D.2

Electrostatic and Gravitational Force

IB PHYSICS | FORCE FIELDS

Quantifying Charge

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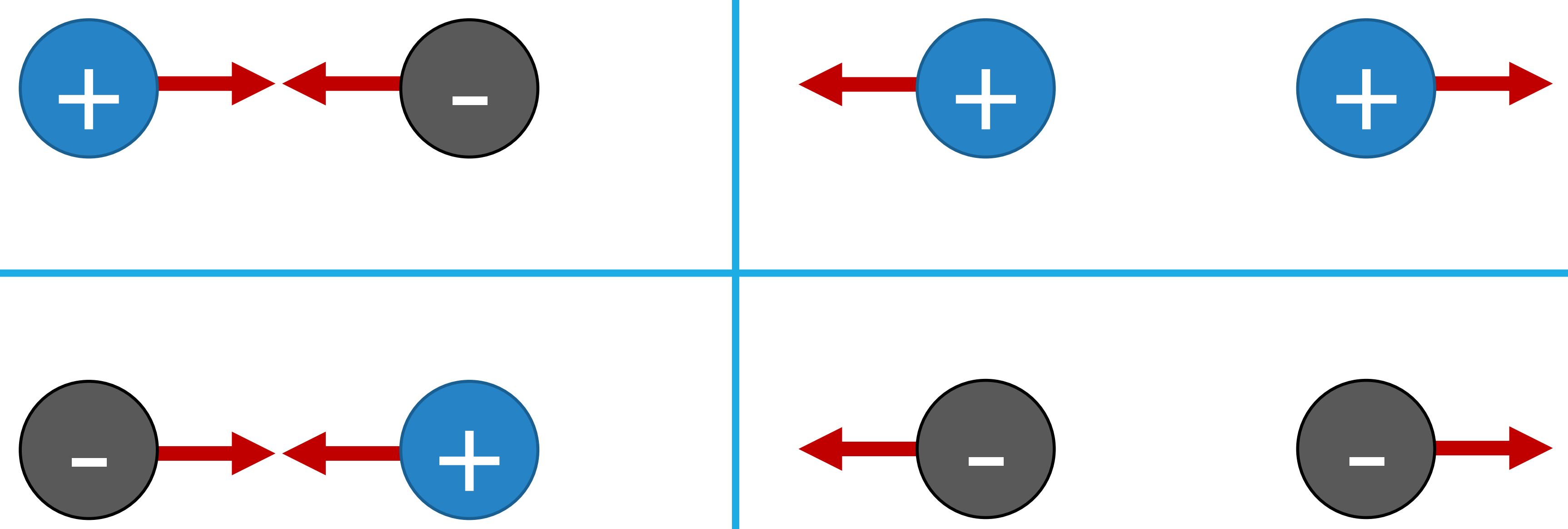
The total charge in Coulombs can be related to the number of electrons

Fundamental constants

Quantity	Symbol	Approximate value
Acceleration of free fall	g	$9.8\,m\,s^{-2}$ (Earth's surface)
Gravitational constant	G	$6.67 \times 10^{-11}\,N\,m^2\,kg^{-2}$
Avogadro constant	N_A	$6.02 \times 10^{23}\,mol^{-1}$
Gas constant	R	$8.31\,J\,K^{-1}\,mol^{-1}$
Boltzmann constant	k_B	$1.38 \times 10^{-23}\,J\,K^{-1}$
Stefan–Boltzmann constant	σ	$5.67 \times 10^{-8}\,W\,m^{-2}\,K^{-4}$
Coulomb constant	k	$8.99 \times 10^{9}\,N\,m^2\,C^{-2}$
Permittivity of free space	ε_0	$8.85 \times 10^{-12}\,C^2\,N^{-1}\,m^{-2}$
Permeability of free space	μ_0	$4\pi \times 10^{-7}\,T\,m\,A^{-1}$
Speed of light in vacuum	c	$3.00 \times 10^{8}\,m\,s^{-1}$
Planck constant	h	$6.63 \times 10^{-34}\,J\,s$
Elementary charge	e	$1.60 \times 10^{-19}\,C$

