Induction of Electromotive (GGL Induksi)

NURRISMA PUSPITASARI

QR CODE PERTEMUAN 25: 268855

POKOK BAHASAN

- **Faraday's Law**
- **Lenz's Law**
- **Motional Electromotive *(emf)***
- **Dynamo Faraday**
- **How to find the direction of Induced current**
- **Aplication of *emf* induction**
- **Inductance**

Michael Faraday
British Physicist and Chemist
(1791–1867)

Faraday is often regarded as the greatest experimental scientist of the 1800s. His many contributions to the study of electricity include the invention of the electric motor, electric generator, and transformer, as well as the discovery of electromagnetic induction and the laws of electrolysis. Greatly influenced by religion, he refused to work on the development of poison gas for the British military.

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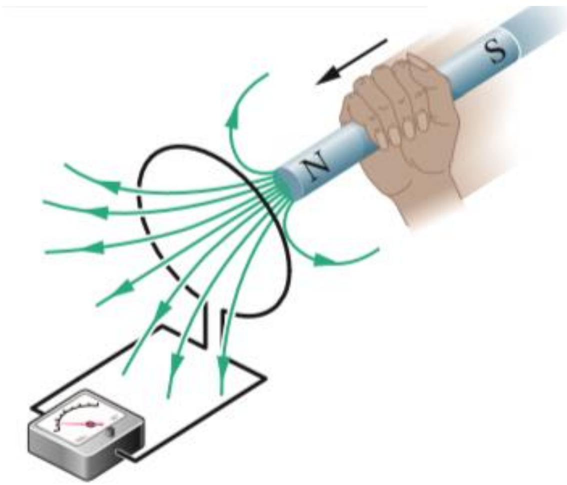
Faraday's Law

Two simple experiments to prepare for our discussion of Faraday's law of induction.

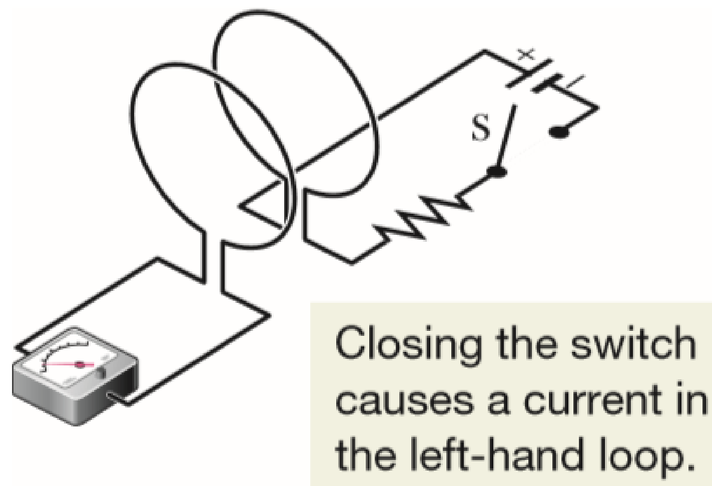
First Experiment



An ammeter registers a current in the wire loop when the magnet is moving with respect to the loop

