BBMerlion

Electricity and Magnetism

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- **Electric Fields**
- **Current of Electricity**
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- **Electromagnetism**
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ELECTRIC FIELDS AND ELECTRIC POTENTIAL

Content

- Force between point charges
- Concept of an electric field
- Electric field of a point charge
- Uniform electric fields
- Electric potential

Electric Force (Gaya Listrik/Gaya Coulomb)

- Nature of the *electric force* F_e (or *Coulomb force*) between two stationary charged particles q_1 and q_2 separated at a distance r:
- *1.* F_e is inversely proportional to r^2.
- *2.* F_e is proportional to the product of q_1 and q_2.
- *3.* F_e is attractive for unlike charges and repulsive for like charges.
  - *Coulomb's law* gives the magnitude of the electric force between two point charges:

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

- where k_e is the *Coulomb constant*.
- Electric force is a vector. Hence, it is important to notice the direction!
- In SI units, charge is measured in the unit of *coulomb* (C).

Electric Force

- With *q* in the unit of Coulomb (C), *r* in metre (m), and *Fe* in Newton (N), the Coulomb constant has a value of

$$k_e = 8.9875 \times 10^9 \ \ Nm^2/C^2$$

- k_e is also expressed as: $$k_e = \frac{1}{4\pi\varepsilon_o}$$

- where ε_0 is called the *permittivity of free space*, with a value of

$$\varepsilon_o = 8.8542 \times 10^{-12} \ \ C^2/Nm^2$$

Electric Force

- Example

What is the electric force between the electron and proton of a hydrogen atom which are separated by a distance of 5.3×10-11m

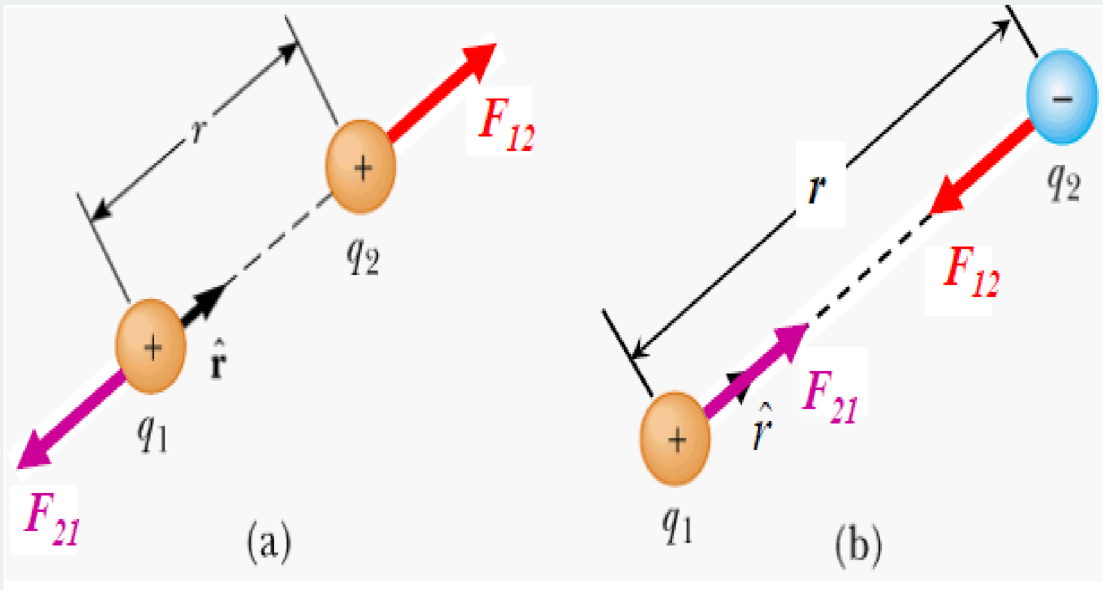
$$F_e = k_e \frac{|q_1||q_2|}{r^2} = k_e \frac{e^2}{r^2}$$

Solution:

$$= \left(8.99\times10^{9}\ \frac{Nm^2}{C^2}\right)\frac{\left(1.60\times10^{-19}\ C\right)^2}{\left(5.3\times10^{-11}\ m\right)^2}$$

$$= 8.2\times10^{-8}\ N$$

- Electric force is a *vector*. The electric force exerted by a charge q_1 on a second charge q_2 can be expressed as
- where $\hat{r}$ is a unit vector directed from q_1 to q_2 . (note $|\hat{r}| = 1$)



- If q_1 and q_2 are of the *same polarity*, F_{12} will be *positive*, acting in the direction of . The force is *repulsive*.
- If q_1 and q_2 are of *opposite polarity*, F_{12} will be *negative*, acting in the direction opposite to . The force is *attractive*.
- From Newton's third law, $\mathbf{F_{12}}$=-$\mathbf{F_{21}}$

Polarity : jenis muatan (positif atau negative)

- Example

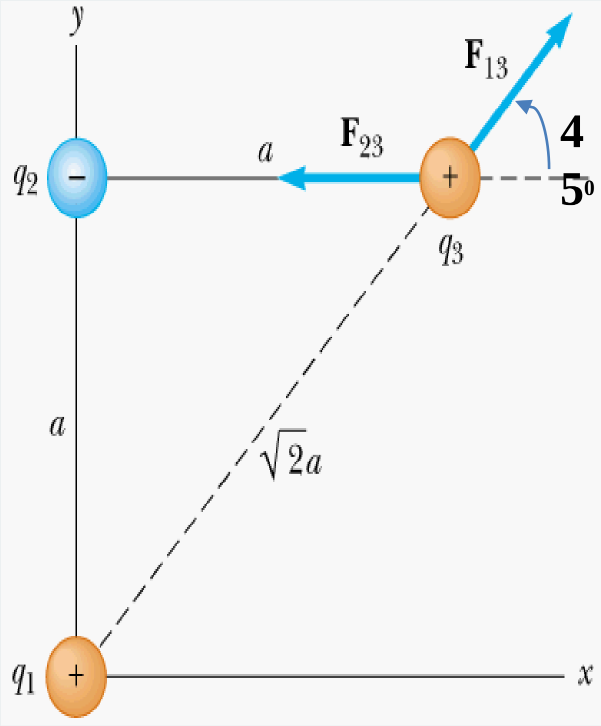
Find the resultant force *F3* exerted on *q*3 by *q*1 and *q*2 if the charges are located at the corners of a right angled triangle. Given that *q*1 = *q*3 = 5 μC, *q*2 = -2 μC and *a*= 0.1 m.

Solution

The magnitude of force extерted by q1

$$F_{13} = k_e \frac{|q_1||q_3|}{\left(\sqrt{2}a\right)^2} = \left(8.99\times10^9 \frac{N.m^2}{C^2}\right)\frac{\left(5.0\times10^{-6}C\right)\left(5.0\times10^{-6}C\right)}{2\left(0.10m\right)^2}$$

$$= 11.23\ N$$



In vector form:

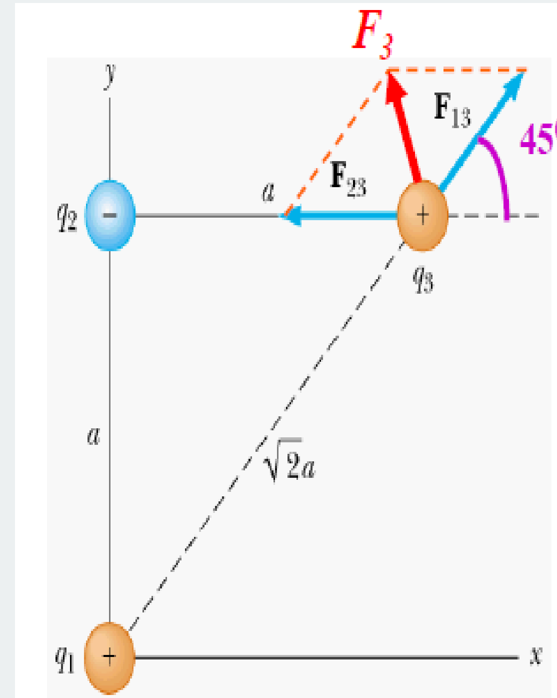
$$\vec{F}_{13} = \left(F_{13}\cos 45^0\ i + F_{13}\sin 45^0\ j\right) N$$
$$= \left(7.9\,i + 7.9\ j\right) N$$

