimes expanded to this form:

$$k = \frac{1}{4\pi\varepsilon_0}$$

ε_0 → Permittivity of Free Space (vacuum)

$\varepsilon_0 = 8.85 \times 10^{-12}\ C^2\ N^{-1}\ m^{-2}$

**Solving for k will get Coulomb's Constant for a vacuum*

IB Physics Data Booklet

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$k = \frac{1}{4\pi\varepsilon_0}$	$\Sigma I = 0$ (junction)
$V = \frac{W}{q}$	$R = \frac{V}{I}$
$E = \frac{F}{q}$	$P = VI = I^2R = \frac{V^2}{}$
$I = nAvq$	

*Solving for k

Sub-topic 5.3 – Electric cells
$\varepsilon = I(R + r)$

Quantity	Symbol	Approximate value
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Permeability of free space	μ_0	$4\pi \times 10^{-7}\ \mathrm{T\,m\,A^{-1}}$
Speed of light in vacuum	c	$3.00 \times 10^{8}\ \mathrm{m\,s^{-1}}$

Permittivity

Permittivity changes relative to the substance

Relative Permittivity

$$\varepsilon_r = \frac{\varepsilon}{\varepsilon_0}$$

IB might ask you about this: the higher the relative permittivity, the harder it is for electrostatic forces to travel over a distance…

Relative Permittivities

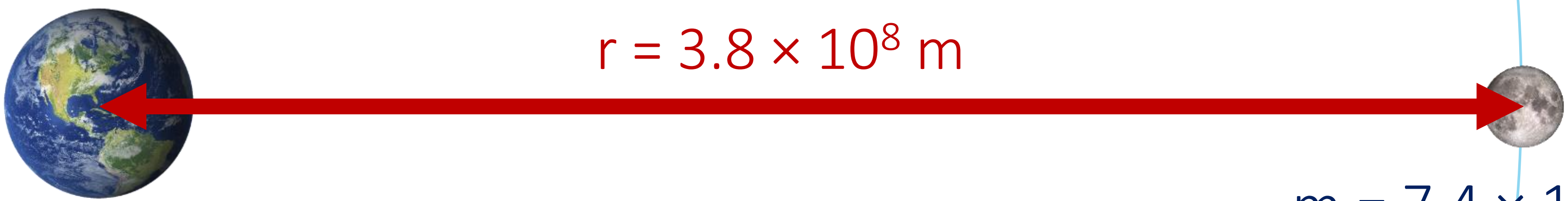
Free Space (a vacuum)	1
Dry Air	1.0005
Paper	4
Concrete	4
Rubber	6

Force Fields

IB PHYSICS | FORCE FIELDS

Warm Up

What is the force of gravity between the earth and the moon?



m = 6×10^{24} kg

m = 7.4×10^{22} kg

$$F = (6.67 \times 10^{-11}) \frac{(6 \times 10^{24})(7.4 \times 10^{22})}{(3.8 \times 10^{8})^2}$$

$$F = 2.05 \times 10^{20}\ \text{N}$$

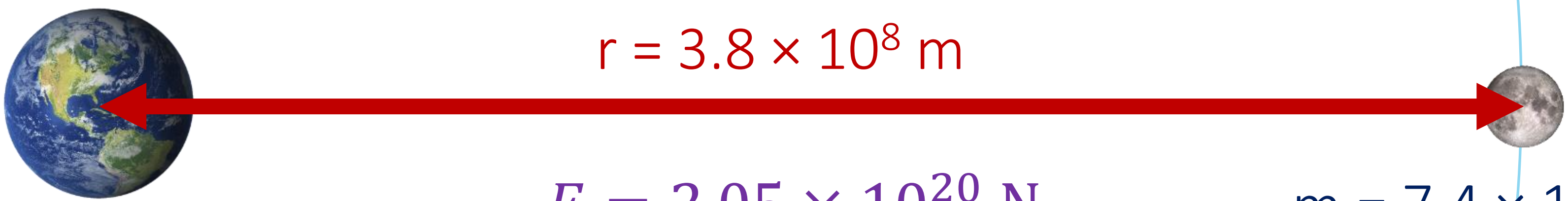
$$F = G\frac{Mm}{r^2}$$

G = 6.67×10^{-11} N m^2 kg^{-2}

Review of Circular Motion

How fast (in m/s) is the moon moving?

r = 3.8×10^8 m



$F = 2.05 \times 10^{20}$ N

m = 6×10^{24} kg

m = 7.4×10^{22} kg

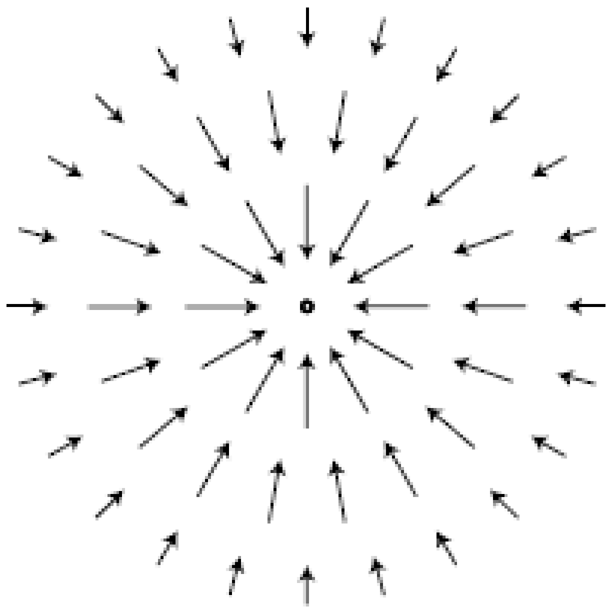
$$2.05 \times 10^{20} = \frac{(7.4 \times 10^{22})v^2}{(3.8 \times 10^8)}$$

$$v = 1026\ \mathrm{m\,s^{-1}}$$

$$F = \frac{mv^2}{r} = m\omega^2 r$$

Force Fields

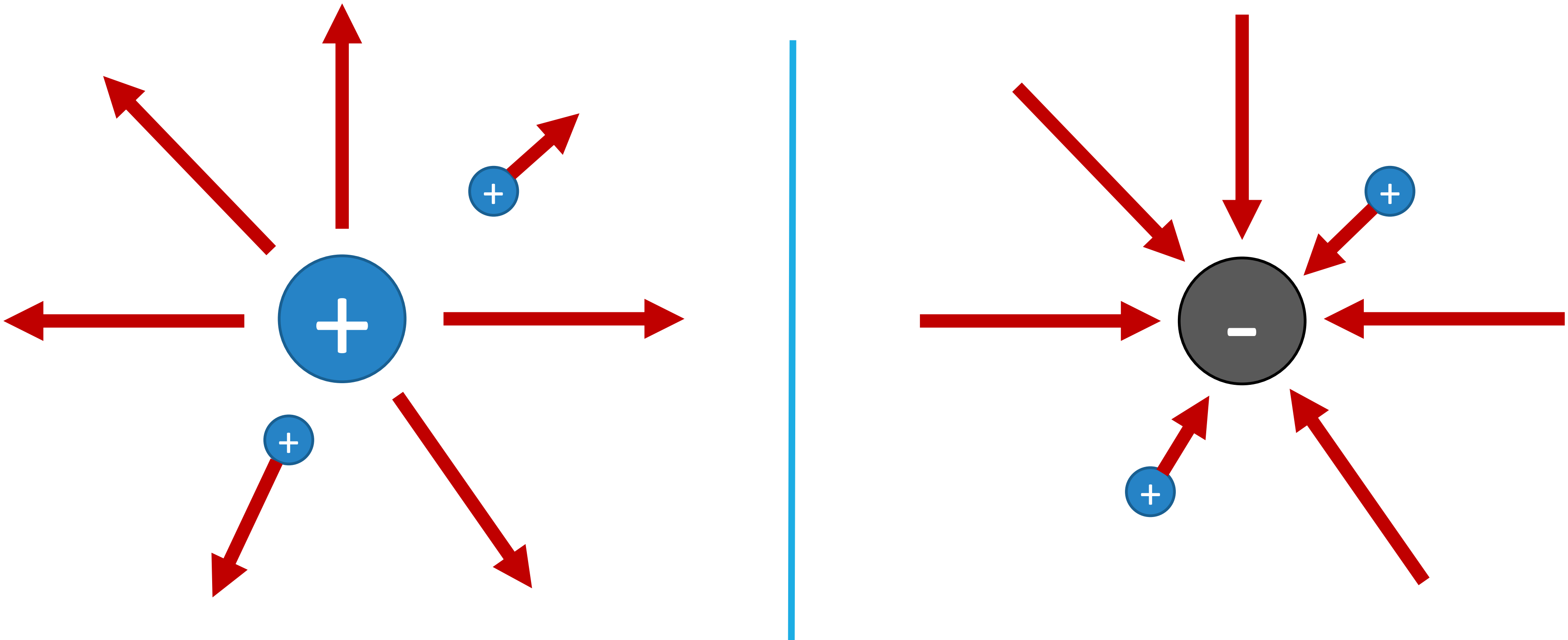
Vector field that describes the force that would act on a particle at various positions



	Electric Field	Gravitational Field
Symbol	$\boldsymbol{E}$	$\boldsymbol{g}$
Unit	$\frac{\mathrm{N}}{\mathrm{C}} = \mathrm{N\ C^{-1}}$	$\frac{\mathrm{N}}{\mathrm{kg}} = \mathrm{N\ kg^{-1}}$

