Electricity Lecture Series

Assoc. Prof. Dr. J.J.

Charges Electric Fields, Potential and Capacitors

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Electric Charges

Objectives:

1. *Explain the gravitational forces acting on any object.*
2. *Mathematically represent the gravitational force and describe its impact on physical events.*
3. *Describe existence of electrical charges in matter and its quantization property.*
4. *Sketch and explain the charging by induction and charging by contact*
5. *Mathematically represent forces acting between electrical charges (Coulomb's Law)*

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Electric Charges

Objectives:

6. *Represent forces acting between charges both pictorially and vectorially.*
7. *Describe and explain gravitational and electric field.*
8. *Derive mathematical relations for electric field of point charges, line charges and surface charges and the use of Gaussian surface.*
9. *Describe and explain capacitors and its purpose.*

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Electric Charges

Objectives:

10. *Write mathematical relations for parallel plate capacitors related to capacitance, potential difference, its geometrical dependence, and electric field it can store.*
11. *Obtain energies stored by capacitors.*
12. *Explain and pictorially and graphically represent the charging and discharging of capacitors.*

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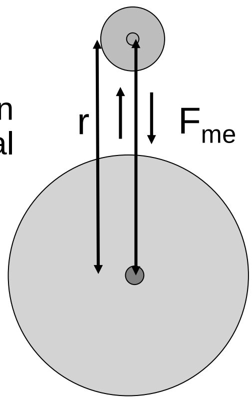
Electric Charges

Objectives:

13. *Describe, draw and obtain resultant capacitances for capacitors connected in parallel and in series respectively.*
14. *Solve conceptual and numerical problems associated with capacitors.*

Electric Forces-Coulomb's Law

Gravitational forces (Law of Gravitation): Earth pulls on the moon and vice-versa. Any 2 objects will always exert and feel attractive gravitational forces. They exert with same magnitude. Moon feels attraction because it is in the earth's gravitational field.



F is inversely proportional to square of separation between masses.

$$F_{moon\ due\ to\ earth} \propto \frac{m_{moon} M_{earth}}{r^2}$$

$$F_{earth\ due\ to\ moon} \propto \frac{M_{earth} m_{moon}}{r^2}$$

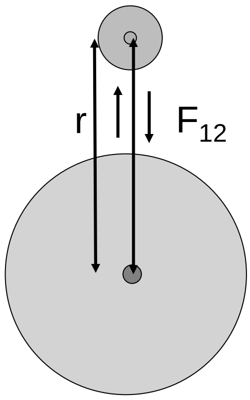
Electric Charges-Forces

Gravitational forces:

F is inversely proportional to square of separation between masses.

$$F_{moon\ due\ to\ earth} = G\frac{m_{moon} M_{earth}}{r^2}$$

r, m	r^2, m^2	F, N	Ratios of F
10	100	$F_1=Gm_1m_2/100$	$F_1/F_2=4$
20	400	$F_2=Gm_1m_2/400$	$F_1/F_3=9$
30	900	$F_3=Gm_1m_2/900$	$F_2/F_3=9/4$



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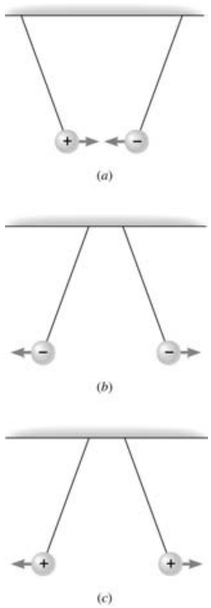
18.2 Charged Objects and the Electric Force
Cutnell & Johnson 7E

Like charges repel and unlike charges attract each other.



