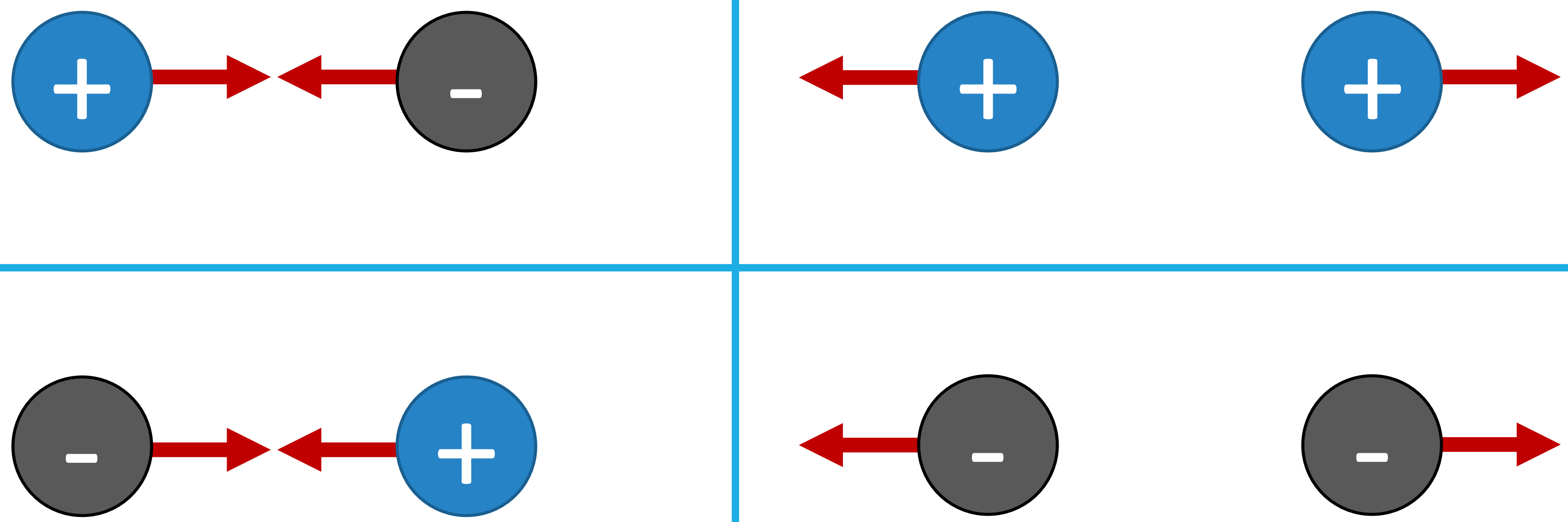
Electrostatic and Gravitational Force

IB PHYSICS | FORCE FIELDS

Review of Charges



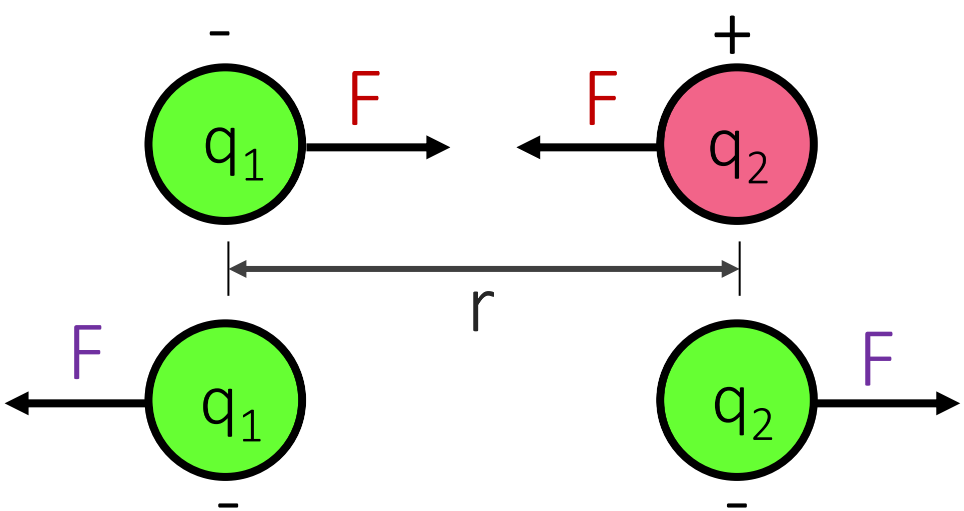
Opposite Charges
Attract

Like Charges
Repel

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]

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	$9.81\ \text{m s}^{-2}$
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	$3.00 \times 10^{8}\ \text{m s}^{-1}$

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 (-)(+)

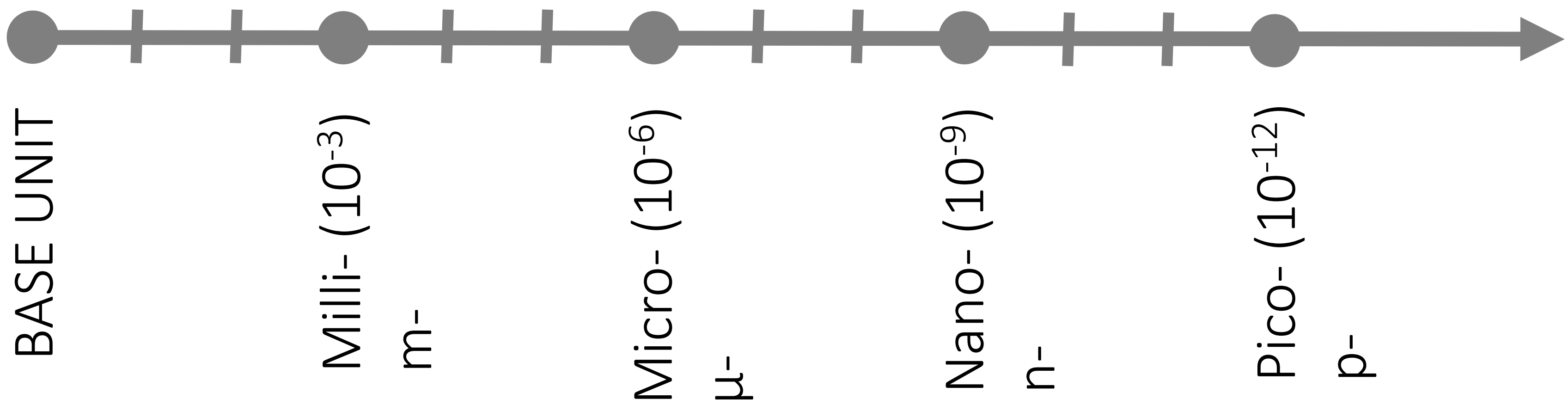
Quantifying Charge

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