-The magnitude of the force exerted by *q2* on *q3* is

$$F_{23} = k_e \frac{|q_2||q_3|}{a^2}$$

$$= \left(8.99\times10^{9}\,\frac{Nm^2}{C^2}\right)\frac{\left(2.0\times10^{-6}C\right)\left(5.0\times10^{-6}C\right)}{(0.10\ m)^2}$$

$$\vec{F}_{23} = -F_{23}\, i \ = -\ 9.0\, i\ N$$ -In vector form



-*F3* can be expressed in vector form as

$$\vec{F}_3 = \vec{F}_{13} + \vec{F}_{23} = \left(7.9\, i + 7.9\, j\right) N - \ 9.0\, i\ N$$
$$= \left(-1.1\, i + 7.9\, j\right)\ N$$

$$F_3 = \sqrt{F_{3x}^2 + F_{3y}^2}$$
$$= \sqrt{(-1.1N)^2 + (7.9N)^2}$$
$$= 8.0\ N$$

-The magnitude of *F*3 is given by

Electric Field (Medan Listrik)

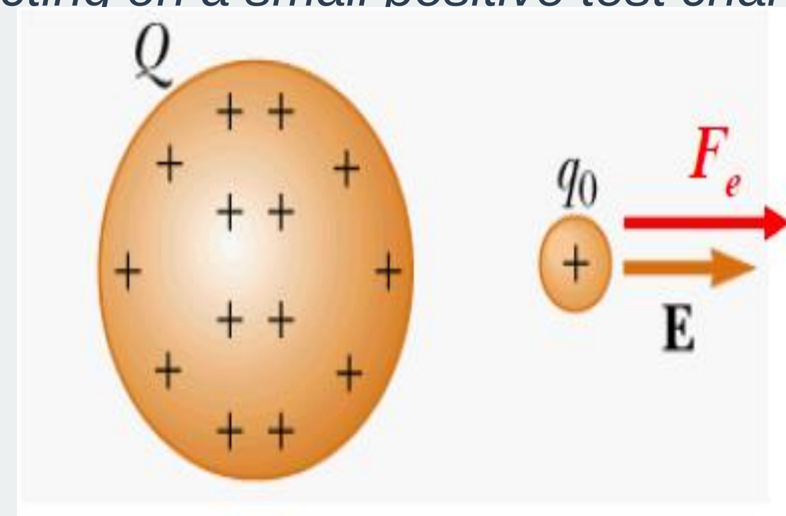
- Electric forces act through space, with no physical contact between the charges. That is to say, there is a field of influence between the charges.
- We can describe this by saying that an *electric field* exists in the region of space around a charged object.
- When a charged particle enters a region with an electric field, an electric force acts on it.
- We quantify the strength of the electric field by defining a physical quantity called the *electric field strength* or the *electric field*.
- *The electric force on a positive charge is in the same direction as E, and that on a negative charge is in opposite direction to E.*

Penting! : jenis muatan (positif atau negatif) sangat penting untuk menentukan arah medan listrik

Electric Field

- The *electric field Eat any point in space is defined as the electric force Fe per unit charge acting on a small positive test charge placed at that point.*

$$\vec{E} = \frac{\vec{F}_e}{q_o} \quad N/C$$

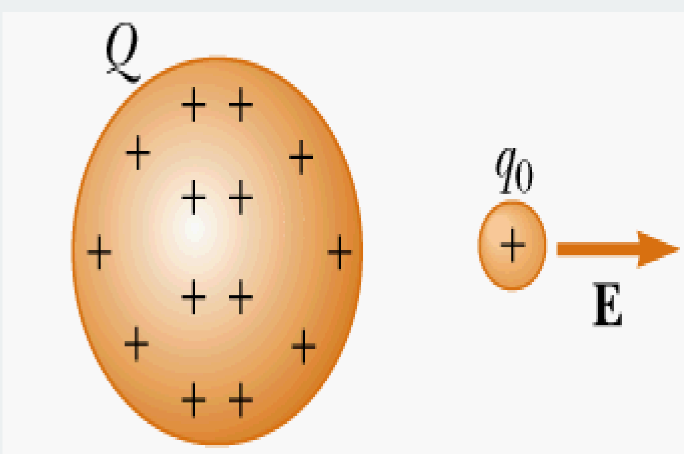


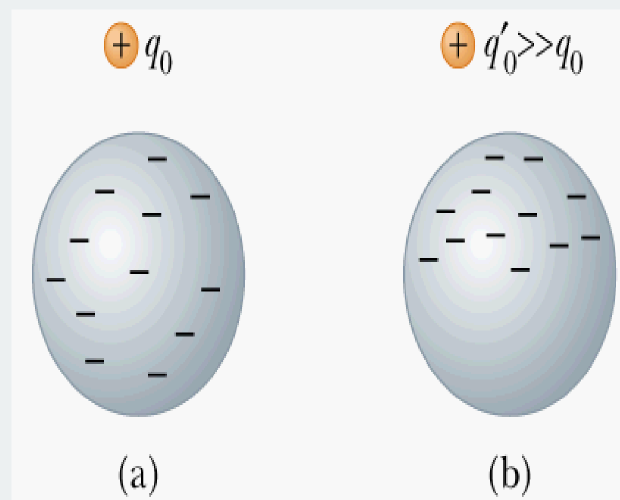
- Electric field *E* is a *vector. Its magnitude is the electric force per unit charge. Its direction is along that of the force acting on a positive charge.*
- The unit of electric field is N/C(or V/m).

Unit = satuan.
Penting! : Satuan dalam fisika sangat penting.

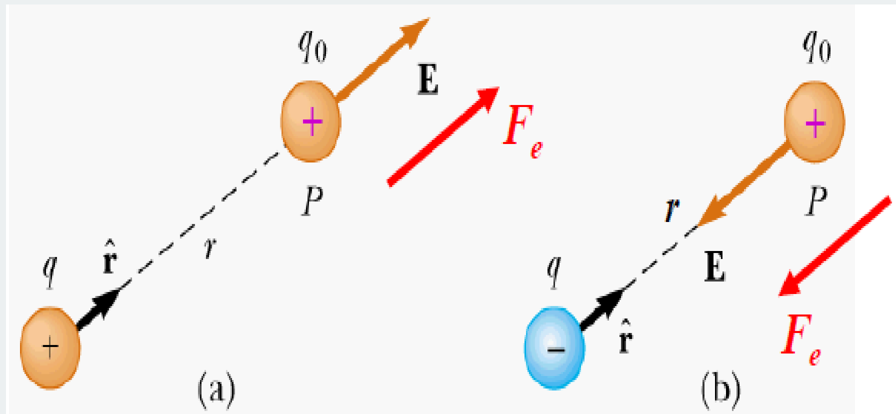
Electric Field

- Since electric field at any point is the *force per unit charge*, it is independent of the charge placed at the point, and is only a property of space and the charges responsible for creating the field.
- The positive test charge q_o must be small enough so that it does not disturb the original charge distribution that sets up the electric field.
- Note : Ini hanya untuk menjelaskan prosedur menghitung E dengan muatan tes, Sebetulnya E bisa dicari dengan rumus.





Electric Field



- Consider a point charge *q*. It sets up an electric field *E* in the region surrounding it. To find *E* at a point *P* at a distance *r* from *q*, consider a small positive test charge *qo* placed at *P*. The force exerted on *qo* by *q* is

- *If q is positive*, *E directs away from q. If q is negative, E directs towards q. In both cases, |E| decreases inversely with r^2. (Arah tergantung jenis muatan)*

$$\vec{F}_e = k_e \frac{q\,q_o}{r^2}\hat{r} \quad ; \quad \vec{E} = \frac{\vec{F}_e}{q_o} = k_e \frac{q}{r^2}\hat{r}$$

Electric Field

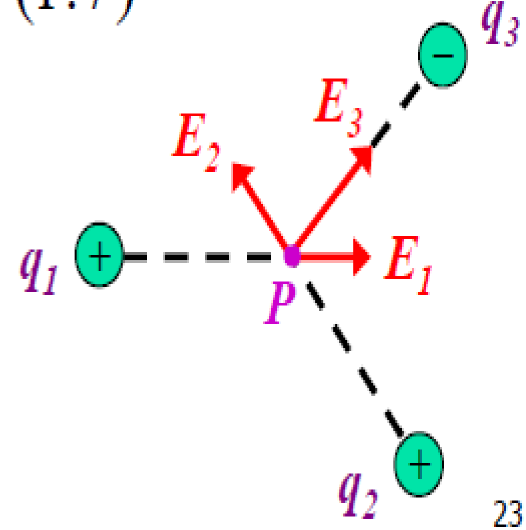
- To find *E* at any point due to a group of point charges, calculate *E* at that point due to each individual charges, then sum them up vectorially to get the resultant *E*, i.e. *a superposition of the individual fields.*

*Note: secara sederhana **superposisi** berarti; menggabungkan berbagai sistem menjadi 1 sistem. Dalam hal ini sistem dari beberapa muatan digabung untuk mendapatkan suatu sistem total (resultan).*

$$\vec{E} = k_e \frac{q_1}{r_1^2}\hat{r}_1 + k_e \frac{q_2}{r_2^2}\hat{r}_2 + k_e \frac{q_3}{r_3^2}\hat{r}_3 + \dots$$

$$= k_e \sum_i \frac{q_i}{r_i^2}\hat{r}_i$$

(1.7)



- Example

A charge $q1 = 7.0\ \mu C$ is located at the origin and a second charge $q2 = -5.0\ \mu C$ is located on the x-axis 0.30 m from the origin. Find the electric field at the point $P(0, 0.40)$ m.