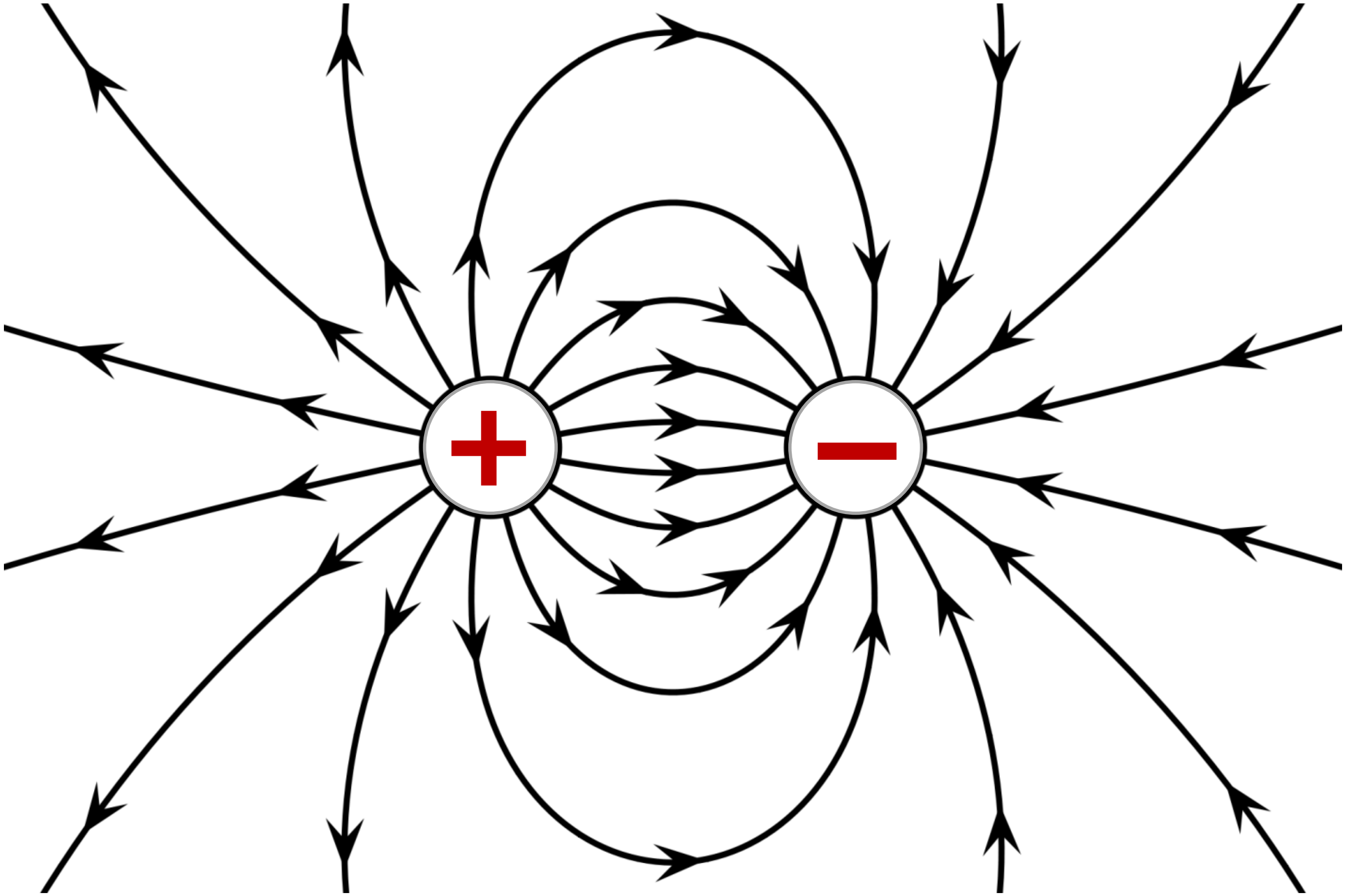
Electric Fields

Electric Fields point in the direction that a ___positive___ charge would travel



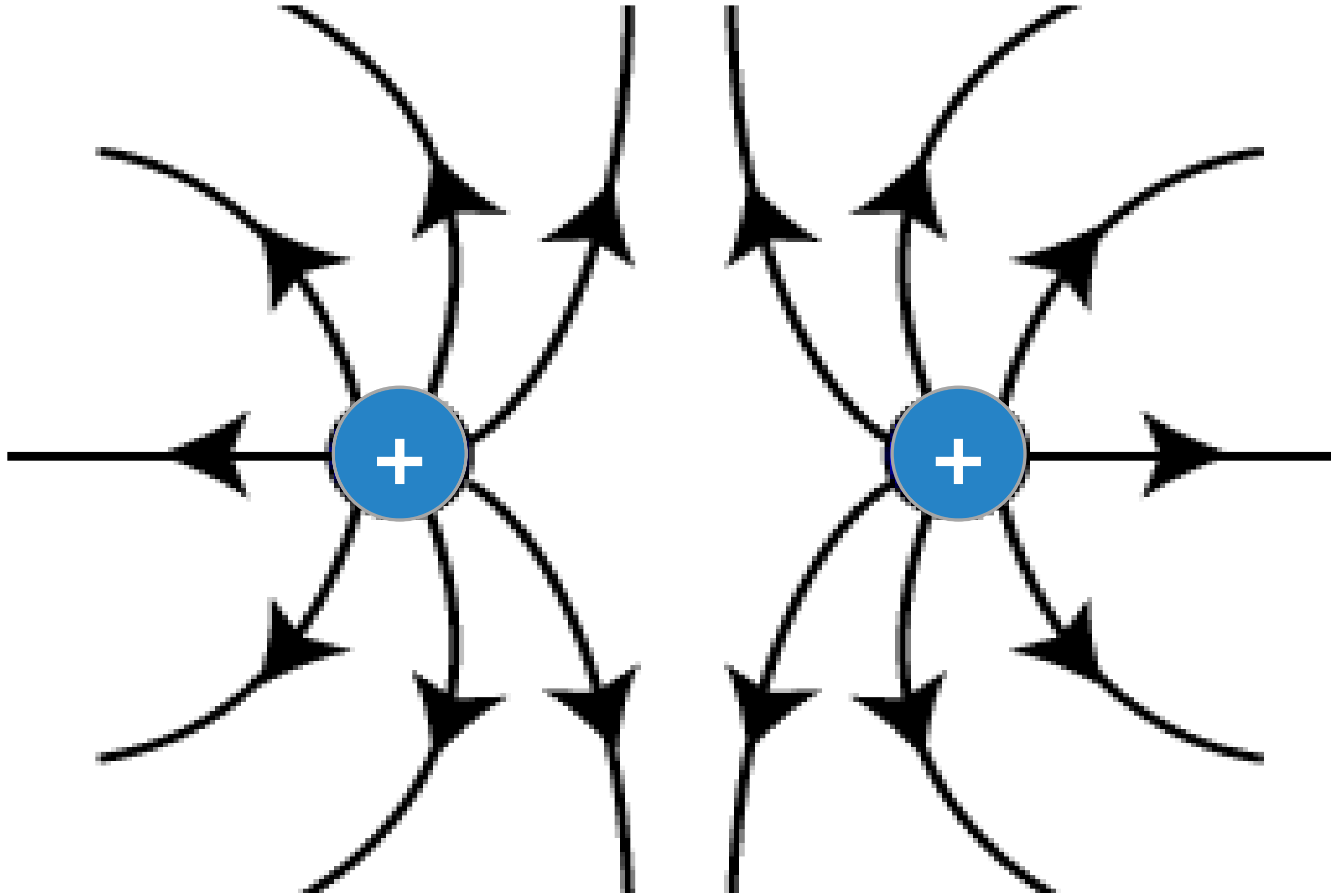
Try This

Label these charges as positive (+) or negative (-)

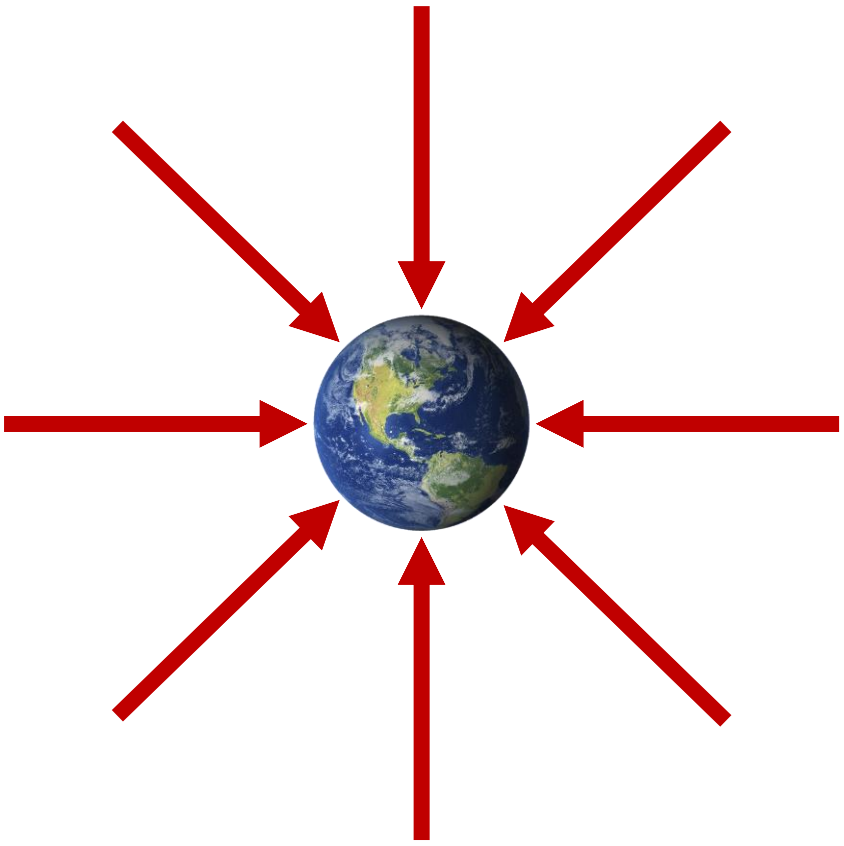


Try This

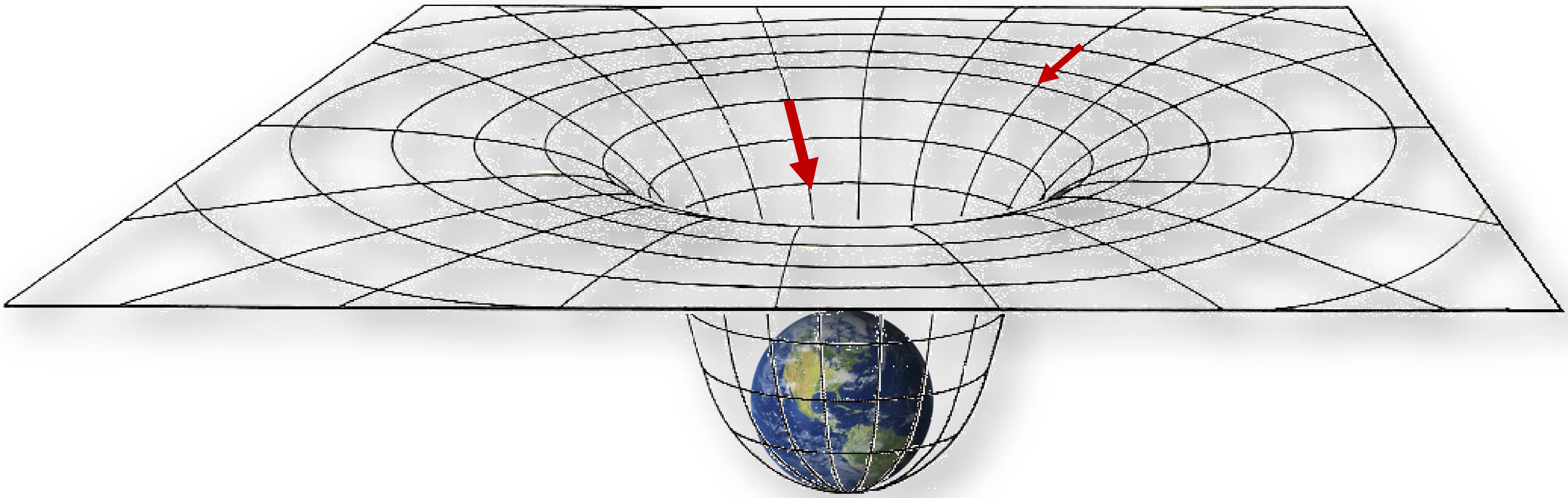
Predict what the field lines will look like:



Gravity as a field



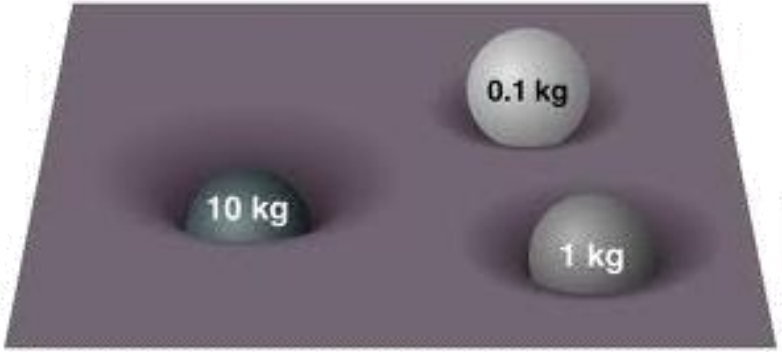
Gravity as a field



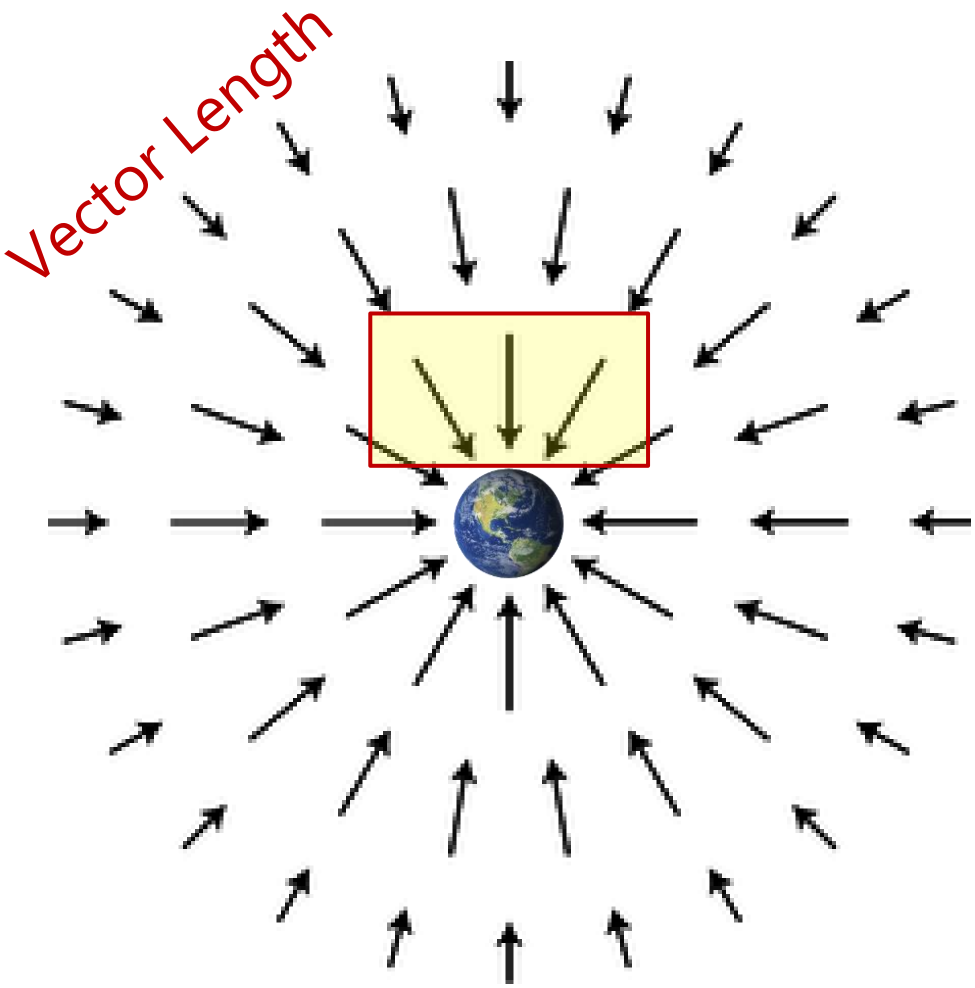
Gravity as a field

- The gravitational field distorts the space around the mass that is causing it so that any other mass placed at any position in the field will “know” how to respond immediately.