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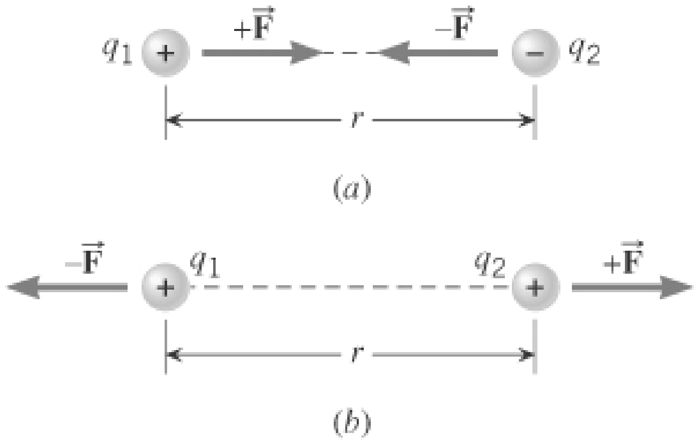
18.5 Coulomb's Law
Cutnell & Johnson 7E



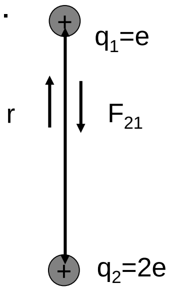
Electric Charges-Coulomb's Law

Electric forces: Charged objects exert electric forces on each other. Can be attractive or repulsive. Like charges repel. Unlike charges attract.

$$F_{12} = F_{1\ due\ to\ 2} \propto \frac{q_1 q_2}{r^2} = k\frac{q_1 q_2}{r^2}$$

$$F_{21} = F_{2\ due\ to\ 1} = k\frac{q_2 q_1}{r^2} = \frac{q_2 q_1}{4\pi\varepsilon_0 r^2}$$

$$k = \frac{1}{4\pi\varepsilon_0} \equiv electric\ constant$$



ε_0 = permittivity of free space
$\varepsilon_0 = 8.85 \times 10^{-12}\ C^2/Nm^2$

18.5 Coulomb's Law
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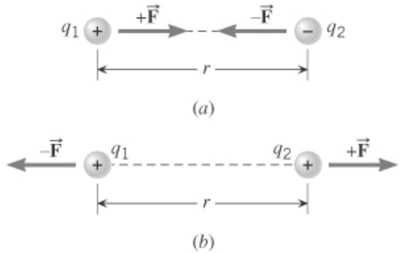
COULOMB'S LAW

The magnitude of the electrostatic force exerted by one point charge on another point charge is directly proportional to the magnitude of the charges and inversely proportional to the square of the distance between them.



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

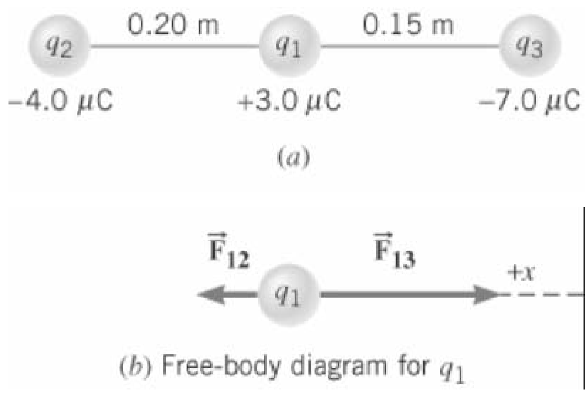
$$\varepsilon_o = 8.85\times10^{-12}\ \mathrm{C^2/(N\cdot m^2)}$$

$$k = 1/(4\pi\varepsilon_o) = 8.99\times10^{9}\ \mathrm{N\cdot m^2/C^2}$$

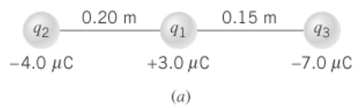
18.5 Coulomb's Law
Cutnell & Johnson 7E

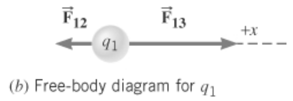
Example 4 **Three Charges on a Line**

Determine the magnitude and direction of the net force on q_1.