Solution

First, draw arrows to indicate the direction of $E1$ and $E2$.

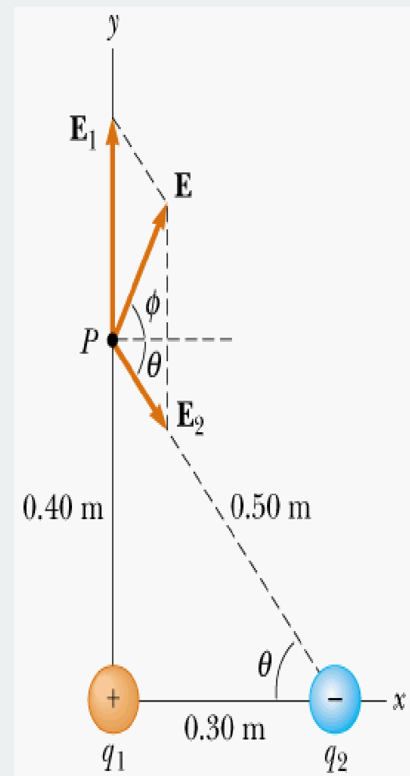
The magnitude of $E1$ due to $q1$ is

$$E_1 = k_e \frac{|q_1|}{r_1^2} = \left(8.99\times10^9 \frac{Nm^2}{C^2}\right)\frac{(7.0\times10^{-6} C)}{(0.40 m)^2}$$

$$= 3.9\times10^5 \quad N/C$$

in vector form

$$\vec{E}_1 = 3.9\times10^5\, j\ N/C$$



- The magnitude of *E2* due to *q2* is

$$E_2 = k_e \frac{|q_2|}{r_2^2} = \left(8.99\times10^9 \frac{N\,m^2}{C^2}\right)\frac{(5.0\times10^{-6}C)}{(0.50\,m)^2}$$
$$= 1.8\times10^5 \quad N/C$$

- In vector form

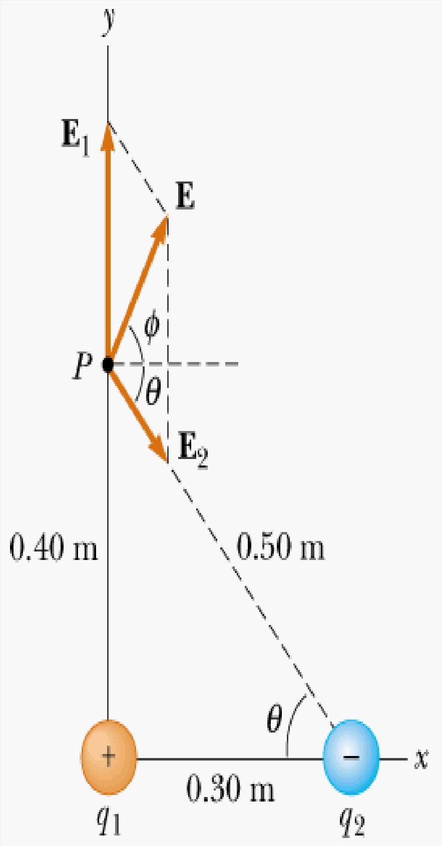
$$\vec{E}_2 = (E_2\cos\theta\, i - E_2\sin\theta\, j)\,N/C$$
$$= (1.1\times10^5\, i - 1.4\times10^5\, j)\,N/C$$

- *The resultant electric field E is the vector sum of E1 and E2*

$$\vec{E} = \vec{E}_1 + \vec{E}_2 = (1.1\times10^5\, i + 2.5\times10^5\, j)\,N/C$$

- Magnitude

$$E = \sqrt{E_x^2 + E_y^2} = \sqrt{(1.1\times10^5)^2 + (2.5\times10^5)^2}\,N/C = 2.7\times10^5\,N/C$$



Penting! : tinjau arah

The direction of *E* is given by ϕ where

$$\tan\phi = \frac{E_y}{E_x} = \frac{2.5\times10^5}{1.1\times10^5} = 2.2727$$
$$\therefore \phi = 66.3^o \text{ wrt } x\text{-axis}$$

Uniform Electric Field

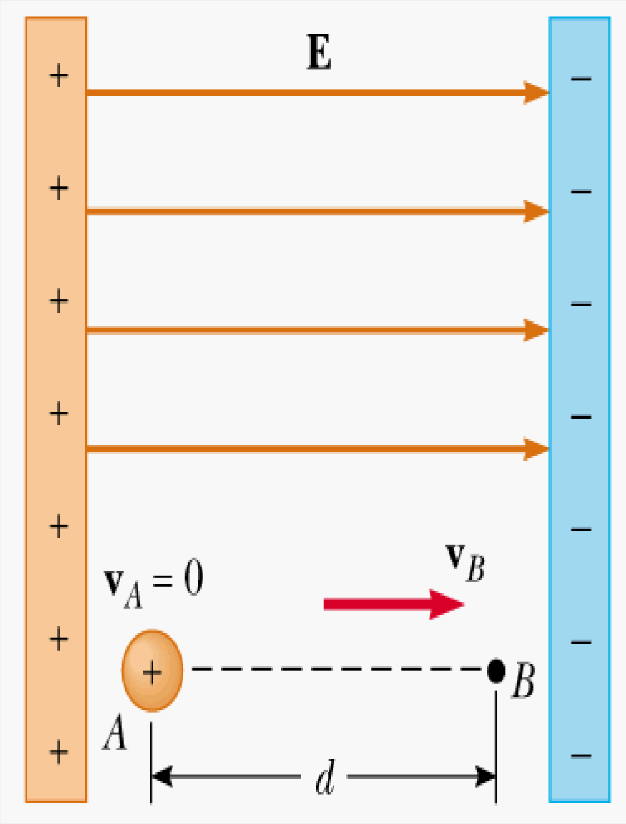
- Consider 2 parallel plates, one is charged positively, the other with negative charges.
- Because the plates are placed very near each other, there will be uniform electric field between the plates, where E is

$$E=V/d$$

V : potential difference between the plates

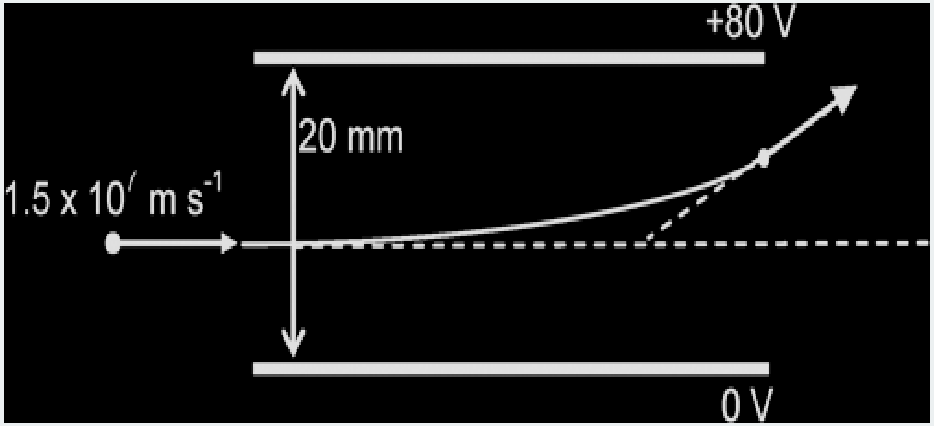
d : the distance between two plates

Note: Sistem ini bukan lagi sistem satu muatan tetapi 2 buah plat bermuatan banyak dan merata di permukaannya. Oleh karena itu sifat medan listriknya berbeda dari sebelumnya



- Example

An electron ($m = 9.11 \times 10^{-31}$ kg; $q = -1.6 \times 10^{-19}$ C) moving with a speed of 1.5×10^{7} ms^{-1}, enters a region between 2 parallel plates, which are 20 mm apart and 60 mm long. The top plate is at a potential of 80 V relative to the lower plate. Determine the angle through which the electron has been deflected as a result of passing through the plates.