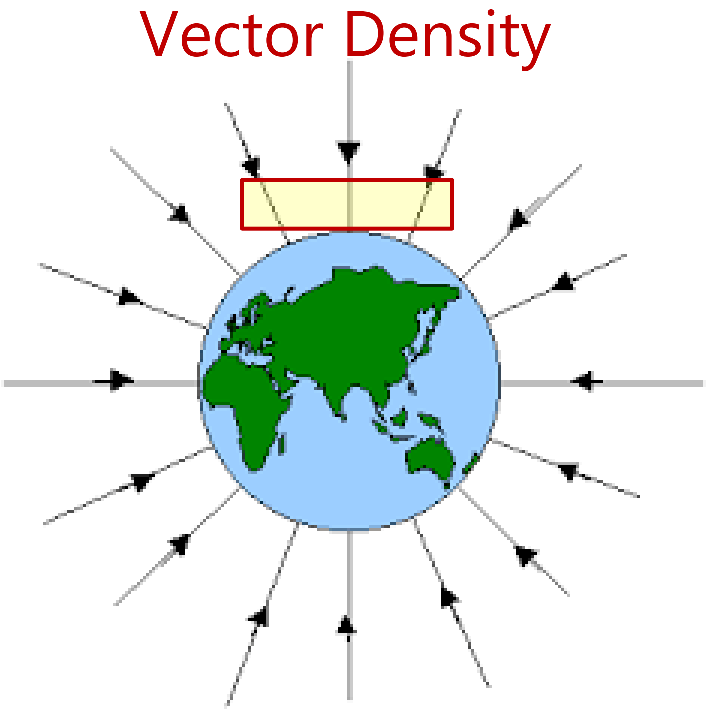
- Bigger masses “curve” the rubber sheet more than smaller masses.



Gravity as a field



How do we visually represent the strength of the field?



IB Physics Data Booklet

Sub-topic 5.1 – Electric fields
$I = \frac{\Delta q}{\Delta t}$
$F = k\frac{q_1 q_2}{r^2}$
$k = \frac{1}{4\pi\varepsilon_0}$
$V = \frac{W}{q}$
$E = \frac{F}{q}$
$I = nAvq$

Sub-topic 5.3 – Electric cells
$\varepsilon = I(R + r)$

Sub-topic 6.2 – Newton's law of gravitation
$F = G\frac{Mm}{r^2}$
$g = \frac{F}{m}$
$g = G\frac{M}{r^2}$

Remember g?

$$g = 9.81 \text{ m s}^{-2}$$

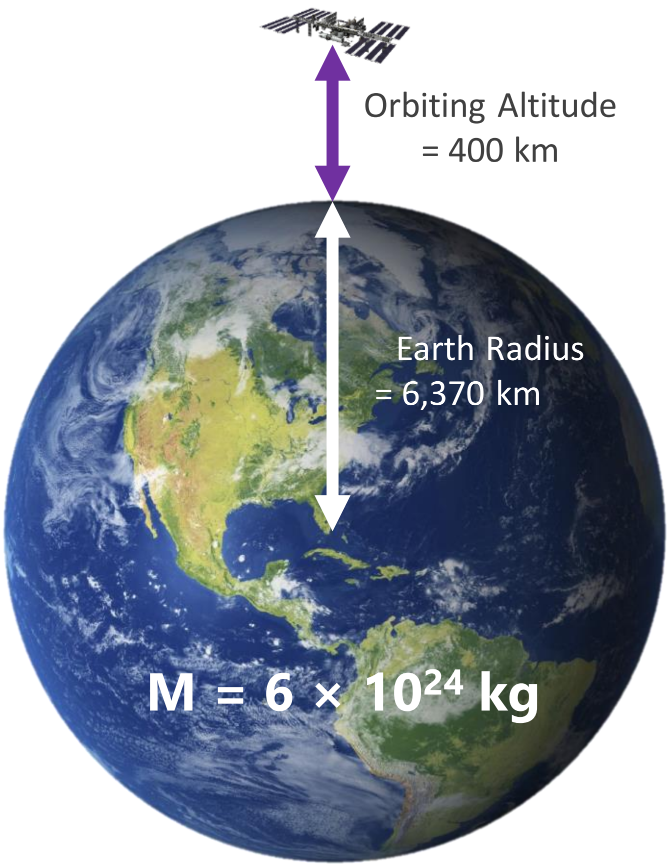
g representing acceleration is not the whole story…

g → Gravitational Field Strength

$$g = \frac{\text{N}}{\text{kg}} = \frac{\cancel{\text{kg}} \times \text{m s}^{-2}}{\cancel{\text{kg}}} = \text{m s}^{-2}$$

Wait, does that mean g changes?

$400\ km + 6370\ km = 6770\ km$



$$g = G\frac{M}{r^2}$$

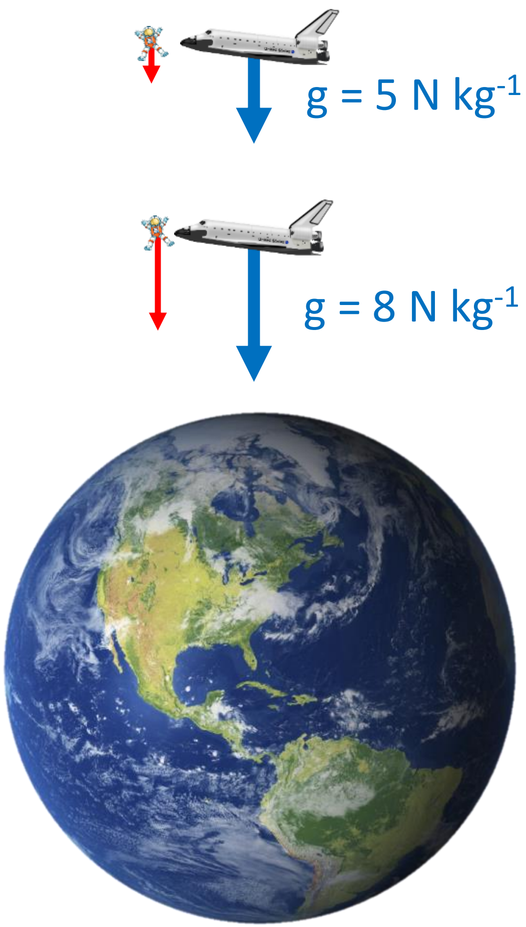
$$g = G\frac{M}{r^2} = (6.67 \times 10^{-11})\frac{(6 \times 10^{24})}{(6{,}770{,}000)^2}$$

$$g = 8.73\ \mathrm{N\ kg^{-1}}$$

Using g

= 2,000,000 kg

= 75 kg



What is the force of gravity for each position?

$F = (75\ kg)(5\ N\ kg^{-1})$

$F = \mathbf{375\ N}$

$F = (2{,}000{,}000\ kg)(5\ N\ kg^{-1})$

$F = \mathbf{10{,}000{,}000\ N}$

$F = (75\ kg)(8\ N\ kg^{-1})$

$F = \mathbf{600\ N}$

$F = (2{,}000{,}000\ kg)(8\ N\ kg^{-1})$

$F = \mathbf{16{,}000{,}000\ N}$

Try This

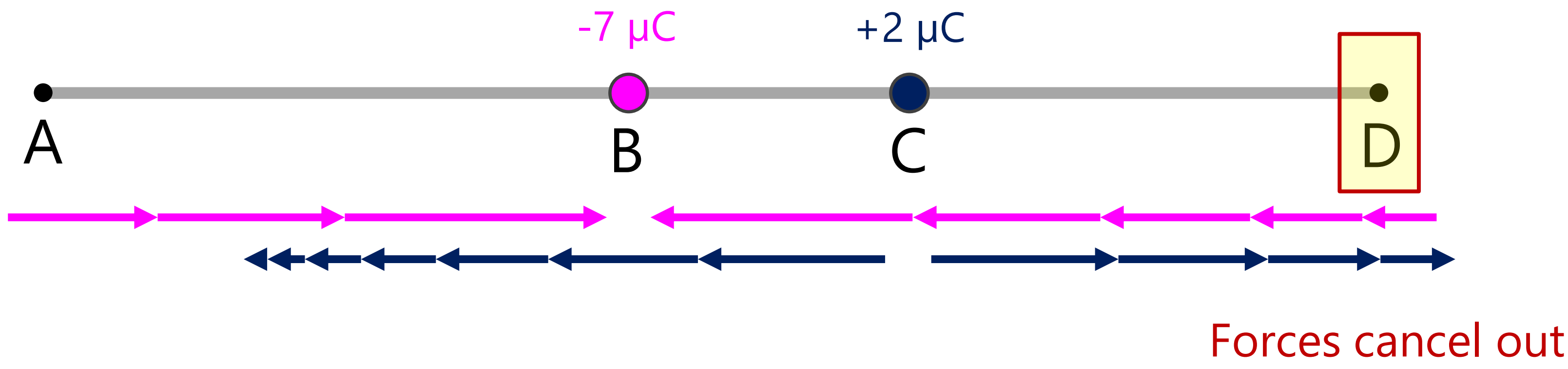
What is the electric field strength if a particle with a charge of +6.3 μC experiences a force of 0.0025 N?

$$E = \frac{F}{q} = \frac{0.0025\ \mathrm{N}}{6.3 \times 10^{-6}\ \mathrm{C}}$$

$$E = 397\ \mathrm{N\ C^{-1}}$$

Think about this...

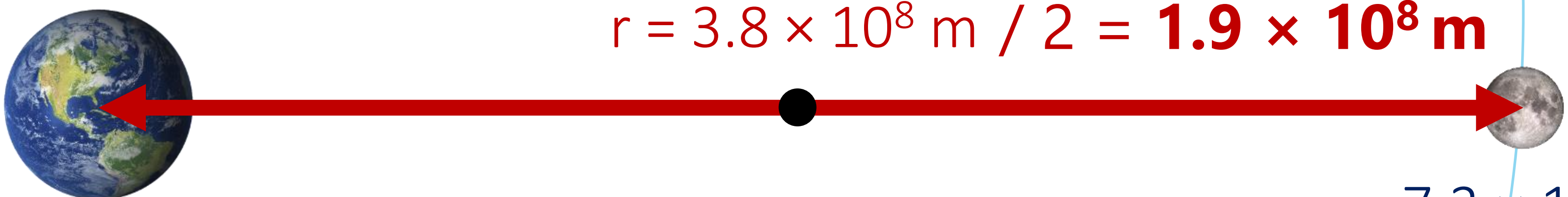
Two isolated point charges, –7 μC and +2 μC, are at a fixed distance apart. At which point is it possible for the electric field strength to be zero?