https://www.youtube.com/watch?v=3HyORmBip-w

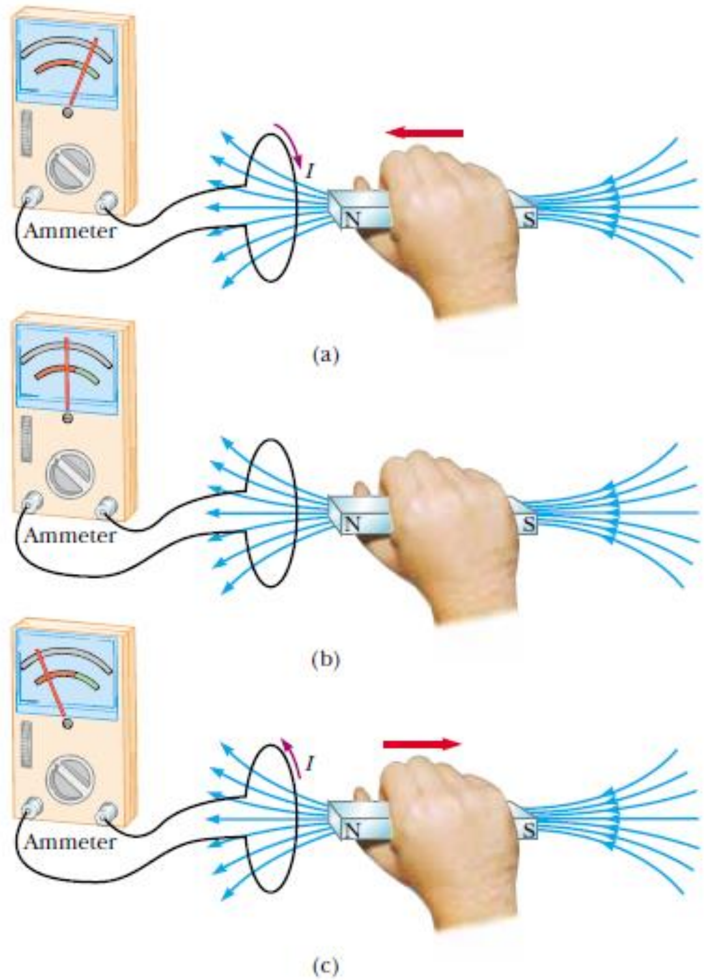
Second Experiment



An ammeter registers a current in the left-hand wire loop just as switch S is closed (to turn on the current in the right-hand wire loop) or opened (to turn off the current in the right-hand loop). No motion of the coils is involved.

First Experiment

How an emf can be Induced by a Changing Magnetic Field



(a) When a magnet is moved toward a loop of wire connected to a sensitive ammeter, the ammeter deflects as shown, indicating that a current is induced in the loop.

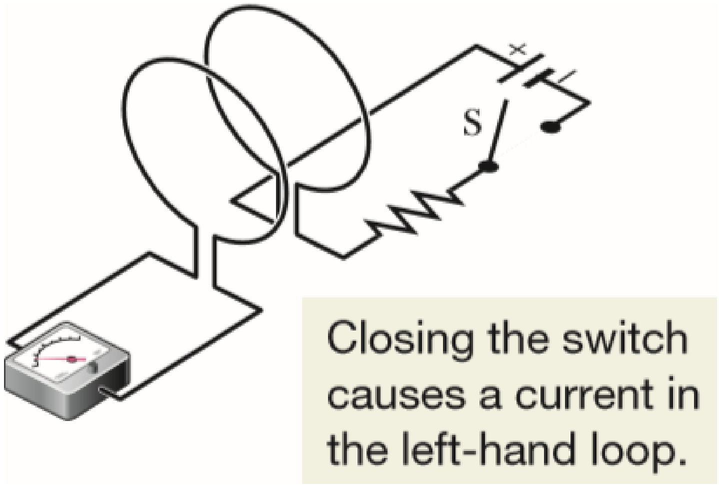
(b) When the magnet is held stationary, there is no induced current in the loop, even when the magnet is inside the loop.

(c) When the magnet is moved away from the loop, the ammeter deflects in the opposite direction, indicating that the induced current is opposite that shown in part (a).

Changing the direction of the magnet's motion changes the direction of the current induced by that motion.

Second Experiment

The two conducting loops close to each other but not touching



- If we close switch S, to turn on a current in the right-hand loop, the meter suddenly and briefly registers a current—an induced current—in the left-hand loop.
- If we then open the switch, another sudden and brief induced current appears in the left-hand loop, but in the opposite direction. We get an induced current (and thus an induced emf) only when the current in the right-hand loop is changing (either turning on or turning off) and not when it is constant (even if it is large).

Faraday's Law. With the notion of magnetic flux, we can state Faraday's law in a more quantitative and useful way:

The magnitude of the emf $\mathcal{E}$ induced in a conducting loop is equal to the rate at which the magnetic flux Φ through that loop changes with time

$$\varepsilon = -N\,\frac{d\Phi}{dt} \qquad \text{where} \qquad \Phi = B \cdot A$$

$$\varepsilon = -N\,\frac{d(B.A)}{dt}$$

$$\varepsilon = -NA\,\frac{d(B)}{dt}$$

$$\varepsilon = -NB\,\frac{d(A)}{dt}$$

$$\frac{d\Phi}{dt} = \text{kecepatan perubahan fluks}$$

The minus sign (-) indicating that opposition

Lenz's Law

Soon after Faraday proposed his law of induction, Heinrich Friedrich Lenz devised a **rule for determining the direction of an induced current in a loop**

In Lenz's words:
"The direction of any magnetic induction effect is such as to oppose the cause of the effect"
In other words:
"the induced magnetic field will oppose the effect that caused it in the first place", or: " the induced magnetic field will oppose the change".