Time taken for the electron to travel 60 mm horizontally = Distance / Speed = $60 \times 10^{-3} / 1.5 \times 10^{7} = 4 \times 10^{-9}$ s

$E = V / d = 80 / 20 \times 10^{-3} = 4000$ V m^{-1}

$a = F / m = (e \times E) / m = (1.6 \times 10^{-19} \times 4000) / (9.1 \times 10^{-31}) = 7.0 \times 10^{14}$ ms^{-2}

$v_y = u_y + at = 0 + (7.0 \times 10^{14})(4 \times 10^{-9}) = 2.8 \times 10^{6}$ ms^{-1}

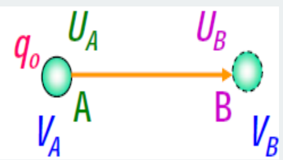
$\tan \theta = v_y / v_x = 2.8 \times 10^{6} / 1.5 \times 10^{7} = 0.187$

Therefore $\theta = 10.6°$

Electric Potential (Potensial listrik)

- Electric potential at a point: is defined as the work done in moving a ***unit positive*** charge from infinity to that point, { a scalar; unit: V } ie V = W / Q
- The electric potential at infinity is defined as zero. At any other point, it may be positive or negative depending on the sign of Q that sets up the field. {Contrast gravitational potential.}
- Relation between E and V: E = - dV / d*r*
- **NB: Electric field lines point in direction of decreasing potential {ie from high to low pot}.**
- **The *electric potential difference*(P.D.)between two points *A* and *B*, *VAB*, is given by**

$$V_{AB} = V_B - V_A = \frac{U_B - U_A}{q_o} = \frac{U_{AB}}{q_o}$$



In other words, the work done W on a charge q in moving it across a potential difference ΔV:

$$W = q\,\Delta V$$

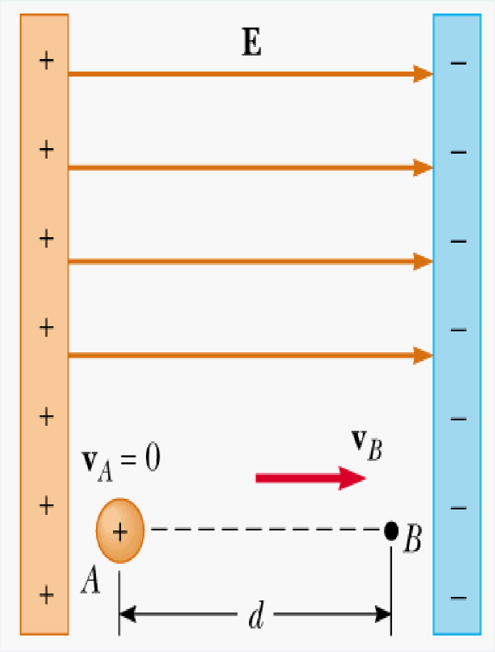
- Electric Potential due to a point charge q :

$$V = \frac{q}{4\pi\varepsilon_o r}$$

Potential Difference between 2 charged plates

- Example 3.1:

A proton is released from rest in a *uniform electric field E* that has a magnitude of 8.0×10^4 V/m and is directed along the +ve *x* axis. If the proton undergoes a displacement of *d*= 0.50 m in the direction of *E*, find (a) the change in electric potential between points *A*and *B*, (b) the change in potential energy of the proton, and (c) the speed of the proton at point *B*, given that it has a mass of 1.67 x 10-27 kg.



Note: +ve x axis berarti arah positif sumbu x

Solution

(a) $V=-Ed = -(8.0 \times 10^4 \text{ V/m})*(0.5 \text{ m})= -4.0 \times 10^4$

$V_{AB}= V_B-V_A< 0$ is expected since *E* is directed from *A*to *B*.

(b) $\Delta U = q\, \Delta V$

$\Delta U = (1.6 \times 10^{-19})(-4.0\times10^4) = -6.4 \times 10^{-15}$

The –ve sign means the proton loses electric potential energy.

As it accelerates in the direction of the field, it gains kinetic energy

at the expense of potential energy.

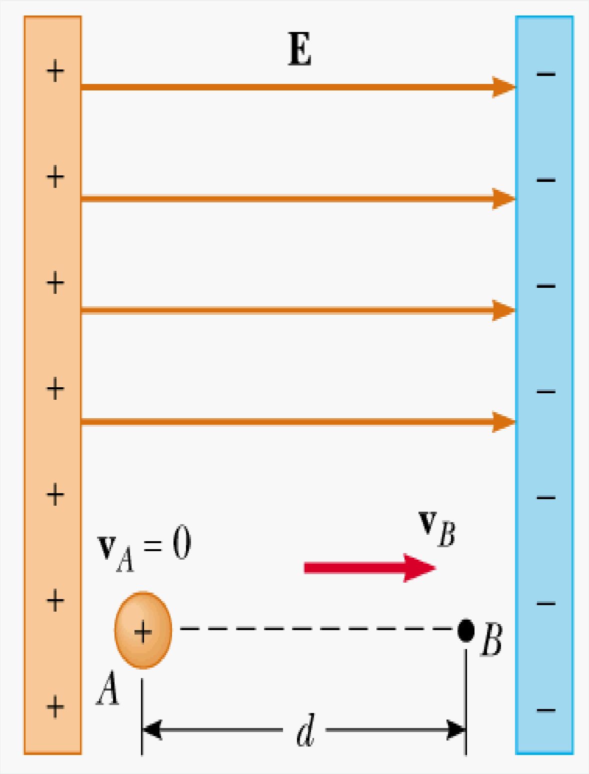
- (c) Let the speed gained at point *B* be v. From the conservation of energy,

$$\frac{1}{2}mv^2 = -\Delta U$$

$$v = \sqrt{\frac{2(-\Delta U)}{m}}$$

$$= \sqrt{\frac{2\left(6.4\times 10^{-15}\,J\right)}{1.67\times 10^{-27}\,kg}}$$

$$\therefore v = 2.77\times 10^{6}\ \text{m/s}$$



CURRENT OF ELECTRICITY

Content

- Electric current
- Potential difference
- Resistance and resistivity
- Sources of electromotive force

Current of Electricity

- Electric current is the rate of **flow** of *charge*. {NOT: charged particles}
- Electric charge Q passing a point is defined as the product of the (steady) current at that point and the time for which the current flows,
- $Q = I t$
- One coulomb is defined as the charge flowing per *second* pass a point at which the current is *one ampere*.

Example:
An ion beam of singly-charged Na^+ and K^+ ions is passing through vacuum. If the beam current is 20 μ A, calculate the total number of ions passing any fixed point in the beam per second. (The charge on each ion is 1.6×10^{-19} C.)

- Current, $I = Q / t = Ne / t$ where N is the no. of ions and e is the charge on one ion.
- No. of ions per second $= N / t = I / e = (20 \times 10^{-6}) / (1.6 \times 10^{-19}) = 1.25 \times 10^{-14}$ ions/s

Potential Difference

- Potential difference is defined as the energy transferred from electrical energy to other forms of energy when unit charge passes through an electrical device,
- V = W / Q
- P. D. = Energy Transferred / Charge = Power / Current or, is the ratio of the power supplied to the device to the current flowing,
- V = P / I
- The volt: is defined as the potential difference between 2 pts in a circuit in which one joule of energy is converted from electrical to non-electrical energy when one coulomb passes from 1 pt to the other, ie 1 volt = One joule per coulomb

Difference between Potential and Potential Difference (PD)

- The potential at a point of the circuit is due to the amount of charge present along with the energy of the charges. Thus, the potential along circuit drops from the positive terminal to negative terminal, and potential differs from points to points.

- Potential Difference refers to the difference in potential between any given two points. For example, if the potential of point A is 1 V and the potential at point B is 5 V, the PD across AB, or V_{AB} , is 4 V. In addition, when there is no energy loss between two points of the circuit, the potential of these points is same and thus the PD across is 0 V.

Example:

A current of 5 mA passes through a bulb for 1 minute. The potential difference across the bulb is 4 V. Calculate:

(a) The amount of charge passing through the bulb in 1 minute.

Charge Q = I t = 5 x 10^{-3} x 60 = 0.3 C

(b) The work done to operate the bulb for 1 minute.

Potential difference across the bulb = W / Q

4 = W / 0.3

Work done to operate the bulb for 1 minute = 0.3 x 4 = 1.2 J

Electrical Power, P = V I = I^2 / R = V^2 / R

{**Brightness** of a lamp is determined by the power dissipated, NOT: by V, or I or R alone}

Example:

A high-voltage transmission line with a resistance of 0.4 Ω km^{-1} carries a current of 500 A. The line is at a potential of 1200 kV at the power station and carries the current to a city located 160 km from the power station. Calculate

(a) the power loss in the line.

The power loss in the line P = I^2 R = 500^2 x 0.4 x 160 = 16 MW

(b) the fraction of the transmitted power that is lost.