Try this

What is the gravitational field strength halfway between the centers of the earth and the moon?

r = 3.8 × 10^{8} m / 2 = **1.9 × 10^{8} m**



m = 6 × 10^{24} kg

m = 7.3 × 10^{22} kg

$$g = (6.67 \times 10^{-11})\frac{(6 \times 10^{24})}{(1.9 \times 10^{8})^2} = \mathbf{0.011\ N\ kg^{-1}}$$

$$g = (6.67 \times 10^{-11})\frac{(7.3 \times 10^{22})}{(1.9 \times 10^{8})^2} = \mathbf{0.00013\ N\ kg^{-1}}$$

$$g = 0.011 - 0.00013 =$$

$$g = 0.0109\ \mathrm{N\ kg^{-1}}$$

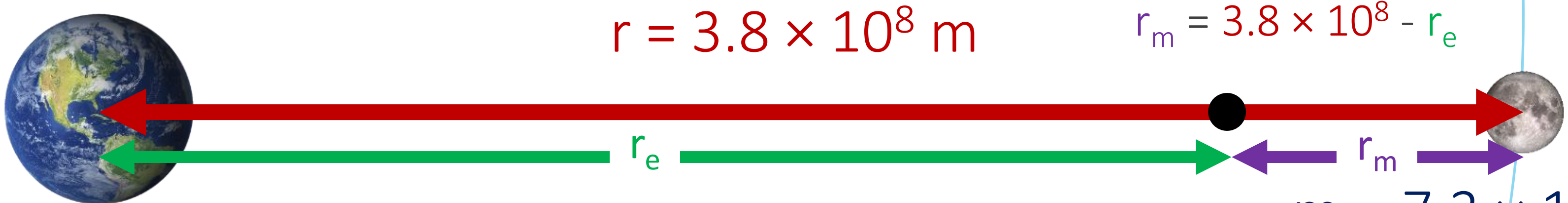
$$g = G\frac{M}{r^2}$$

G = 6.67 × 10^{-11} $\frac{N \times m^2}{kg^2}$

Try this

Where would an object experience a gravitational field of 0 N kg^{-1}

$$G\frac{M_e}{{r_e}^2} = G\frac{M_m}{{r_m}^2}$$



$r = 3.8 \times 10^8$ m

$r_m = 3.8 \times 10^8 - r_e$

m = 6×10^{24} kg

m = 7.3×10^{22} kg

cancel out G
and
square root everything

$$\sqrt{G\frac{M_e}{{r_e}^2}} = \sqrt{G\frac{M_m}{{r_m}^2}}$$

$$\frac{\sqrt{M_e}}{r_e} = \frac{\sqrt{M_m}}{r_m}$$

$$\frac{\sqrt{6 \times 10^{24}}}{r_e} = \frac{\sqrt{7.3 \times 10^{22}}}{(3.8 \times 10^8 - r_e)}$$

$$(9.31 \times 10^{20}) - (2.45 \times 10^{12})r_e = (2.70 \times 10^{11})r_e$$

$$(9.31 \times 10^{20}) = (2.72 \times 10^{12})r_e$$

$$r_e = 3.42 \times 10^8 \text{ m}$$

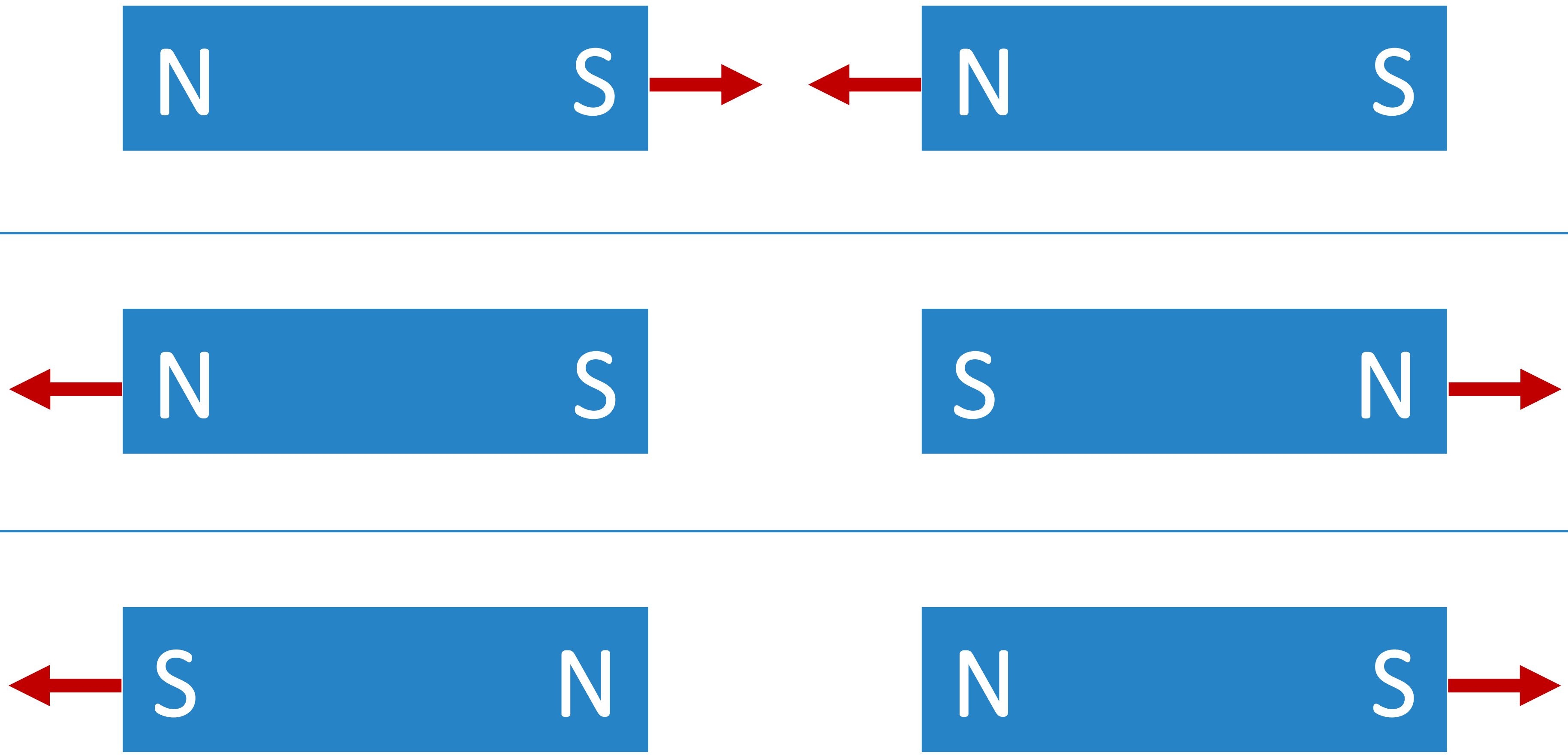
$$g = G\frac{M}{r^2}$$

G = 6.67×10^{-11} $\frac{N \times m^2}{kg^2}$

Magnetism & Right Hand Rule

IB PHYSICS | FORCE FIELDS

Rules of Interaction



Cutting Magnets in Half

Poles cannot be isolated – a magnet cannot be broken to get a separate north and south pole. Instead, it creates two magnets, each with a north and south pole

Magnetic Domains

Domains Before Magnetization

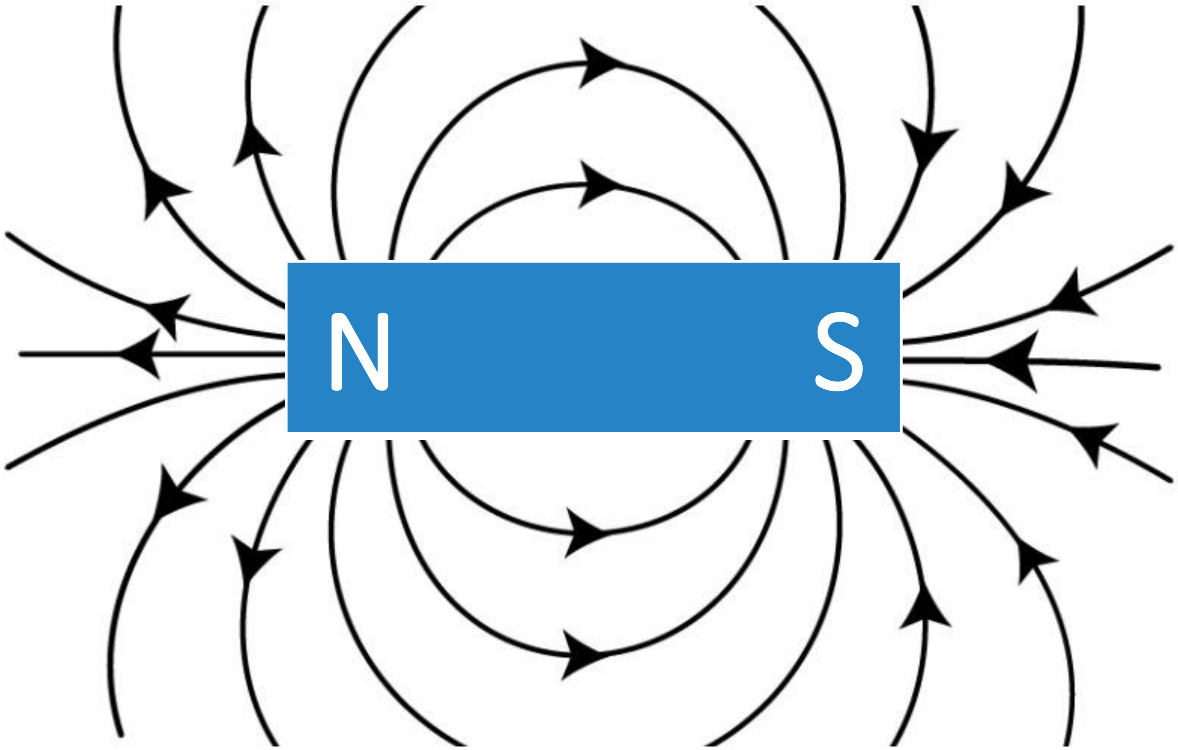
Domains After Magnetization

In order for a material with domains to become magnetic, the domains have to be aligned by an external magnetic field.

If enough of a materials domains become aligned, the material forms a magnetic dipole and becomes a permanent magnet

Magnetic Fields

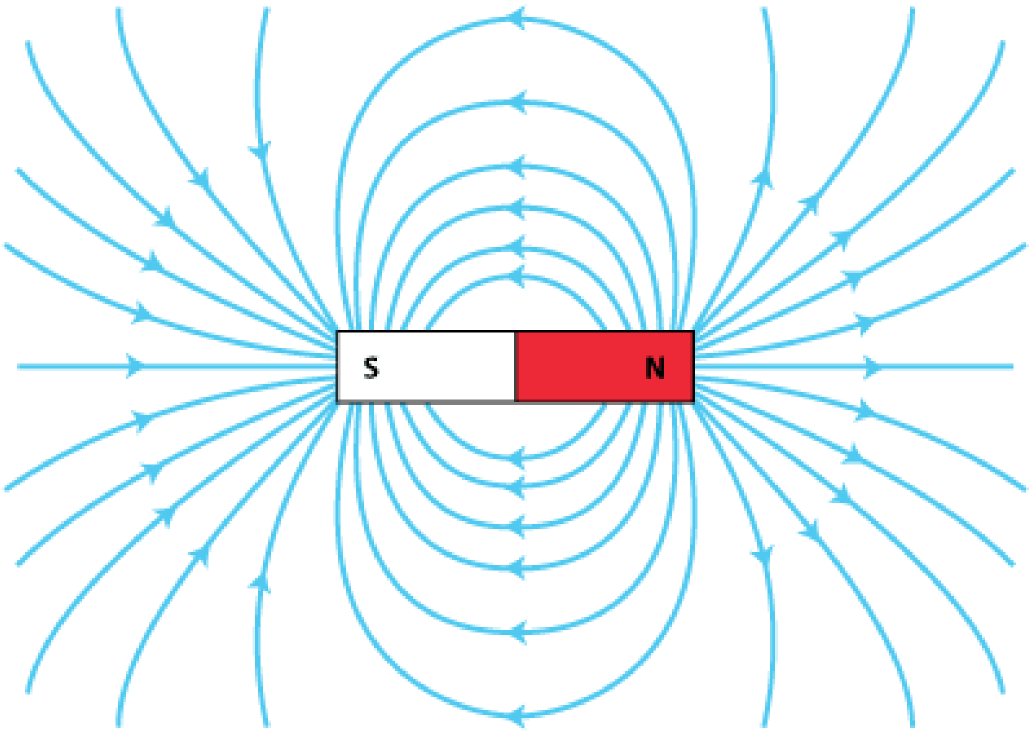
Magnetic field lines point from __North__ to __South__