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

$7\ \mu C \rightarrow C$

$7 \times 10^{-6}\ C$

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?

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

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

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??

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

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

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

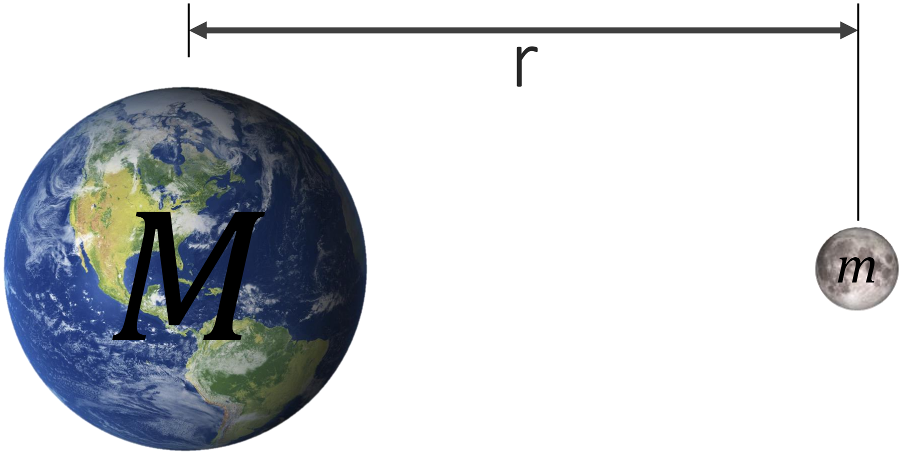
Idea #3: All mass attracts all other mass