The total power transmitted = I V = 500 x 1200 x 10^3 = 600 MW

The fraction of power loss = 16 / 600 = 0.267

Resistance and Resistivity

Resistance is defined as the *ratio* of the potential difference across a component to the current flowing through it ,

R = VI

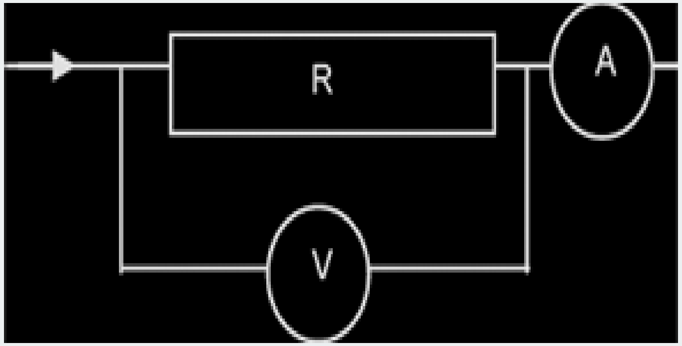
{It is **NOT** ***defined*** as the gradient of a V-I graph; however for an **ohmic** conductor, its resistance *equals* the gradient of its V-I graph as this graph is a straight line which passes through the origin}

The Ohm: is the resistance of a resistor if there is a current of 1 A flowing through it when the pd across it is 1 V, ie,

1 Ω = One volt per ampere

Example 4:

In the circuit below, the voltmeter reading is 8.00 V and the ammeter reading is 2.00 A. Calculate the resistance of R.



Resistance of R = V / I = 8 / 2 = 4.0 Ω

Resistance and Resistivity

Ohm's law: The current in a component is proportional to the potential difference across it provided physical conditions (eg temp) stay constant.

$R = \rho L / A$ {for a conductor of length l, uniform x-sect area A and resistivity ρ}

Resistivity (ρ) is defined as the resistance of a material of unit cross-sectional area and unit length. {From $R = \rho l / A$, $\rho = RA / L$}

Example 5:
Calculate the resistance of a nichrome wire of length 500 mm and diameter 1.0 mm, given that the resistivity of nichrome is $1.1 \times 10^{-6}\ \Omega$ m.
Resistance, $R = \rho l / A = [(1.1 \times 10^{-6})(500 \times 10^{-3})] / \pi(1 \times 10^{-3} / 2)^2 = 0.70\ \Omega$

Penting!: Perlu diingat bahwa Resistence berbeda dengan Resistivitas satuan Resistence adalah Ω, sedangkan Resistivity Ω.m

Sources of electromotive force

Electromotive force (Emf) is defined as the energy transferred / converted from non-electrical forms of energy into electrical energy when unit charge is moved round a complete circuit. ie EMF = Energy Transferred per unit charge

$$E = W/Q$$

EMF refers to the electrical energy generated from non-electrical energy forms, whereas PD refers to electrical energy being changed into non-electrical energy. For example,

EMF Sources	Energy Change	PD across	Energy Change
Chemical Cell	Chem → Elec	Bulb	Elec → Light
Generator	Mech → Elec	Fan	Elec → Mech
Thermocouple	Thermal → Elec	Door Bell	Elec → Sound
Solar Cell	Solar → Elec	Heating element	Elec → Thermal

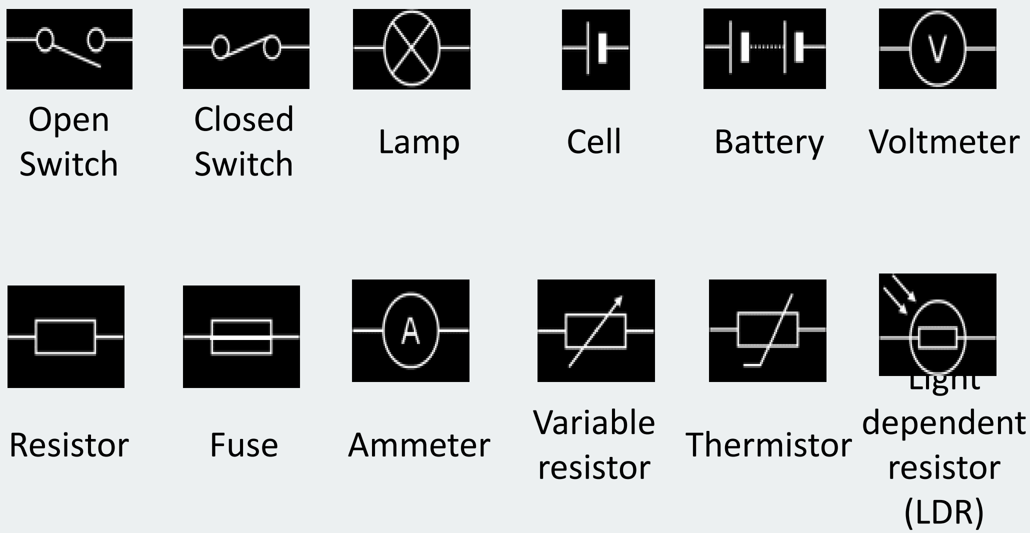
DC CIRCUIT

Content

- **Practical circuits**
- **Series and parallel arrangements**
- **Potential divider**
- **Balanced potentials**

DC Circuit

- Circuit Symbols



DC Circuit

Series and parallel arrangements

- Series Arrangments
- If you have more than one resistor in a circuit it is often useful to be able to calculate the total resistance of the combination
- The current flowing through each resistor will be the same as they are connected in series, but the energy used per coulomb (for instance, pd) will depend on the value of each resistance.

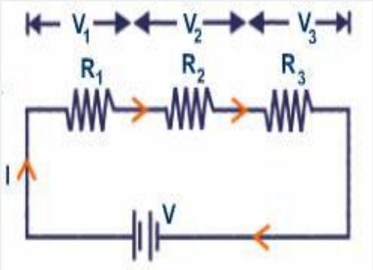
$$V_T = V_1 + V_2 + V_3$$

- But V = I R

$$IR_T = IR_1 + IR_2 + IR_3$$

- Cancel the Is

$$R_T = R_1 + R_2 + R_3$$



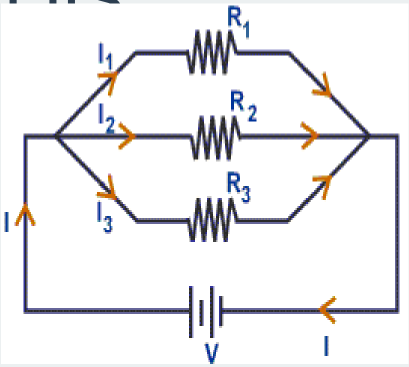
DC Circuit

Series and parallel arrangements

- Parallel Arrangements
- Here the potential difference across all three routes will be the same, but the current through each route depends on its resistance.

$$I_T = I_1 + I_2 + I_3$$

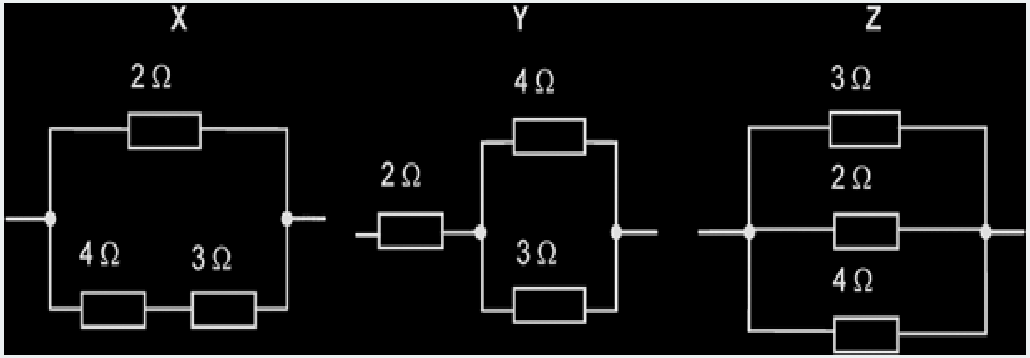
$$\frac{V}{R_T} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$



- Where V is the potential difference across each of the resistors.

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Example:
Three resistors of resistance 2 Ω, 3 Ω and 4 Ω respectively are used to make the combinations X, Y and Z shown in the diagrams. List the combinations in order of increasing resistance.



Resistance for X = $[1/2 + 1/(4+3)]^{-1}$ = 1.56 Ω
Resistance for Y = $2 + (1/4 + 1/3)^{-1}$ = 3.71 Ω
Resistance for Z = $(1/3 + 1/2 + 1/4)^{-1}$ = 0.923 Ω
Therefore, the combination of resistors in order of increasing resistance is Z X Y

Example:

A battery with an EMF of 20 V and an internal resistance of 2.0 Ω is connected to resistors R_1 and R_2 as shown in the diagram. A total current of 4.0 A is supplied by the battery and R_2 has a resistance of 12 Ω. Calculate the resistance of R_1 and the power supplied to each circuit component.