18.5 Coulomb's Law
Cutnell & Johnson 7E





$$\vec{F}_{12} = k\frac{|q_1||q_2|}{r^2} = \frac{\left(8.99\times10^{9}\ N\cdot m^2/C^2\right)\left(3.0\times10^{-6}C\right)\left(4.0\times10^{-6}C\right)}{(0.20m)^2} = -2.7N$$

$$\vec{F}_{13} = k\frac{|q_1||q_3|}{r^2} = \frac{\left(8.99\times10^{9}\ N\cdot m^2/C^2\right)\left(3.0\times10^{-6}C\right)\left(7.0\times10^{-6}C\right)}{(0.15m)^2} = +8.4N$$

$$\vec{\mathbf{F}} = \vec{\mathbf{F}}_{12} + \vec{\mathbf{F}}_{13} = -2.7\text{N} + 8.4\text{N} = +5.7\text{N}$$

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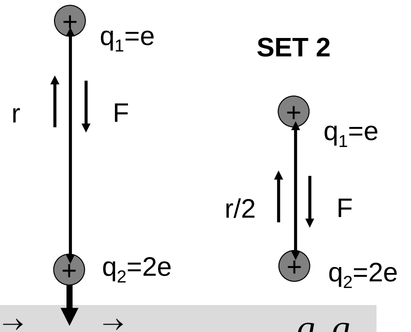
Electric Point Charges

Electric forces: repulsive forces since both are positively charged.



$$\vec{F}_{21} = \vec{F}_{2\,due\,to\,1} = k\frac{q_2 q_1}{(r/2)^2}$$

$$\vec{F}_{21} = k\frac{q_2 q_1}{r^2/4}$$ down

$$\vec{F}_{21} = 4k\frac{q_2 q_1}{r^2}$$

$$\vec{F}_{21} = \vec{F}_{2\ due\ to\ 1} = k\frac{q_2 q_1}{r^2}$$ down

F_{set1} < F_{set2}

Is acc_{set1} bigger or smaller than acc_{set2}??

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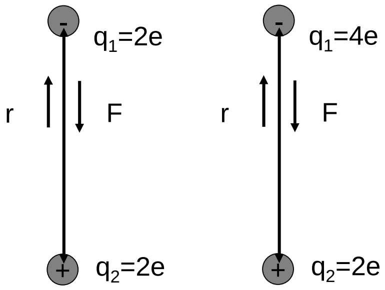
Electric Point Charges

Electric forces: attractive forces since opposite charges



$$\vec{F}_{21} = k\frac{q_2 q_1}{r^2}$$ up

$$\vec{F}_{21} = k\frac{8e^2}{r^2}$$

$$\vec{F}_{21} = 2k\frac{4e^2}{r^2}$$

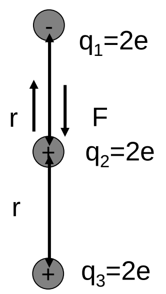
$$\vec{F}_{21} = k\frac{2e\,2e}{r^2} = k\frac{4e^2}{r^2}$$ up

$F_{set1} <$ F_{set2}

Is acc_{set1} bigger or smaller than acc_{set2}??

Electric Point Charges

Electric forces: Determine forces acting on charge 2



$$\vec{F}_{21} = k\frac{2e2e}{r^2} = k\frac{4e^2}{r^2}$$ up

$$\vec{F}_{23} = k\frac{q_2 q_3}{r^2} = k\frac{2e\,2e}{r^2}$$ up

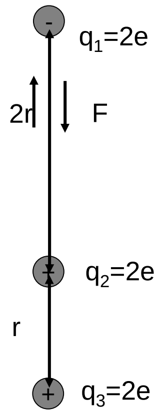
What is the magnitude and direction of net force acting on q_2?

$$\vec{F}_{21} + \vec{F}_{23} = k\frac{4e^2}{r^2} + k\frac{4e^2}{r^2} = k\frac{8e^2}{r^2}$$ up

What is the magnitude and direction of acceleration of q_2?