A compass would align with these field lines

B-Field

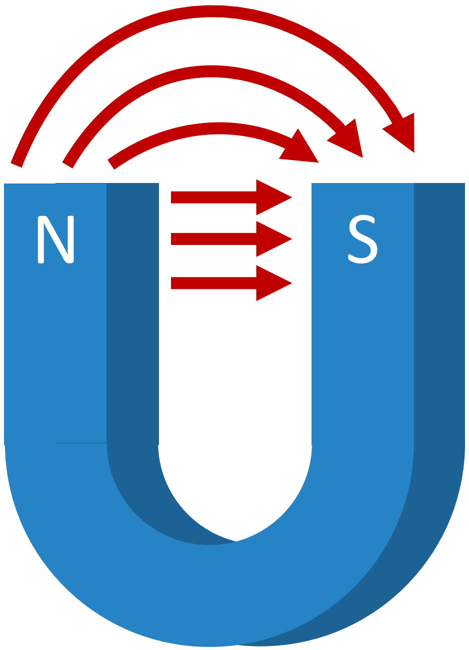
B → Magnetic Field Strength



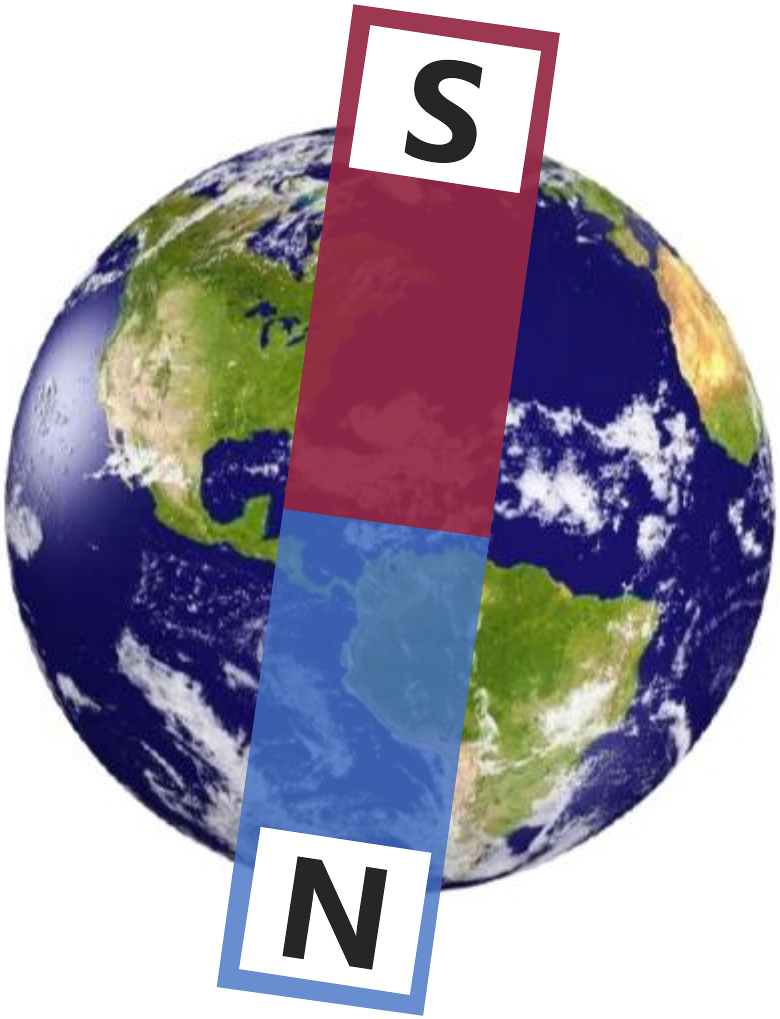
Units
Tesla [T]

Magnetic Fields

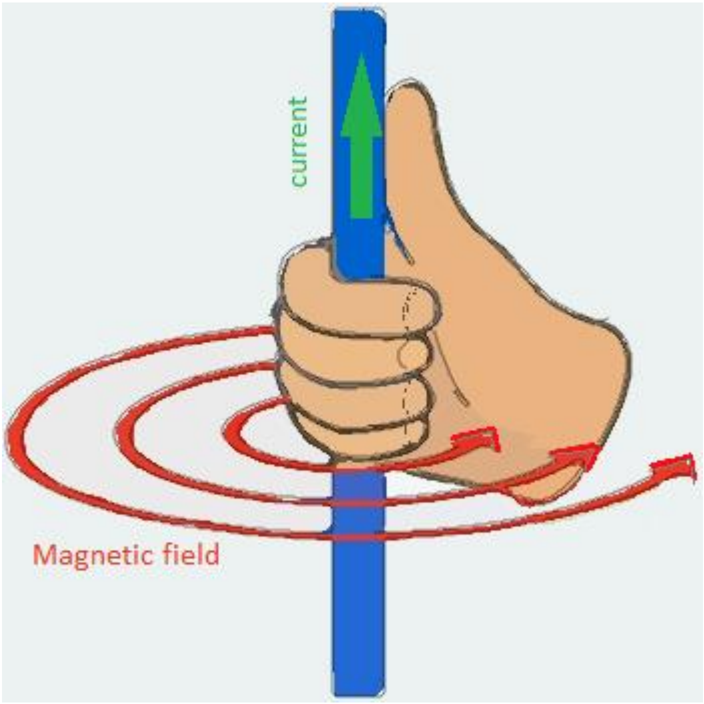
A horseshoe magnet is just a bent bar magnet. The rules for magnetic fields still apply.



The Earth is a Magnet



Right Hand Rule #1

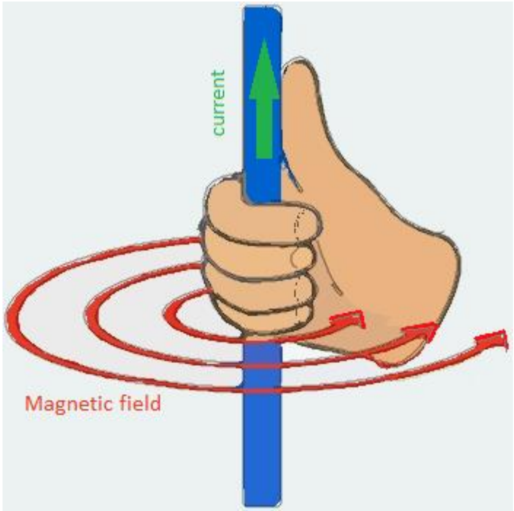


If you make a "thumbs up" sign and point your thumb down a wire in the direction of the current, your other four fingers will point in the direction of the magnetic field.

Thumb points in direction of the current

Fingers point in direction of the field lines

Drawing in 3D



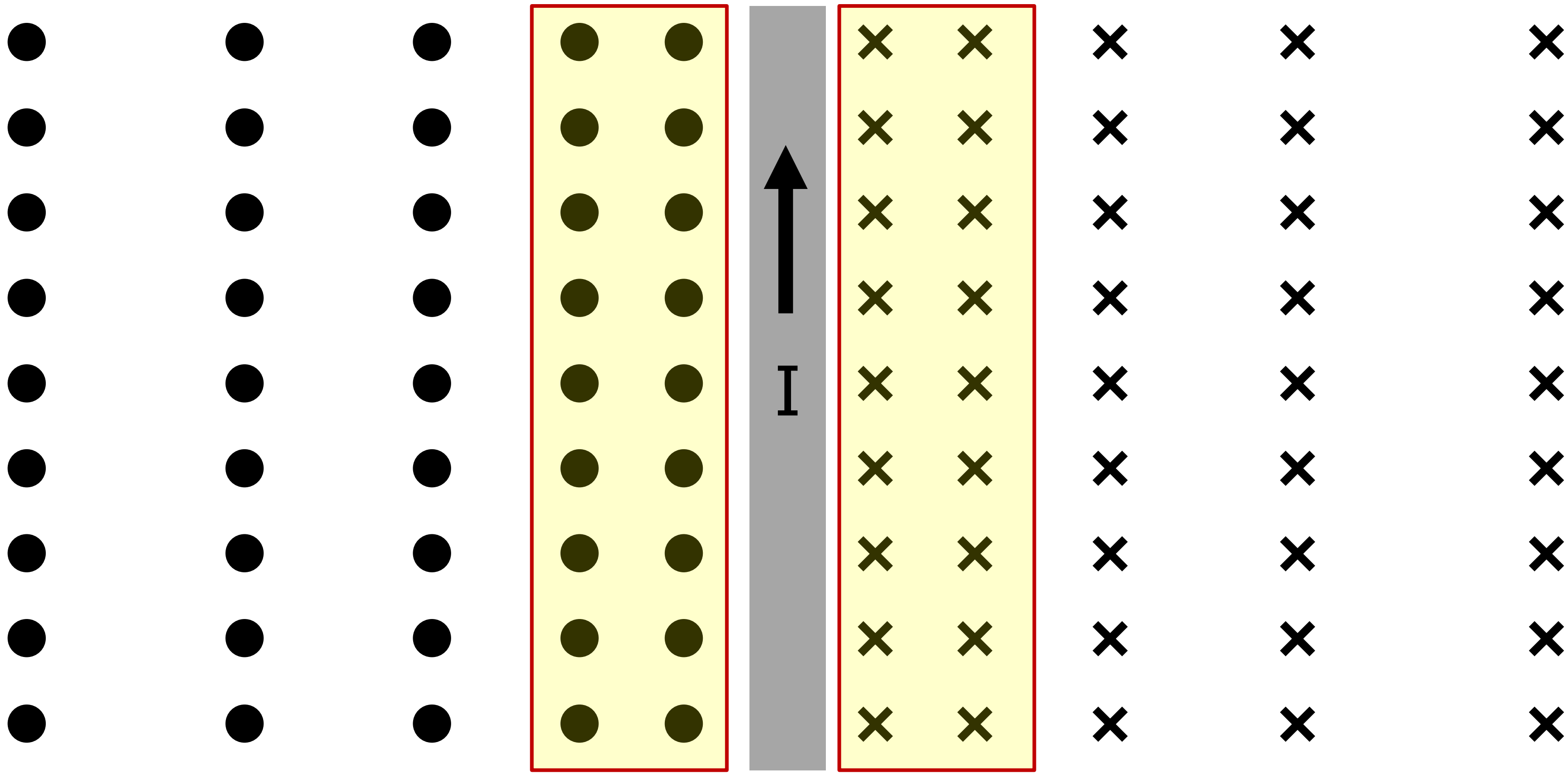
It can be hard to translate a 3rd dimension into a 2-dimensional diagram so there some conventions to help us out

How do you represent a direction that's perpendicular to the paper?

Into the paper	✖
Out of the paper	●

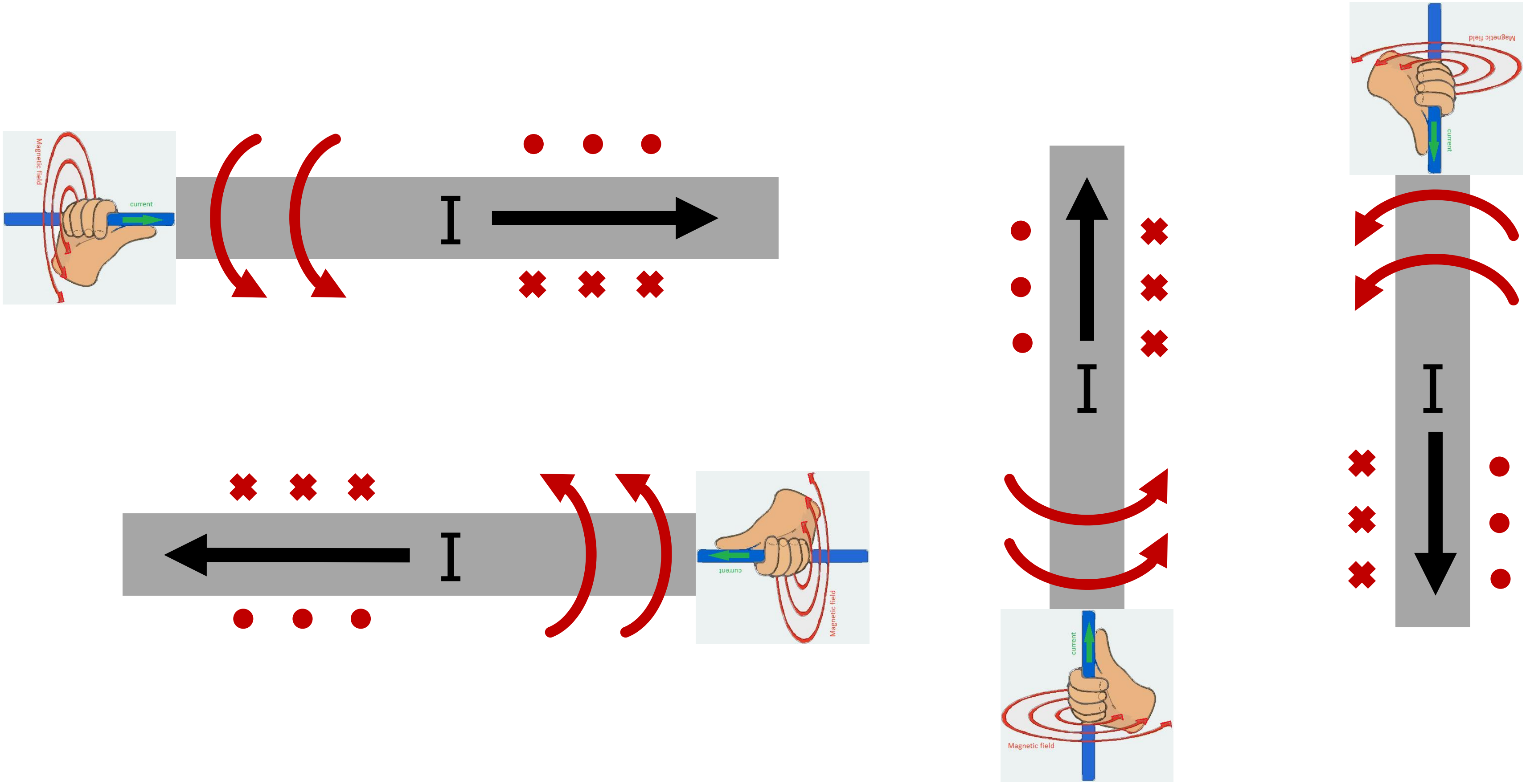
Drawing in 3D

Where is Magnetic Flux Density the highest?