$E - I\,r = I_2\,R_2$

$20 – 4\,(2) = I_2\,(12)$

$I_2 = 1A$

Therefore, $I_1 = 4 – 1 = 3\ A$

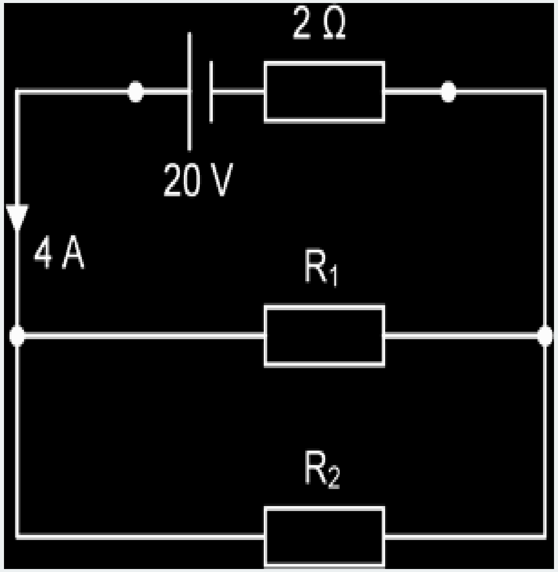
$E – I\,r = I_1\,R_1$

$12 = 3\,R_1$

Therefore, $R_1 = 4$

Power supplied to $R_1 = (I_1)^2\,R_1 = 36\ W$

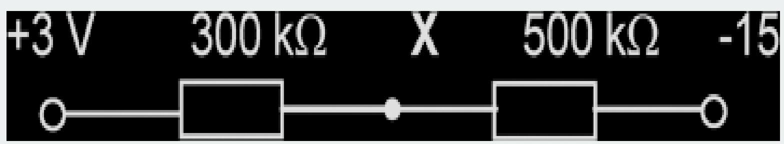
Power supplied to $R_2 = (I_2)^2\,R_2 = 12\ W$



DC Circuit (Potential Divider)

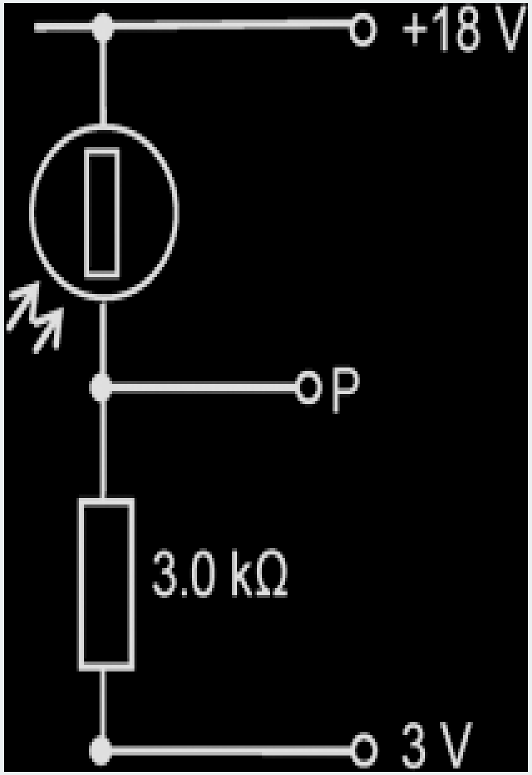
Two resistors divide up the potential difference supplied to them from a cell. The proportion of the available potential difference that the two resistors get depends on there resistance values. Potential drop across R_1,
$V1 = R_1 / (R_1 + R_2) \times V$ across R_1 & R_2
Potential drop across R_2, **$V1 = R_2 / (R_1 + R_2) \times V$** across R_1 & R_2

Example:
Two resistors, of resistance 300 kΩ and 500 kΩ respectively, form a potential divider with outer junctions maintained at potentials of +3 V and -15 V.



Determine the potential at the junction **X** between the resistors.
The potential difference across the 300 kΩ resistor = 300 / (300 + 500) [3 - (-15)] = 6.75 V
The potential at X = 3 - 6.75 = -3.75 V

- **Example:**
  In the figure below, the resistance of the LDR is 6.0 MΩ in the dark but then drops to 2.0 kΩ in the light. Determine the potential at point P when the LDR is in the light.



In the light the potential difference across the LDR

- = [2k / (3k + 2k)] x (18 - 3)
  = 6 V
- The potential at P = 18 – 6= 12 V

The potential difference along the wire is proportional to the length of the wire. The sliding contact will move along wire AB until it finds a point along the wire such that the galvanometer shows a zero reading.

When the galvanometer shows a zero reading, the current through the galvanometer (and the device that is being tested) is zero and the potentiometer is said to be “balanced”.

If the cell has negligible internal resistance, and if the potentiometer is balanced,
EMF/Potential Difference of the unknown source, **Vn = [L1 / (L1 + L2)] x V**

Example:

In the circuit shown, the potentiometer wire has a resistance of 60 Ω. Determine the EMF of the unknown cell if the balanced point is at B.

Resistance of wire AB

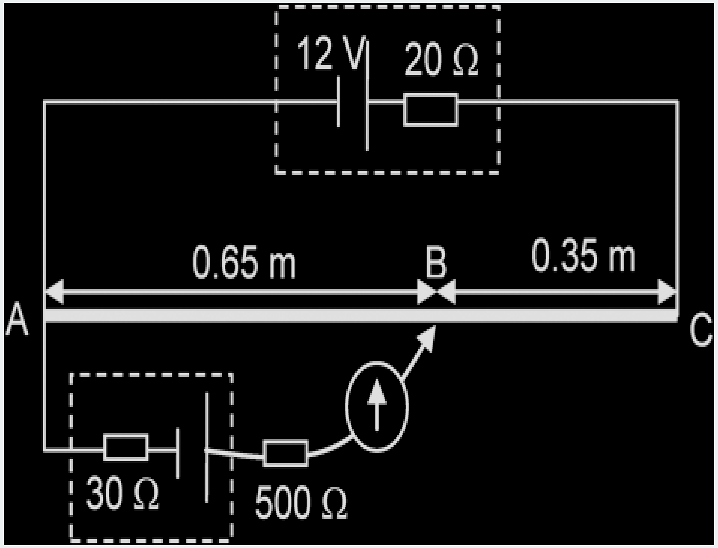
$= [0.65 / (0.65 + 0.35)] \times 60$

$= 39\ \Omega$

EMF of the test cell

$= [39 / (60 + 20)] \times 12$

$= 5.85\ V$



Catatan: EMF (gaya gerak listrik) sama seperti beda potensial (satuannya volt). *Potentiometer wire* adalah sebuah alat yang bisa diukur voltasenya sepanjang *wire*.

ELECTROMAGNETISM

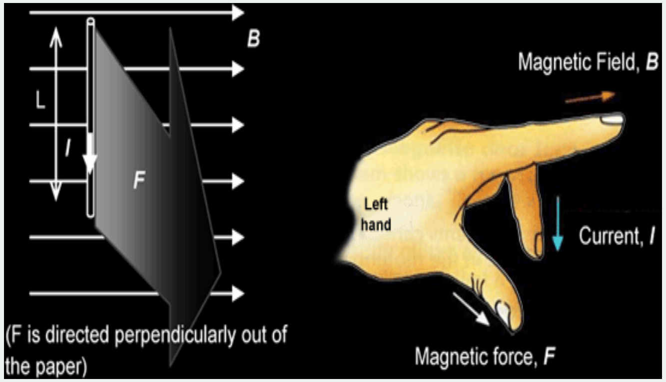
Content

- Force on a current-carrying conductor
- Force on a moving charge
- Magnetic fields due to currents
- Force between current-carrying conductors

Electromagnetism

Force on a current-carrying conductor

When a conductor carrying a current is placed in a magnetic field, it experiences a magnetic force.



The figure above shows a wire of length L carrying a current I and lying in a magnetic field of flux density B. Suppose the angle between the current I and the field B is ϑ , the <u>magnitude</u> of the force F on the conductor is given by

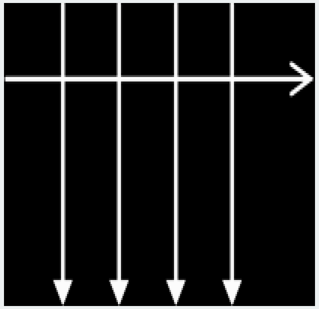
$$F = BIL\sin\theta$$

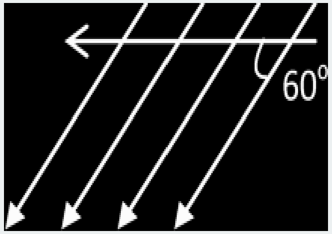
The <u>direction</u> of the force can be found using **Fleming‟s Left Hand Rule** (see figure above). Note that the force is always perpendicular to the *plane* containing both the current I and the magnetic field B.