Electric Point Charges

Electric forces: Determine forces acting on charge 2



$$\vec{F}_{21} = k\frac{q_2 q_1}{r^2} = k\frac{2e2e}{(2r)^2} = k\frac{4e^2}{4r^2}$$ up

$$\vec{F}_{23} = k\frac{q_2 q_3}{r^2} = k\frac{2e2e}{r^2}$$ up

$$\vec{F}_{21} + \vec{F}_{23} = k\frac{e^2}{r^2} + k\frac{4e^2}{r^2} = k\frac{5e^2}{r^2}$$ up

What is the magnitude and direction of acceleration of q_2?

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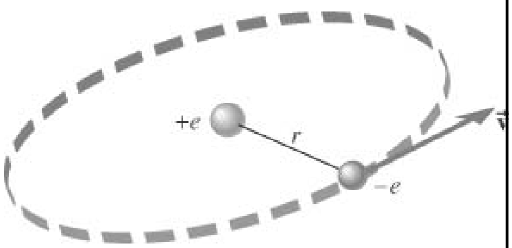
18.5 Coulomb's Law
Cutnell & Johnson 7E

Example 3 **A Model of the Hydrogen Atom**

In the Bohr model of the hydrogen atom, the electron is in orbit about the nuclear proton at a radius of 5.29×10^{-11}m. Determine the speed of the electron, assuming the orbit to be circular.



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

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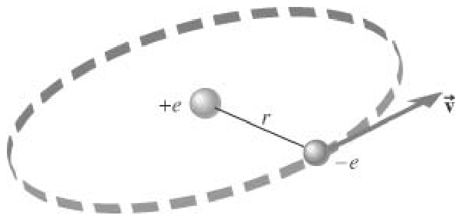
18.5 Coulomb's Law
Cutnell & Johnson 7E



$$F = k\frac{|q_1||q_2|}{r^2} = \frac{\left(8.99\times10^{9}\ \mathrm{N\cdot m^2/C^2}\right)\left(1.60\times10^{-19}\ \mathrm{C}\right)^2}{\left(5.29\times10^{-11}\ \mathrm{m}\right)^2} = 8.22\times10^{-8}\ \mathrm{N}$$

For circular motion & using Newton's 2nd law of motion ➡ $F = ma_c = mv^2/r$

➡ $$v = \sqrt{Fr/m} = \sqrt{\frac{\left(8.22\times10^{-8}\ \mathrm{N}\right)\left(5.29\times10^{-11}\ \mathrm{m}\right)}{9.11\times10^{-31}\ \mathrm{kg}}} = 2.18\times10^{6}\ \mathrm{m/s}$$

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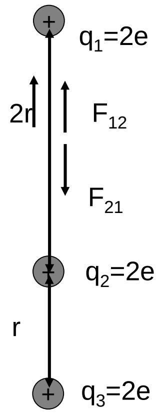
Electric Point Charges

Electric forces: Determine forces acting on charge 2



$$\vec{F}_{21} = k\frac{q_2q_1}{r^2} = k\frac{2e2e}{(2r)^2} = k\frac{4e^2}{4r^2}$$ down

$$\vec{F}_{23} = k\frac{q_2q_3}{r^2} = k\frac{2e2e}{r^2}$$ up

$$\vec{F}_{21} + \vec{F}_{23} = -k\frac{e^2}{r^2} + k\frac{4e^2}{r^2} = k\frac{3e^2}{r^2}$$ up

What is the magnitude and direction of acceleration of q_2?