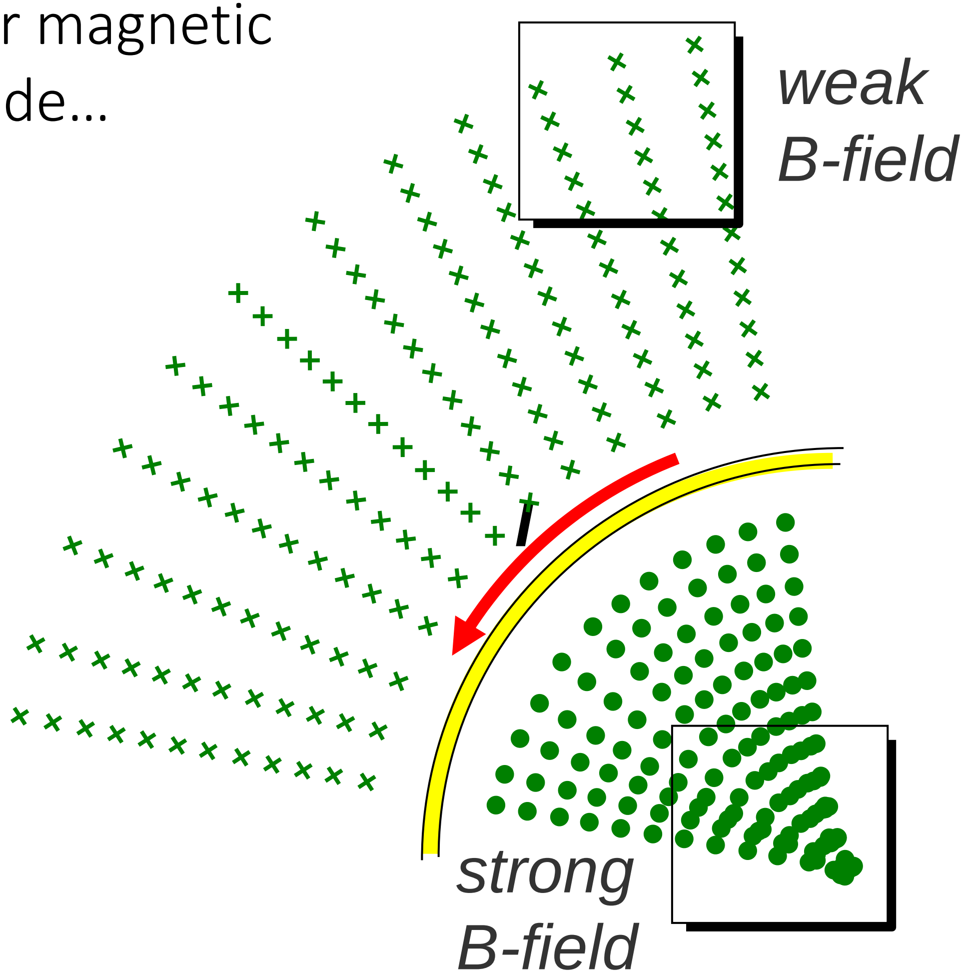
Right Hand Rule #1

Draw in the magnetic field lines around these current carrying wires

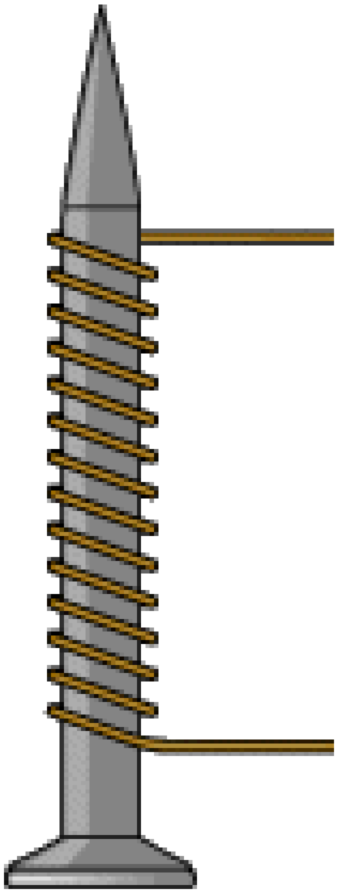


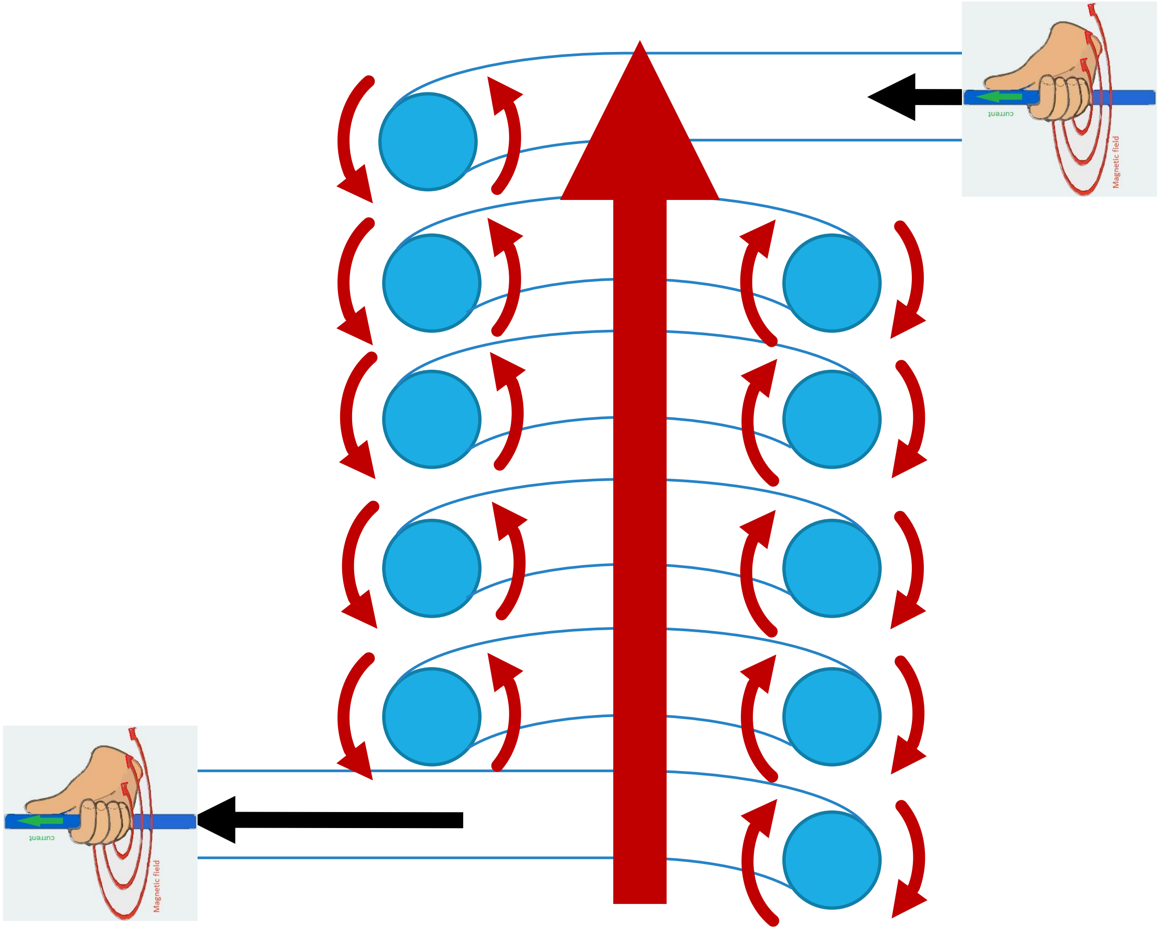
Looped Wire

A wire in a loop has as stronger magnetic field inside the loop than outside…

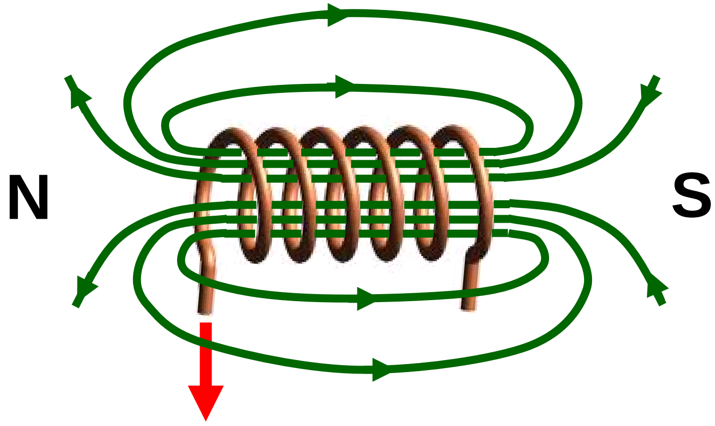


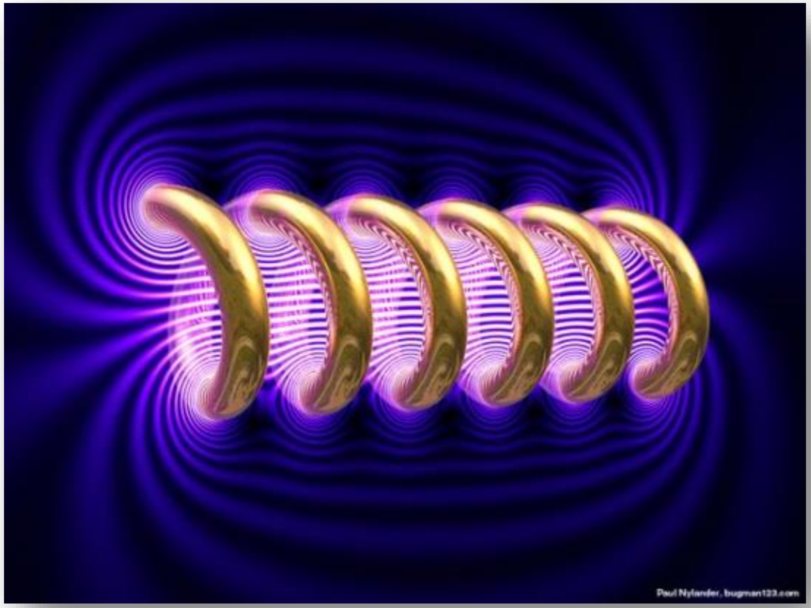
Creating an electromagnet





Magnetic Field





Electromagnet Applications

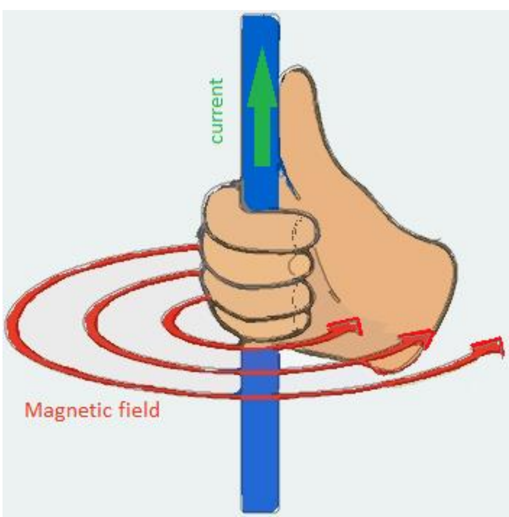
Electromagnetic Force

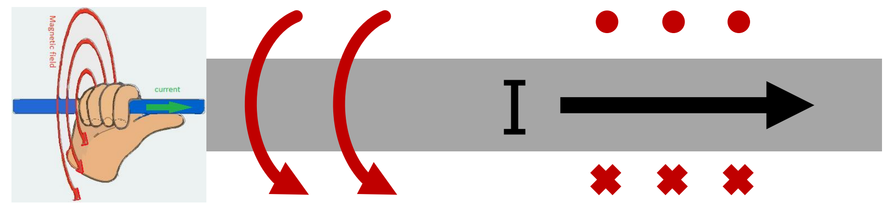
IB PHYSICS | FORCE FIELDS

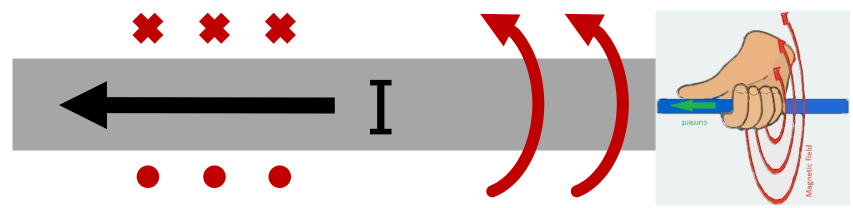
Remember the Right Hand Rule?