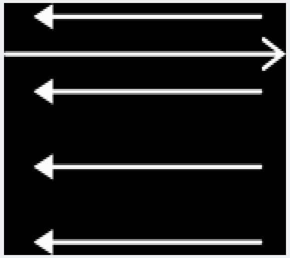
•If the wire is parallel to the field lines, then $\theta = 0°$, and $F = 0$. (No magnetic force acts on the wire)

•If the wire is at right angles to the field lines, then $\theta = 90°$, and the magnetic force acting on the wire would be
maximum ($F = BIL$)

- Example
  The 3 diagrams below each show a magnetic field of flux density 2 T that lies in the plane of the page. In each case, a current I of 10 A is directed as shown. Use Fleming's Left Hand Rule to predict the directions of the forces and work out the magnitude of the forces on a 0.5 m length of wire that carries the current. (Assume the horizontal is the current)







F = BIL sinθ = 2 x 10 x 0.5 x sin90 = 10 N

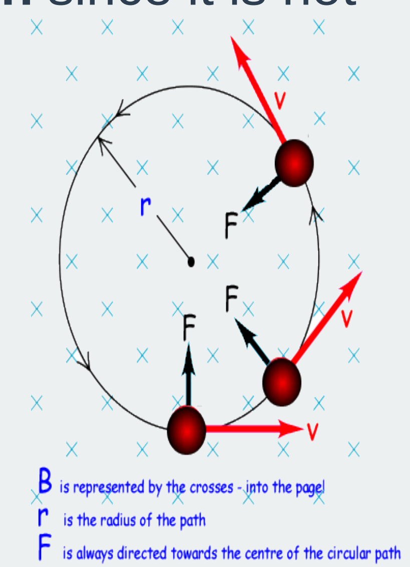
F = BIL sinθ = 2 x 10 x 0.5 x sin60 = 8.66 N

F = BIL sin θ = 2 x 10 x 0.5 x sin180 = 0 N

Electromagnetism

<u>Force on a moving charge</u>

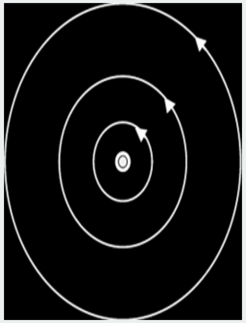
- Force acting on a moving charge: F = B Q v sin θ {θ: Angle between B and v.}
- The <u>direction</u> of this force may be found by using Fleming's left hand rule.
  The angle θ determines the type of path the charged particle will take when moving through a uniform magnetic field:
- If **θ = 0°**, the charged particle takes a **straight path** since it is not deflected (F = 0)
- If **θ = 90°**, the charged particle takes a **circular path** since the force at every point in the path is perpendicular to the motion of the charged particle.
- Since F is <u>always</u> be <u>perpendicular</u> to v {even if θ ≠0},
  the magnetic force can provide the centripetal force, → $Bqv = mv^2 / r$



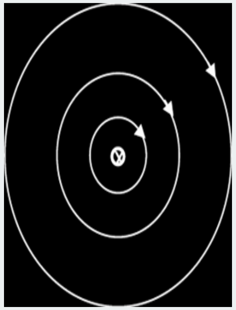
BBMerlion

Electromagnetism

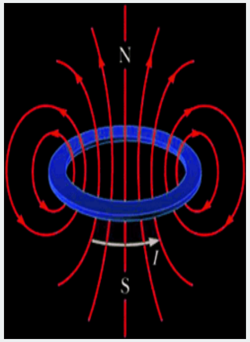
Magnetic Field due to current



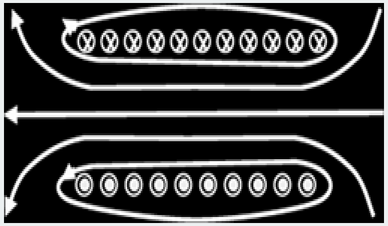
LONG STRAIGHT WIRE
(current goes out of the paper)
B = μI/2πr



LONG STRAIGHT WIRE
(current goes into the paper)
B= μI/2πr



FLAT CIRCULAR COIL
At the center, B=μI/2R

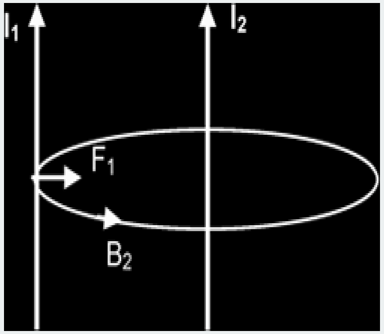


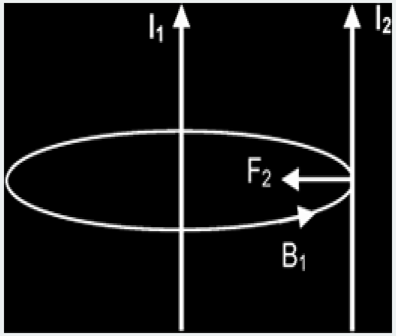
SOLENOID
B=μIn
n:turns of coil/the length

Electromagnetism

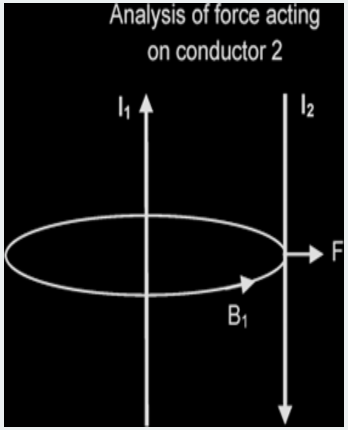
Force between current-carrying conductors

CURRENTS FLOWING IN SAME DIRECTION





CURRENTS FLOWING IN OPPOSITE DIRECTIONS



ELECTROMAGNETIC INDUCTION

Content

- **Magnetic flux**
- **Laws of electromagnetic induction**

Electromagnetic Induction

Magnetic flux

Magnetic Flux is defined as the product of the magnetic flux density (B) and the area *normal* to the field through which the field is passing. It is a scalar quantity and its S.I. unit is the weber (Wb).

$$\phi = B\,A$$

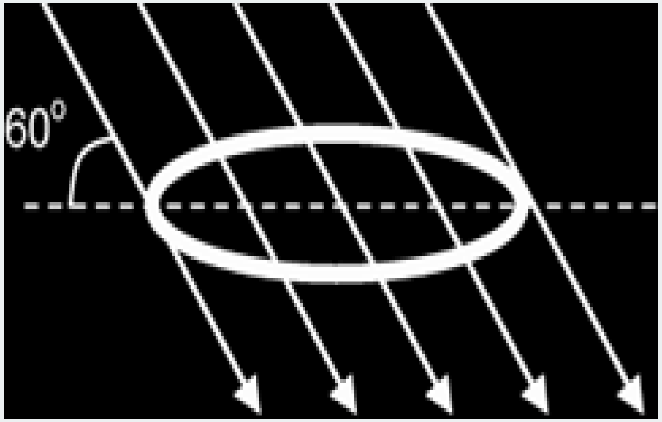
The Weber is defined as the magnetic flux if a flux density of one tesla passes perpendicularly through an area of one square metre.