Review of Charges



Opposite Charges
Attract

Like Charges
Repel

Coulomb's Law

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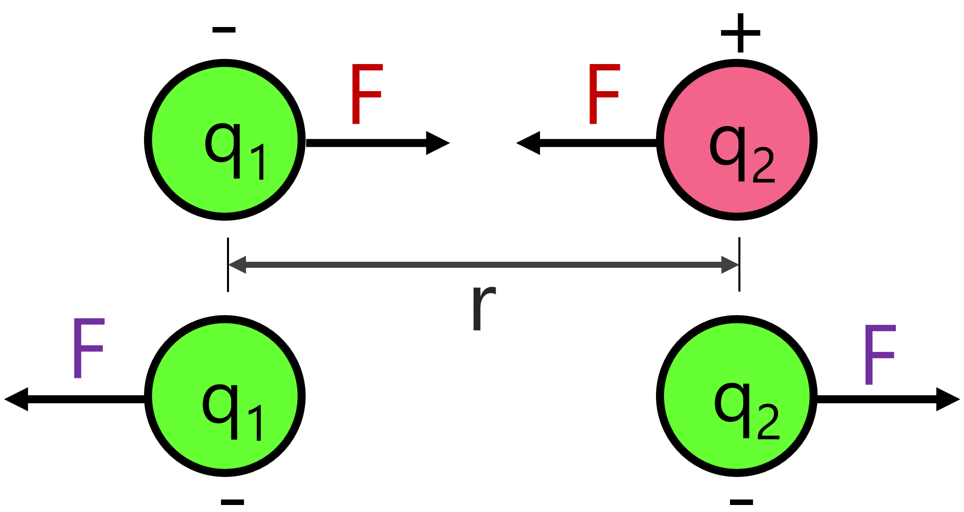
$$F_e = k\frac{q_1 q_2}{r^2}$$

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_e	[N]
Object 1 Charge	q_1	[C]
Object 2 Charge	q_2	[C]
Separation Distance	r	[m]

Coulomb's Constant

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

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

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

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D. Fields

Standard level and higher level	
D.1 Gravitational fields	$F = G\frac{m_1 m_2}{r^2}$ $g = \frac{F}{m} = G\frac{M}{r^2}$
D.2 Electric and magnetic fields	$F = k\frac{q_1 q_2}{r^2}$ where $k = \frac{1}{4\pi\varepsilon_0}$ $E = \frac{F}{q}$ $E = \frac{V}{d}$
D.3 Motion in electromagnetic fields	$F = qvB\sin\theta$ $F = BIL\sin\theta$ $\frac{F}{L} = \mu_0\frac{I_1 I_2}{2\pi r}$

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Sign is important!

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

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

+ F → Repel (+)(+) or (-)(-)

- F → Attract (+)(-) or (-)(+)

Conversion Check

D.2

7 μC → 7×10^{-6} C

14 cm → 0.14 m

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?

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

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

attract

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

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

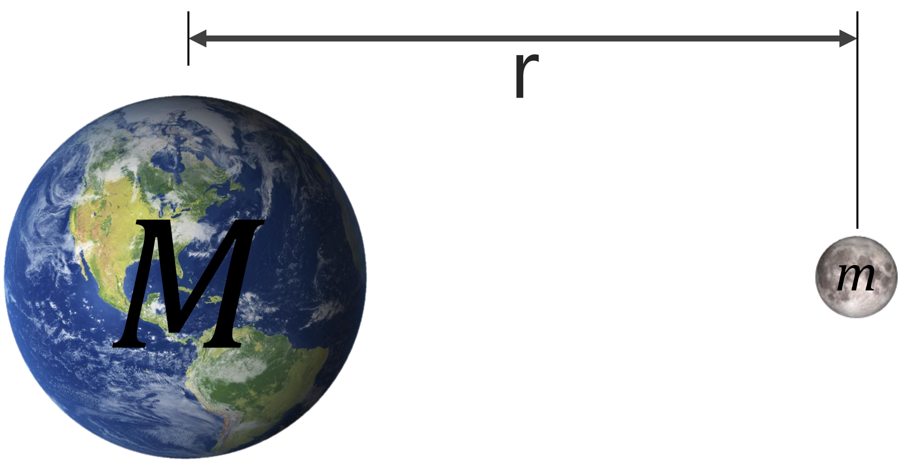
Elementary Charge = 1.60×10^{-19} C

D.1

Universal Law of Gravitation

$$F_g = G\frac{m_1 m_2}{r^2}$$

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_1	[kg]
Object 2 Mass	m_2	[kg]
Separation Distance	r	[m]