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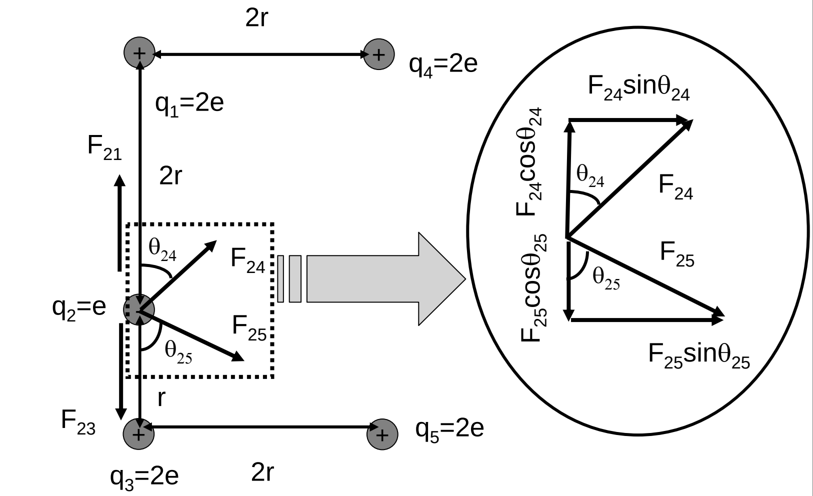
Electric Point Charges

Electric forces: Determine forces acting on charge 2



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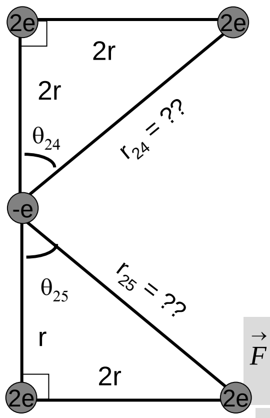
Electric Point Charges

Electric forces: Determine forces acting on charge 2

Pythagoras theorem: Charge 2 & 4 is separated by the distance:



$$r_{24} = \sqrt{(2r)^2 + (2r)^2} = \sqrt{8r^2} = 2r\sqrt{2}$$

Charge 2 & 5 is separated by the distance:

$$r_{25} = \sqrt{r^2 + (2r)^2} = \sqrt{5r^2} = r\sqrt{5}$$

$$\vec{F}_{21} = k\frac{q_2 q_1}{r_{21}^2} = k\frac{e2e}{(2r)^2} = k\frac{e^2}{2r^2}$$ up

$$\vec{F}_{23} = k\frac{q_2 q_3}{r_{23}^2} = k\frac{e2e}{r^2} = k\frac{2e^2}{r^2}$$ down

$$\vec{F}_{24} = k\frac{q_2 q_4}{r_{24}^2} = k\frac{e2e}{(2r\sqrt{2})^2} = k\frac{2e^2}{8r^2} = k\frac{e^2}{4r^2}$$

$$\vec{F}_{25} = k\frac{q_2 q_5}{r_{25}^2} = k\frac{e2e}{(r\sqrt{5})^2} = k\frac{2e^2}{5r^2} = k\frac{2e^2}{5r^2}$$

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Electric Point Charges

Electric forces: Determine forces acting on charge 2

$$\vec{F}_{21} = k\frac{q_2 q_1}{r^2} = k\frac{e2e}{(2r)^2} = k\frac{e^2}{2r^2} \quad \text{up}$$

$$\vec{F}_{23} = k\frac{q_2 q_3}{r^2} = k\frac{e2e}{r^2} = k\frac{2e^2}{r^2} \quad \text{down}$$

$$\vec{F}_{24} = k\frac{q_2 q_4}{r^2} = k\frac{e2e}{\left(2r\sqrt{2}\right)^2} = k\frac{2e^2}{8r^2} = k\frac{e^2}{4r^2}$$

$$\vec{F}_{25} = k\frac{q_2 q_5}{r^2} = k\frac{e2e}{\left(r\sqrt{5}\right)^2} = k\frac{2e^2}{5r^2} = k\frac{2e^2}{5r^2}$$

