Electrostatic and Gravitational Force

IB PHYSICS | FORCE FIELDS

Review of Charges



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.



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

Symbol

Unit

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Sub-topic 5.1 – Electric fields		Sub-topic 5.	2 – Heat	ing effect of electric currents
$I = \frac{\Delta q}{\Delta q}$ Kirchhoff's d		Kirchhoff's ci	circuit laws:	
Δt		$\Sigma V = 0$ (loop)		
$F = k \frac{q_1 q_2}{r^2} * Coulomb's Law \qquad \Sigma I = 0$		$\Sigma I = 0$ (junction)		
, 1		V		
$k = \frac{1}{4\pi\varepsilon_0}$	Quantity		Symbol	Approximate value
$V = \frac{W}{W}$	Acceleration of free fall (Earth	ı's surface)	g	9.81 m s ⁻²
q F	Gravitational constant		G	$6.67 imes 10^{-11} \mathrm{N}\mathrm{m}^2\mathrm{kg}^{-2}$
$E = \frac{F}{q}$	Avogadro's constant		N _A	$6.02 \times 10^{23} mol^{-1}$
I = nAvq	Gas constant		R	$8.31 \mathrm{J} \mathrm{K}^{-1} \mathrm{mol}^{-1}$
	Boltzmann's constant		$k_{ m B}$	$1.38 \times 10^{-23} \text{J}\text{K}^{-1}$
	Stefan-Boltzmann constant		σ	$5.67 \times 10^{-8}Wm^{-2}K^{-4}$
Sub-topic 5.3 – Electric cells	Coulomb constant		k	$8.99 \times 10^9 \mathrm{N}\mathrm{m}^2\mathrm{C}^{-2}$
$\varepsilon = I(R+r)$	Permittivity of free space		ε	$8.85 \times 10^{-12} \text{C}^2 \text{N}^{-1} \text{m}^{-2}$
	Permeability of free space		μ_0	$4\pi imes 10^{-7} T m A^{-1}$
	Speed of light in vacuum		с	$3.00 \times 10^8 \mathrm{ms^{-1}}$

Sign is important!

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

 $+ F \rightarrow$

 $- F \rightarrow$

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

Quantifying Charge

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

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

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

$7 \,\mu C \rightarrow C$

kilo	k	10 ³
hecto	h	10 ²
deca	da	101
deci	d	10-1
centi	с	10-2
milli	m	10-3
micro	μ	10-6
nano	n	10-9
	1	I contract of the second se

Try This

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

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

$$F = k \frac{q_1 q_2}{r^2}$$
 k = 8.99 × 10⁹ N m² C⁻² Elementary Charge = 1.60 × 10⁻¹⁹

How many electrons??

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

How many excess electrons on the second cork??

$$F = k \frac{q_1 q_2}{r^2}$$
 k = 8.99 × 10⁹ N m² 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 Onic	Syn	nbol	Unit
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	Symbol	Unit
Gravitational Force		
Object 1 Mass		
Object 2 Mass		
Separation Distance		

Universal Law of Gravitation

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

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G → Universal Gravitational Constant

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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."





5 to 40 km

6,370 km

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.

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

Comparison

Electrostatic Force

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

Gravitational Force



 $k \rightarrow Coulomb \ Constant$ $q_1, q_2 \rightarrow Charges [C]$ $G \rightarrow Gravitational Constant$ $M, m \rightarrow$ Masses [kg]

Permittivity

Coulomb's Constant is sometimes expanded to this form:

$$k = \frac{1}{4\pi\epsilon_0}$$

 $\varepsilon_0 \rightarrow$ Permittivity of Free Space (vacuum) $\varepsilon_0 = 8.85 \times 10^{-12} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2}$

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

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$I = \frac{\Delta q}{\Delta q}$	Kirchhoff's circuit laws:			
Δt	$\Sigma V = 0$ (loop)			
$F = k \frac{q_1 q_2}{r^2}$	$\Sigma I = 0$ (junction)			
$k = \frac{1}{4\pi\varepsilon_0}$	$R = \frac{V}{I}$			
$V = \frac{W}{a}$	$P = VI = I^2 R = \frac{V^2}{r}$			
F	Quantity	Symbol	Approximate value	
$E = -\frac{1}{q}$	Acceleration of free fall (Earth's surface)	g	9.81 m s ⁻²	
I = nAvq	Gravitational constant	G	$6.67 \times 10^{-11} \mathrm{N}\mathrm{m}^2\mathrm{kg}^{-2}$	
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$\varepsilon = I(\kappa + r)$	Boltzmann's constant	k _B	$1.38 imes 10^{-23} \text{J} \text{K}^{-1}$	
	Stefan-Boltzmann constant	σ	$5.67 imes 10^{-8} W m^{-2} K^{-4}$	
	Coulomb constant	k	$8.99 \times 10^9 \text{N}\text{m}^2\text{C}^{-2}$	
	Permittivity of free space	ε_0	$8.85\times 10^{-12}\text{C}^{2}\text{N}^{-1}\text{m}^{-2}$	
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	Speed of light in vacuum	с	$3.00 \times 10^8 \mathrm{ms^{-1}}$	

Permittivity

Permittivity changes relative to the substance



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