Universal Law of Gravitation

$$F_g = G\frac{m_1 m_2}{r^2}$$

G → Universal Gravitational Constant

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

IB Physics Data Booklet

D.1

D. Fields

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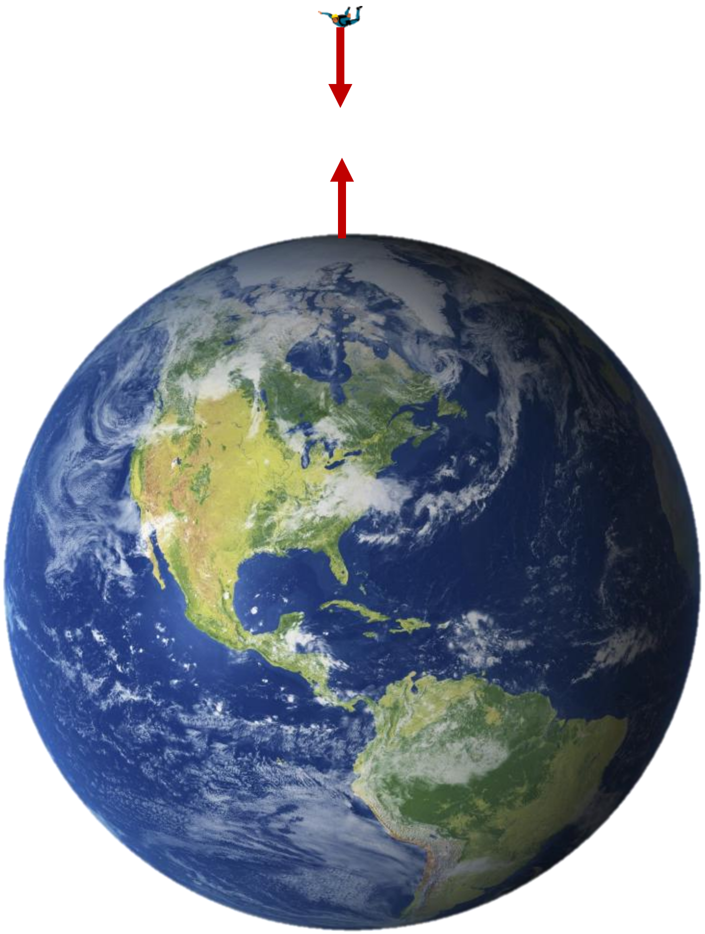
Gravity – Equal and Opposite

D.1

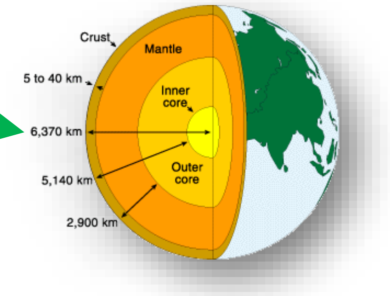


The force on the skydiver is the same as the force on the earth but the earth's huge mass means that there is hardly any acceleration

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.

$$F_g = G\frac{m_1 m_2}{r^2} = (6.67 \times 10^{-11})\frac{(5.98 \times 10^{24})(70)}{(6.39 \times 10^6)^2}$$

$$F_g = 684\ \mathrm{N}$$

Comparison

Electrostatic Force

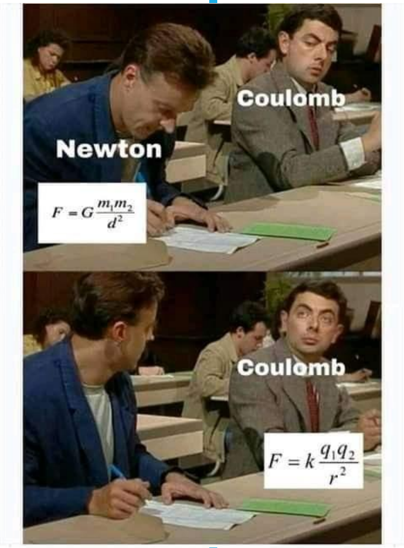
$$F_e = k\frac{q_1 q_2}{r^2}$$

Gravitational Force

$$F_g = G\frac{m_1 m_2}{r^2}$$

$k \rightarrow Coulomb\ Constant$

$q_1, q_2 \rightarrow$ Charges [C]



$G \rightarrow Gravitational\ Constant$

$m_1, m_2 \rightarrow$ 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*

D.2

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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

Lesson Takeaways

D.2

- ❑ I can calculate electric force using Coulomb's Law
- ❑ I can calculate gravitation force using the Universal Law of Gravitation
- ❑ I can describe how the sign of the calculated electrostatic force indicates attraction or repulsion
- ❑ I can describe the impact of separation distance on electric and gravitational force