$$\cos\theta_{24} = \frac{2r}{2r\sqrt{2}} = \frac{1}{\sqrt{2}}$$

$$\sin\theta_{24} = \frac{2r}{2r\sqrt{2}} = \frac{1}{\sqrt{2}}$$

$$\cos\theta_{25} = \frac{r}{r\sqrt{5}} = \frac{1}{\sqrt{5}}$$

$$\sin\theta_{25} = \frac{2r}{r\sqrt{5}} = \frac{2}{\sqrt{5}}$$

Then

$$\vec{F}_{24_y} = k\frac{e^2}{4r^2\sqrt{2}}; up \qquad \vec{F}_{24_x} = k\frac{e^2}{4r^2\sqrt{2}}; right$$

$$\vec{F}_{25_y} = k\frac{e^2}{4r^2\sqrt{5}}; down \qquad \vec{F}_{25_x} = k\frac{e^2}{2r^2\sqrt{5}}; right$$

Electric Point Charges

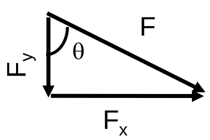
Electric forces: Determine forces acting on charge 2

$$\vec{F}_y = \vec{F}_{21} + \vec{F}_{23} + \vec{F}_{24_y} + \vec{F}_{25_y} = k\frac{e^2}{r^2}\left(\frac{1}{2} - 2 + \frac{1}{4\sqrt{2}} - \frac{1}{4\sqrt{5}}\right); down$$

$$\vec{F}_x = \vec{F}_{24_x} + \vec{F}_{25_x} = k\frac{e^2}{r^2}\left(\frac{1}{4\sqrt{2}} + \frac{1}{2\sqrt{5}}\right); right$$

$$Then,\ \left|\vec{F}\right| = \sqrt{\left|\vec{F}_x\right|^2 + \left|\vec{F}_y\right|^2}$$

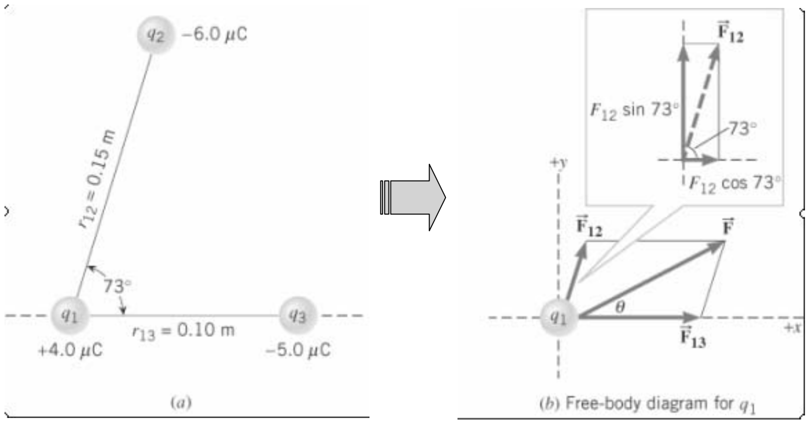
$$Then,\ \left|\vec{F}\right| = k\frac{e^2}{r^2}\sqrt{\left(\frac{1}{4\sqrt{2}} + \frac{1}{2\sqrt{5}}\right)^2 + \left(\frac{3}{2} + \frac{1}{4\sqrt{2}} - \frac{1}{4\sqrt{5}}\right)^2}$$



$$Tan\,\theta = \frac{\frac{1}{4\sqrt{2}} + \frac{1}{2\sqrt{5}}}{\frac{3}{2} + \frac{1}{4\sqrt{2}} - \frac{1}{4\sqrt{5}}}$$

Take the arctan of theta to determine the force direction

18.5 Coulomb's Law
Cutnell & Johnson 7E



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Electric field & forces

Assignment: Due Feb 1st 2008.

Chap 18
Exercises from the back of chapter.
1,3,5,9, 13, 17,70, 71, 75
Submit all

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