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

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

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Sub-topic 6.2 – Newton's law of gravitation

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

*Universal Law of Gravitation

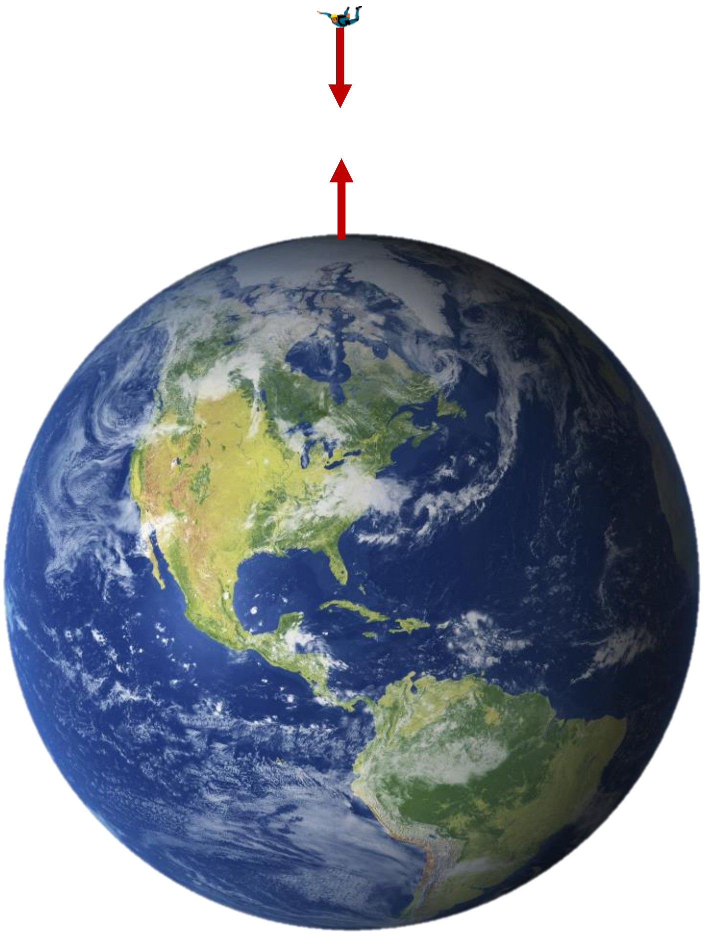
$$g = \frac{F}{m}$$

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

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

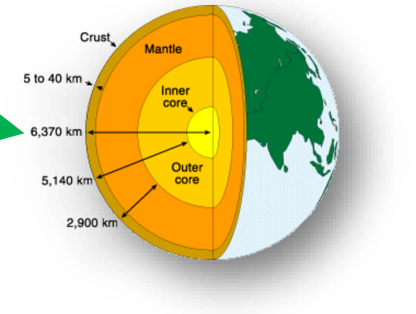


The force on the skydiver is the same as the force on the earth but the earth's huge mass means that there is hardly any acceleration

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.

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

$$F = 684\ \text{N}$$

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*

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

*Solving for k

Sub-topic 5.2 – Heating effect of electric currents
Kirchhoff's circuit laws:
$\Sigma V = 0$ (loop)
$\Sigma I = 0$ (junction)
$R = \frac{V}{I}$
$P = VI = I^2R = \frac{V^2}{R}$

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

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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