Magnetic Flux Linkage is the product of the magnetic flux passing through a coil and the number of turns of the coil.

$$\Phi = N\,\phi = N\,B\,A$$

Penting!: *magnetic flux linkage* pada dasarnya adalah total flux yang melewati selonoid, diketahui selonoid terdiri dari koil-koil

- Example:
  A magnetic field of flux density 20 T passes down through a coil of of wire, making an angle of 60° to the plane of the coil as shown. The coil has 500 turns and an area of 25 cm^2. Determine:
- (i) the magnetic flux through the coil
  $\varphi = B\ A$
  $= 20\ (\sin 60°)\ 25 \times 10^{-4}$
  $= 0.0433$ Wb
- (ii) the flux linkage through the coil
  $\Phi = N\ \varphi$
  $= 500 \times 0.0433 = 21.65$ Wb



Electromagnetic Induction

Laws of electromagnetic induction

- Faraday's Law
  The magnitude of *induced* EMF is directly proportional/equal to the rate of change of *magnetic flux-linkage*.

  $$|E| = dNBA / dt$$

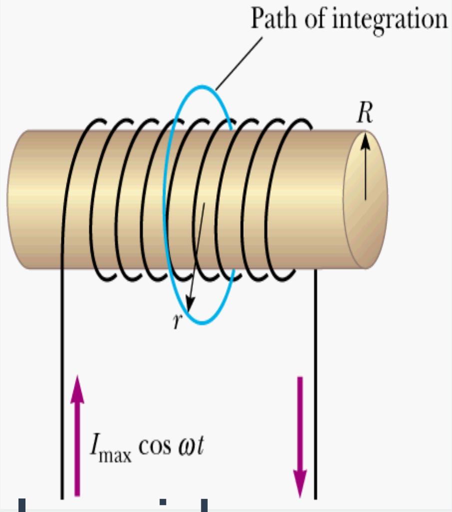
- Lenz's Law:
  The direction of the induced EMF is such that *its effects* oppose the change which causes it, or The induced current in a closed loop must flow in such a direction that its effects opposes the flux change {or change} that produces it

- Example
  A long solenoid of radius *R* has *n* turns of wire per unit length and carries a time-varying current *I* = *Imax cos ω t*. Determine the magnitude of the induced emf at a distance *r* outside the solenoid.

Solution

$$\frac{d\Phi_B}{dt} = \frac{d}{dt}\left(B\pi R^2\right) = \pi R^2 \frac{dB}{dt}$$

emf =



From the formula of B from solenoid

$$B = \mu_o n I = \mu_o n I_{\max} \cos \omega t \Rightarrow \frac{dB}{dt} = -\mu_o n \omega I_{\max} \sin \omega t$$

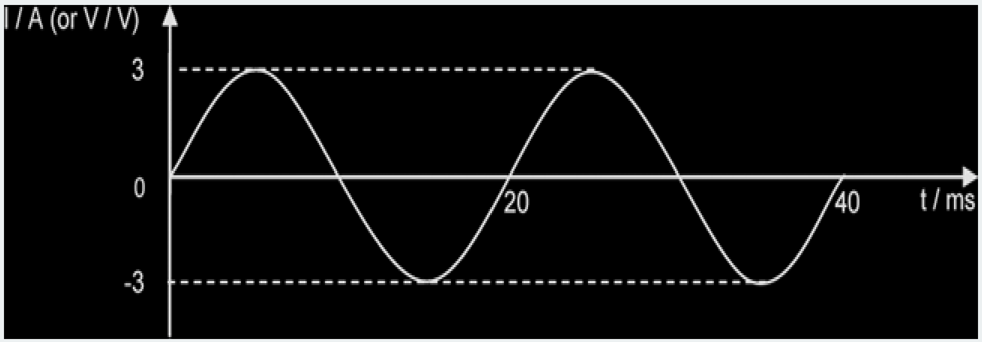
ALTERNATING CURRENTS

Content

- **Characteristics of alternating currents**
- **The transformer**
- **Rectification with a diode**

Alternating Currents

characteristics of AC



Peak current, I_0 = 3 A

Peak-to-peak current, I_{p-p} = 6 A

Period, T = 20 ms

Period, T = 20 ms

Angular Frequency, ω = 2 π f = 314 ra

Instantaneous current: the current at a particular instant.
Since this A.C. signal can be described by the equation:

I = I0 sin (ω t)

or V = V0 sin (ω t)

the instantaneous current I or voltage V at time t is given by $I_0 \sin(\omega t)$ or $V_0 \sin(\omega t)$.

Note: Both the period and amplitude of a sinusoidal A.C should be **constant**.

Alternating Currents

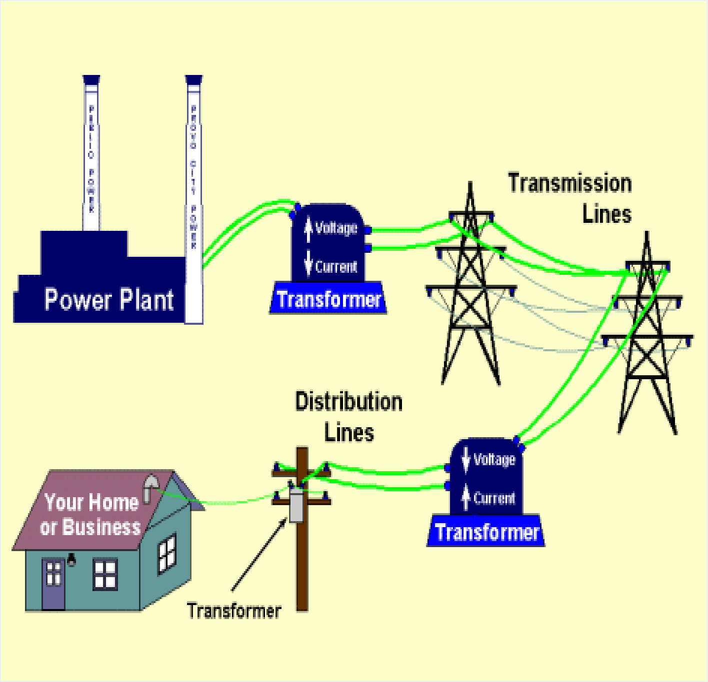
characteristics of AC

- Root-mean-square current of an alternating current is defined as that steady {NOT *direct*} current that produces the same heating effect {ie $I^2 R$} as the alternating current in a given resistor.
- (Instantaneous) sinusoidal current: $I = I_0 \sin\omega t$, { Similarly, $V = V_0 \sin\omega t$ }
- $I_{rms} = I_o / \sqrt{2}$, $V_{rms} = v_o / \sqrt{2}$, {for **sinusoidal** ac only}
- Relationship between Peak, & RMS values of PD & Current: $V_0 = I_0 R$, $V_{rms} = I_{rms} R$
- **Mean/Ave Power, $P_{ave} = I_{rms}^2 R = V_{rms}^2 / R = I_{rms} / V_{rms}$** = ½ x Maximum Instantaneous Power = **½ $I_0 V_0$** {for sinusoidal AC}
- Max (Instantaneous) Power, $P_{max} = I_0 V_0 = I_0^2 R$
- The **root-mean-square** (R.M.S.) value, I_{rms}, of an A.C. is the magnitude of the direct current that produces the same **average** heating effect as the alternating current in a given resistance whereas peak value is the maximum current of an AC.

Alternating Currents

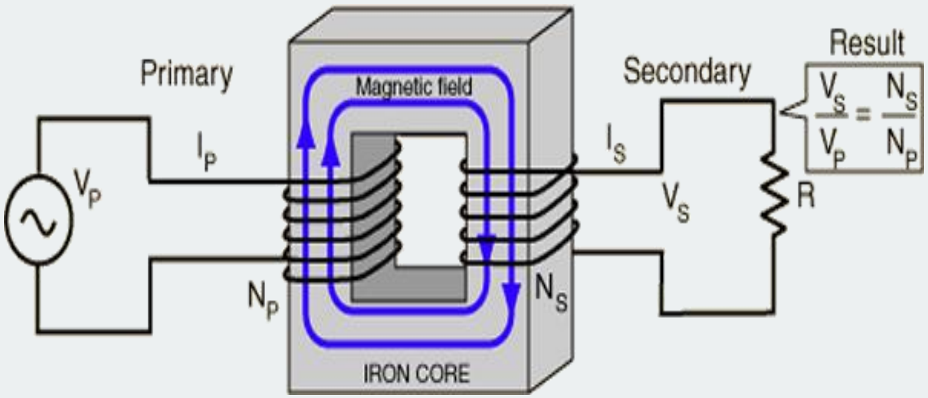
Transformers

- So we can produce a varying current and voltage with a generator. Big deal, why would we want to? We can nearly as simply generate a direct current.
- The key to this is in electricity transmission. If we can keep moving electric currents low in overhead power lines then we can reduce resistance, heat generation and thus heat losses.
- In order for this to happen and for us to be able to transmit large quantities of power over long distances we must be able to generate large voltages. (Remember P=VI).
- We are able to do this using AC transformers...
- A transformer is a device for increasing (steping up) and decreasing (stepping down) voltages.



Alternating Currents

Transformers



Ideal transformer: $V_p I_p = V_s I_s \rightarrow N_S / N_P = V_S / V_P = I_P / I_S$

{Mean power in the primary coil = Mean power in the secondary coil)

{Values of I & V may be either R.M.S. or peak but not instantaneous values; N_S / N_P: turns ratio}

Alternating Current

Rectification with a diode

- If a single diode is connected to an A.C. circuit as shown, a **half-wave rectification** occurs.

- The graphs for the input and output voltages, and the output current, are shown beside.

- In the regions A and C, the diode is forward biased, allowing current to flow. When the input voltage becomes negative, the diode prevents the current flow, because it is reverse biased.