Thumb points in direction of the current

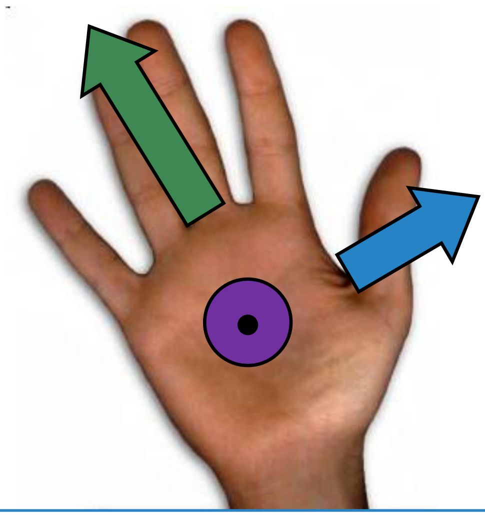
Fingers point in direction of the field lines







Right Hand Rule #2



Thumb points in direction of the current

Fingers point in direction of the field lines

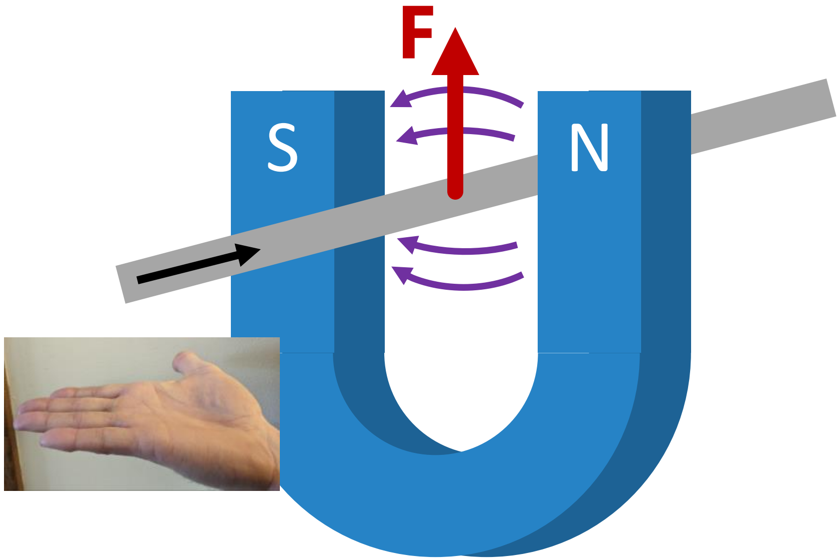
Palm points in direction of the force

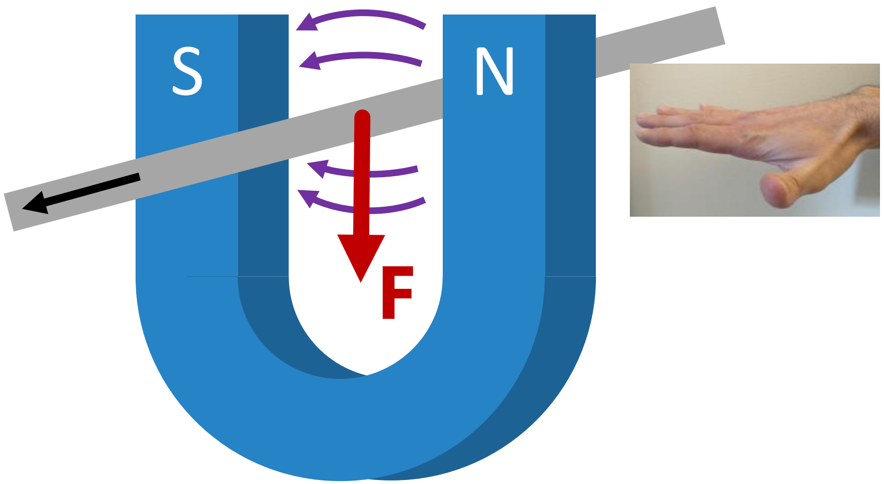
How do you represent a direction that's perpendicular to the paper?

Into the paper	✖	Out of the paper	●

Right Hand Rule #2

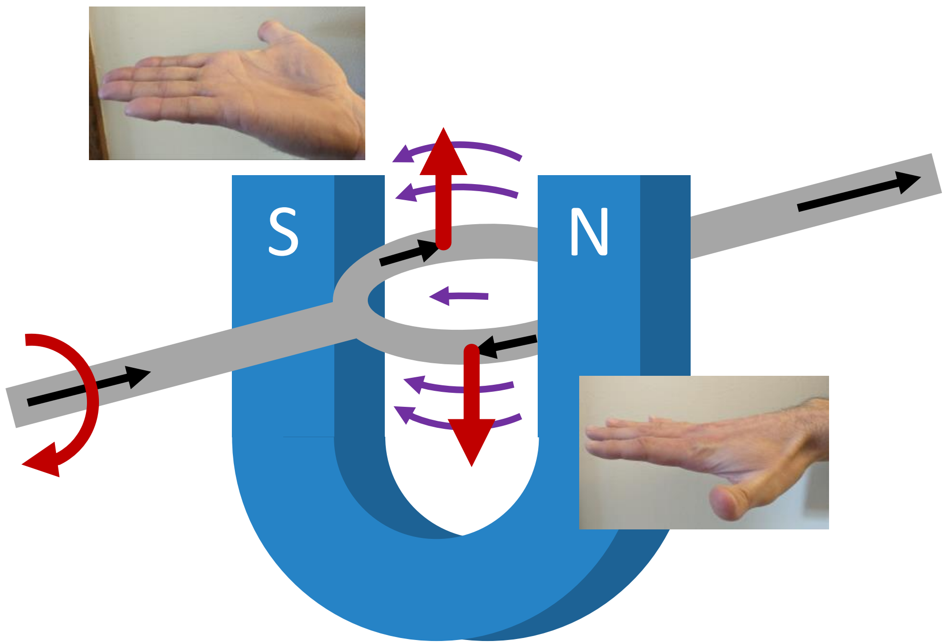
A current-carrying wire is placed in a magnetic field and the magnetic field exerts a force on the wire





Designing a Motor

When electric current is passed through a magnetic field, you get ___motion___



Motors vs Generators

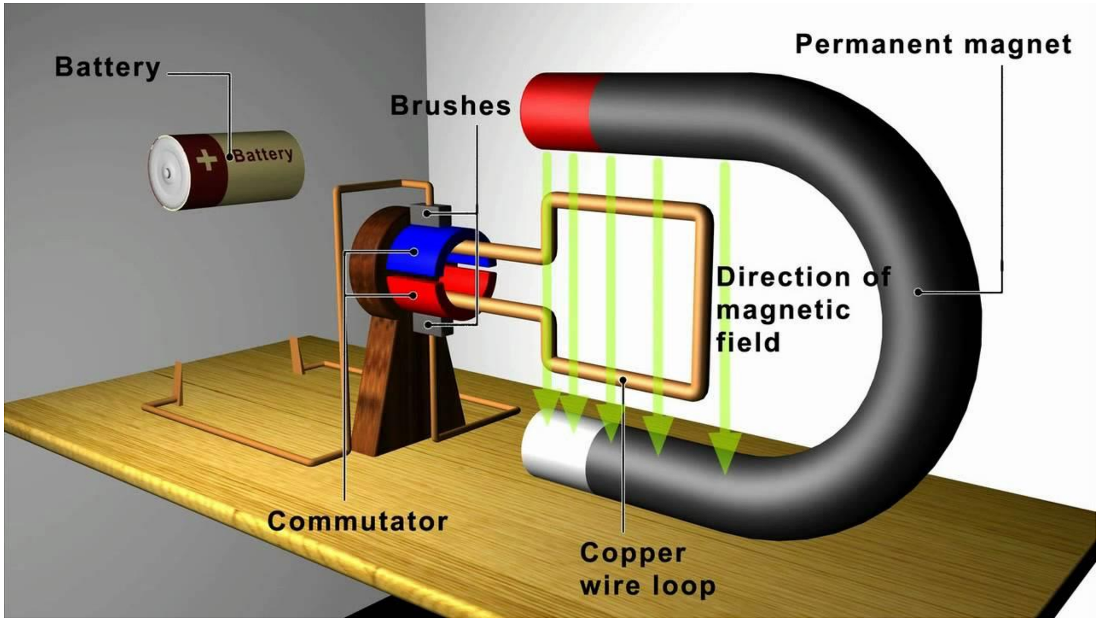
Electric Motors convert

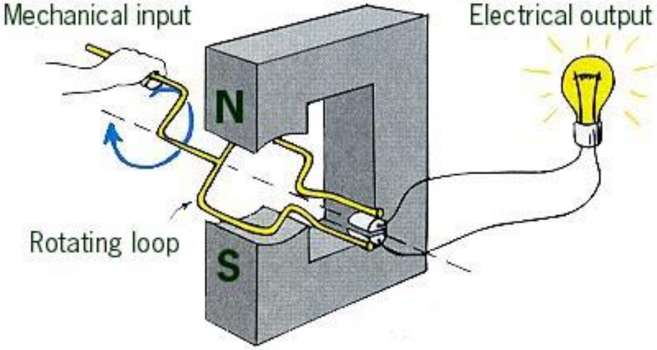
Electricity → Motion

Electric Generators convert

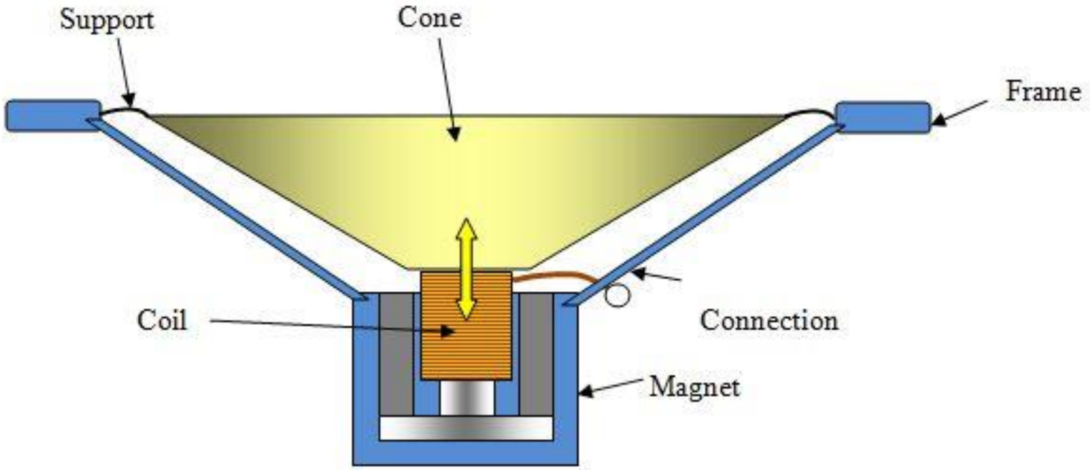
Motion → Electricity

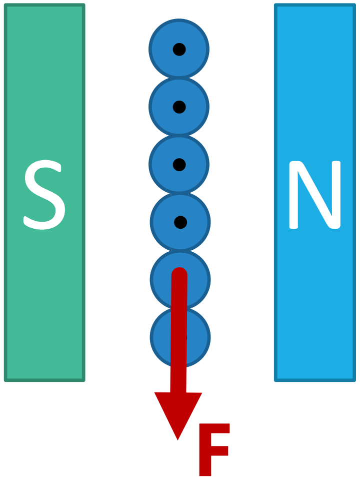
Examples

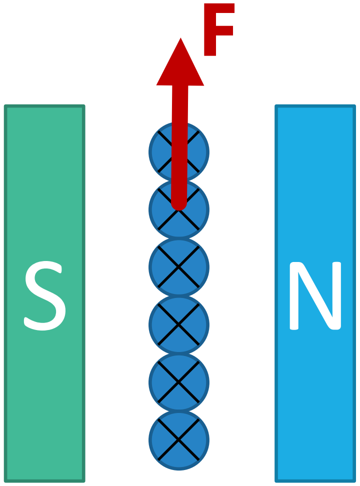

Battery
Brushes
Permanent magnet
Battery
Direction of magnetic field
Commutator
Copper wire loop