Remember
The induced magnetic field opposed the CHANGE in the magnetic field that caused it in the first place.

1. If the magnetic flux because of External Field ($\Phi_{\boldsymbol{B}_{ext}}$) is **INCREASING**, then the induced magnetic field ($\boldsymbol{B}_{ind}$) and the external field ($\boldsymbol{B}_{ext}$) will be in the **OPPOSITE** direction.
2. If the magnetic flux because of External Field ($\Phi_{\boldsymbol{B}_{ext}}$) is **DECREASING**, then the induced magnetic field ($\boldsymbol{B}_{ind}$) and the external field ($\boldsymbol{B}_{ext}$) will be in the **SAME** direction.

Increasing the external field $\vec{B}$ induces a current with a field $\vec{B}_{ind}$ that *opposes the change.*

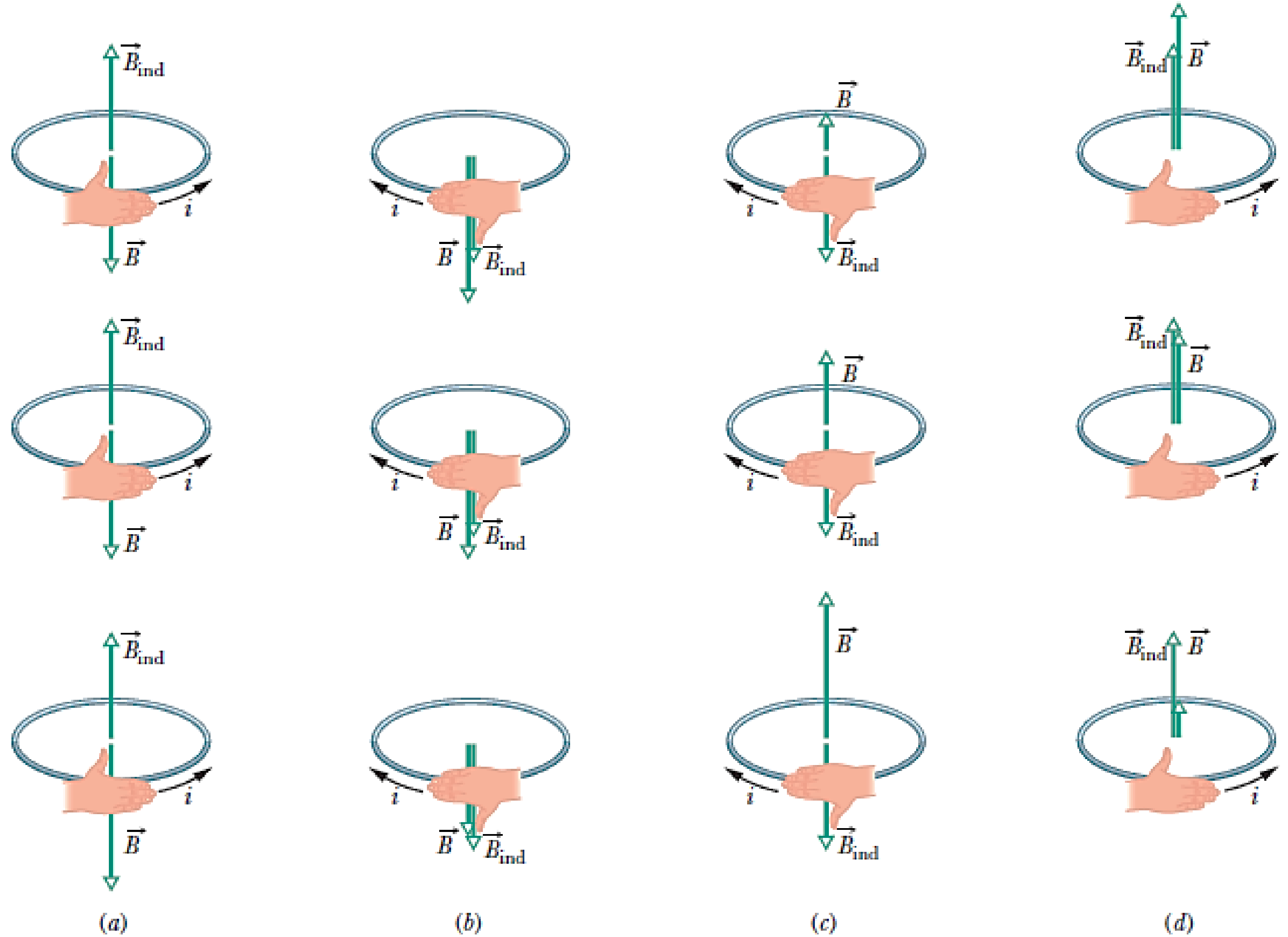
Decreasing the external field $\vec{B}$ induces a current with a field $\vec{B}_{ind}$ that *opposes the change.*