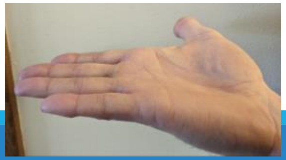

Mechanical input
Electrical output
N
S
Rotating loop

Speakers

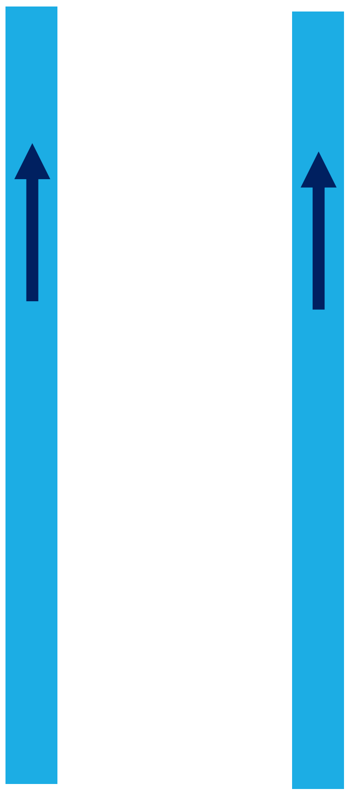




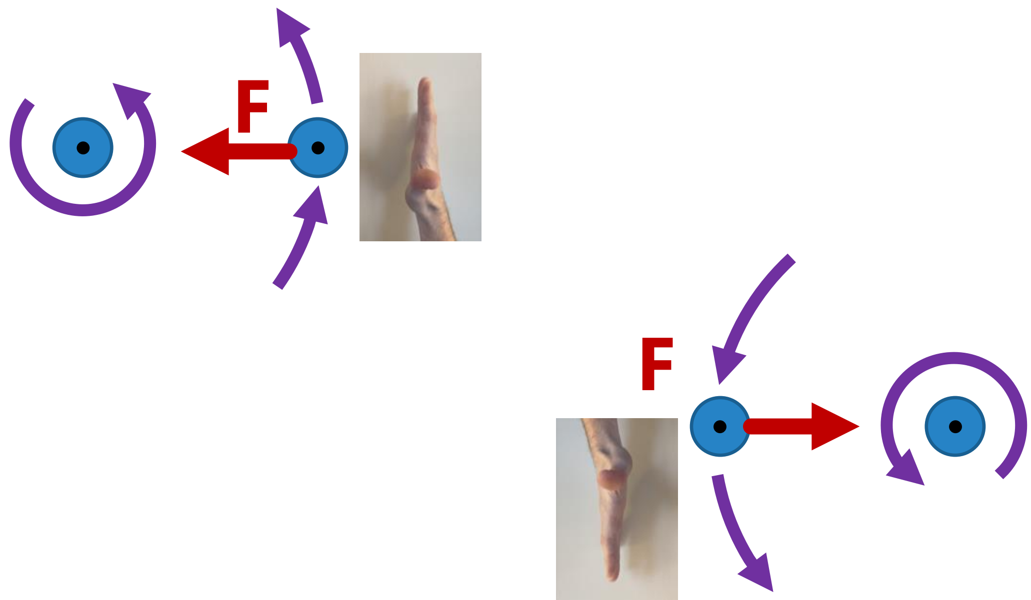




Definition of the Ampere



Consider two parallel wires, with current in the same direction. Do they attract or repel??



***One ampere is defined as the current that would cause a force of 2 × 10^{-7} N per meter between two long parallel conductors separated by 1 m in a vacuum*

Fields

Gravitational Field

$$g = \frac{F}{m} = \frac{[\mathrm{N}]}{[\mathrm{kg}]}$$

Magnetic Field

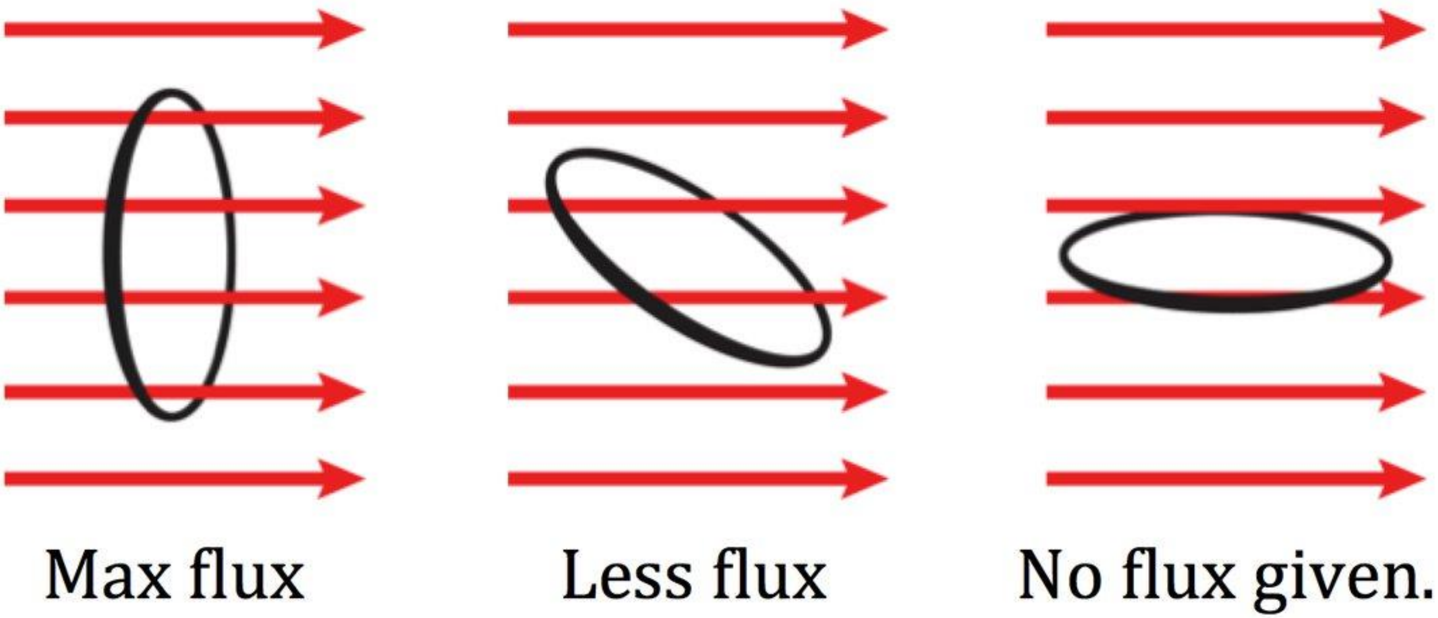
$$B = \frac{F}{I} = \frac{[\mathrm{N}]}{[\mathrm{A}]} = [\mathrm{T}]$$

Electric Field

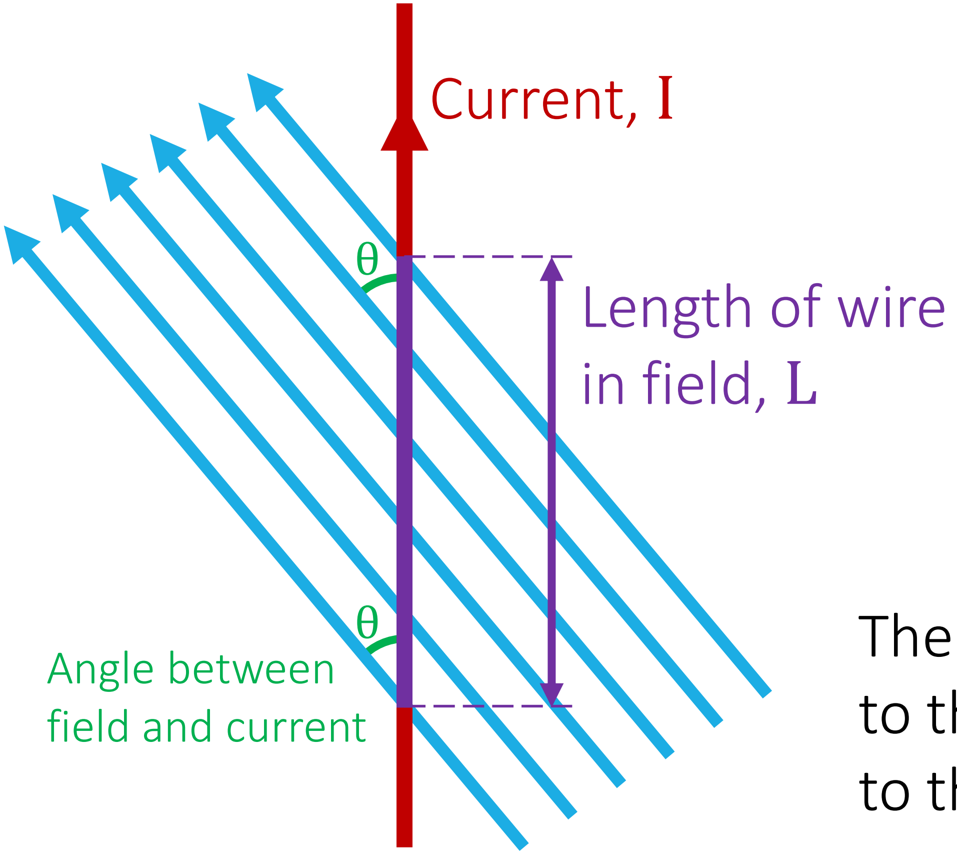
$$E = \frac{F}{q} = \frac{[\mathrm{N}]}{[\mathrm{C}]}$$

Magnetic Flux

The magnetic field strength is sometimes referred to as magnetic flux and depends on how perpendicular the current is in relation to the field direction



Magnetic field Strength



$$B = \frac{F}{ILsin\theta}$$

The force on the wire is proportional to the charge moving perpendicular to the field. Because of these the perpendicular component must be used in the calculation

Fields

$$B = \frac{F}{IL\ sin\theta}$$

$$F = BIL\ sin\theta$$

F	Magnetic force *Newtons [N]*
B	Magnetic field strength *Tesla [T]*
I	Current *Amperes [A]*

L	Length of conductor in uniform magnetic field
θ	Angle between magnetic field and current

IB Physics Data Booklet

Sub-topic 5.1 – Electric fields	Sub-topic 5.2 – Heating effect of electric currents
$I = \frac{\Delta q}{\Delta t}$ $F = k\frac{q_1 q_2}{r^2}$ $k = \frac{1}{4\pi\varepsilon_0}$ $V = \frac{W}{q}$ $E = \frac{F}{q}$ $I = nAvq$	Kirchhoff's circuit laws: $\Sigma V = 0$ (loop) $\Sigma I = 0$ (junction) $R = \frac{V}{I}$ $P = VI = I^2R = \frac{V^2}{R}$ $R_{total} = R_1 + R_2 + \cdots$ $\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$ $\rho = \frac{RA}{L}$
Sub-topic 5.3 – Electric cells	**Sub-topic 5.4 – Magnetic effects of electric currents**
$\varepsilon = I(R + r)$	$F = qvB\sin\theta$ $F = BIL\sin\theta$

Try This...

A current of 3.8 A in a long wire experiences a force of 5.7×10^{-3} N when it flows through a magnetic field of strength 25 mT. If the length of wire in the field is 10 cm, what is the angle between the field and current?

$$F = BIL\,sin\theta$$

$$\theta = sin^{-1}\left(\frac{F}{BIL}\right) = sin^{-1}\left(\frac{(5.7 \times 10^{-3})}{(25 \times 10^{-3})(3.8)(0.1)}\right)$$

$F = 5.7 \times 10^{-3}$ N

$B = 25$ mT $= 25 \times 10^{-3}$ T

$I = 3.8$ A

$L = 10$ cm $= 0.1$ m

$$\theta = 36.87°$$

Force on a Charged Particle

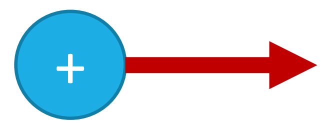
When there is a magnetic force on a current carrying wire, the force is really on the moving charges inside of the conductor.

Single charged particles can also experience a magnetic force when moving through a magnetic field…

$$F = BIL\,sin\theta$$

$$F = B\left(\frac{q}{\cancel{t}}\right)\left(v\cancel{t}\right)\,sin\theta$$

$$F = Bqv\,sin\theta$$



$$v = \frac{L}{t}$$

$$L = vt$$

$$I = \frac{q}{t}$$

IB Physics Data Booklet

Sub-topic 5.1 – Electric fields	Sub-topic 5.2 – Heating effect of electric currents
$I = \frac{\Delta q}{\Delta t}$ $F = k\frac{q_1 q_2}{r^2}$ $k = \frac{1}{4\pi\varepsilon_0}$ $V = \frac{W}{q}$ $E = \frac{F}{q}$ $I = nAvq$	Kirchhoff's circuit laws: $\Sigma V = 0$ (loop) $\Sigma I = 0$ (junction) $R = \frac{V}{I}$ $P = VI = I^2R = \frac{V^2}{R}$ $R_{\text{total}} = R_1 + R_2 + \cdots$ $\frac{1}{R_{\text{total}}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$ $\rho = \frac{RA}{L}$
Sub-topic 5.3 – Electric cells	**Sub-topic 5.4 – Magnetic effects of electric currents**
$\varepsilon = I(R + r)$	$F = qvB\sin\theta$ $F = BIL\sin\theta$

Try This...

What is the magnetic force acting on a proton (+1.6 × 10^{-19} C) moving at an angle of 32° across a magnetic field of 5.3 × 10^{-3} T at a speed of 3.4 × 10^{5} m s^{-1}?

$$F = qvB\ sin\theta$$

$$F = (1.6 \times 10^{-19})(3.4 \times 10^{5})(5.3 \times 10^{-3}) sin 32°$$

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

$v = 3.4 \times 10^{5}$ m s^{-1}

$B = 5.3 \times 10^{-3}$ T

$\theta = 32°$

$$F = 1.5 \times 10^{-16}\ \text{N}$$

Particles Moving Across Fields