Increasing the external field $\vec{B}$ induces a current with a field $\vec{B}_{ind}$ that *opposes the change.*

Decreasing the external field $\vec{B}$ induces a current with a field $\vec{B}_{ind}$ that *opposes the change.*

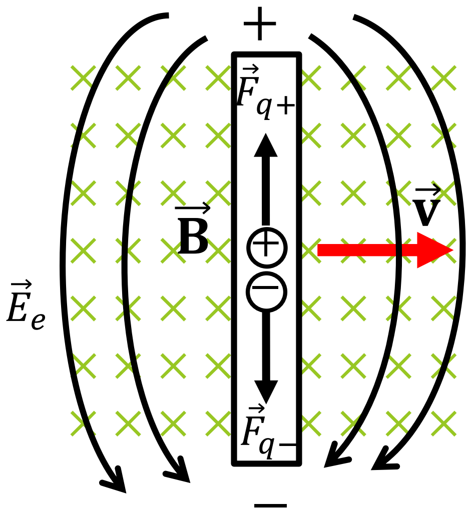
The induced current creates this field, trying to offset the change.

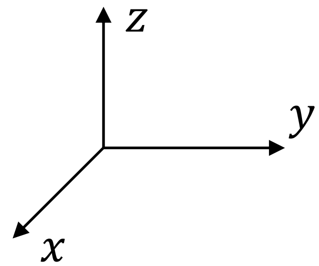
The fingers are in the current's direction; the thumb is in the induced field's direction.



Motional emf,

The emf induced in a conductor moving through a constant magnetic field.





$$\vec{F} = \mathrm{q}(\vec{\mathrm{v}} \times \vec{\mathrm{B}})$$

$$\vec{F}_{q+} = \mathrm{qvB}(\hat{\jmath} \times -\hat{\imath})$$

$\vec{F}_{q+} = \mathrm{qvB}(\hat{\mathrm{k}})$ ➡ moving to the upper end

$$\vec{F}_{q-} = -\mathrm{qvB}(\hat{\jmath} \times -\hat{\imath})$$

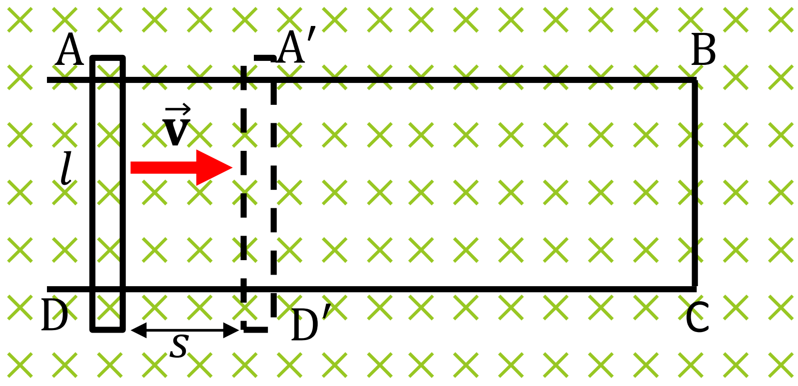
$\vec{F}_{q+} = \mathrm{qvB}(-\hat{\mathrm{k}})$ ➡ moving to the lower end

Thus, the upper end of conductor become positive pole (+), the lower end of conductor become negative pole (-), which create the electrostatic field ($\vec{E}_e$)

- A straight electrical conductor of length l moving with a velocity **v** through a uniform magnetic field **B** directed perpendicular to **v**.
- Due to the magnetic force on electrons, the ends of the conductor become oppositely charged.
- This establishes an electric field in the conductor. In steady state, the electric and magnetic forces on an electron in the wire are balanced.

Motional emf,

The emf induced in a conductor moving through a constant magnetic field.



The AD conducting bar, length l, moving to the right with a velocity $\vec{\mathbf{v}}$. The initial magnetic flux is :

$$\Phi_1 = \text{B . area of ABCD}$$

After moving for time dt, the conductor move for $s = \vec{v}dt$, Thus the final magnetc flux become:

$$\Phi_2 = \text{B . area of A}'\text{BCD}'$$

The changing of the flux:

$$\begin{aligned} \mathrm{d}\Phi &= \Phi_2 - \Phi_1 \\ &= \mathrm{B}\ (\square \mathrm{A'BCD'} - \square \mathrm{ABCD} \\ &= \mathrm{B}\ (\square \mathrm{A'BCD'} - \square \mathrm{ABCD}) \\ &= -\mathrm{B}\ (\square \mathrm{AA'D'D}) \\ &= -\mathrm{B}\ (l.s) \\ &= -B(l.v.dt) \end{aligned}$$

$$\frac{\mathrm{d}\Phi}{dt} = -Blv$$

Faraday’s Law

$$\varepsilon = -\frac{\mathrm{d}\Phi}{dt} = Blv$$

The direction of Induced Current ??

Soal buku hal. 138 no. 2

Sebuah loop persegi Panjang dengan luas A diletakkan di suatu daerah dimana medan magnetnya tegak lurus bidang loop. Besarnya medan magnet berubah terhadap waktu menurut $B = B_{max}e^{-\frac{t}{\alpha}}$, dengan B_{max} dan α adalah konstanta. Untuk t < 0 harga medan magnet adalah B_{max}.

a. Gunakan hukum faraday untuk menunjukkan bahwa ggl yang terinduksi dalam loop diberikan oleh $\varepsilon = \frac{AB_{max}}{\alpha}e^{-\frac{t}{\alpha}}$,

b. Bila A= 0,16 m^2, B_{maks} = 0,35 T dan $\alpha = 2$, hitunglah ε pada saat t = 4 s

c. Berapakah nilai ε_{max}

Penyelesaian:

a. GGL induksi

$$\varepsilon = -\mathrm{N}\frac{d\Phi}{dt} = -\mathrm{N}\frac{d(B.A)}{dt}$$

$$\varepsilon = -\mathrm{N}\frac{d(B.A)}{dt}$$

$$\varepsilon = -\mathrm{A}\frac{d\left(B_{max}e^{-\frac{t}{\alpha}}\right)}{dt}$$

$$\varepsilon = -\mathrm{A}B_{max}\frac{d\left(e^{-\frac{t}{\alpha}}\right)}{dt}$$

$$\boxed{\varepsilon = \frac{AB_{max}e^{-\frac{t}{\alpha}}}{\alpha}}$$

b. Bila A= 0,16 m^2, B_{maks} = 0,35 T dan $\alpha = 2$, hitunglah ε pada saat t = 4 s

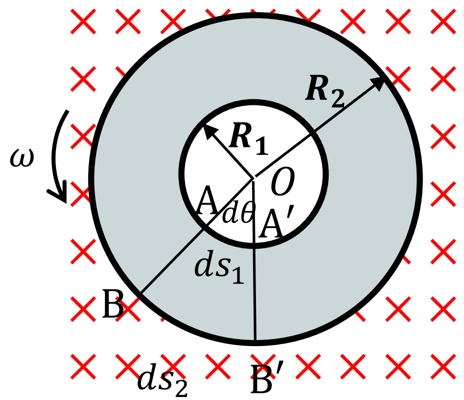
$$\varepsilon = \frac{0{,}16 \times 0{,}35 \times e^{-\frac{4}{2}}}{2}$$

$$\varepsilon = 19{,}4 \text{ mV}$$

c. Berapakah nilai ε_{max}

$$\varepsilon = \frac{AB_{max}}{\alpha} = \frac{0{,}16 \times 0{,}35}{2} = 28\text{mV}$$

Dynamo Faraday



$$ds = Rd\theta$$

$$ds_1 = R_1 d\theta$$

$$ds_2 = R_2 d\theta$$

Misalkan besarnya simpangan sudut yang ditempuh cakram dalam selang waktu dt, maka berkurangnya fluks magnet:

$$\mathrm{d}\Phi = -\mathrm{B}\,(\mathrm{ABB'A'})$$

$$\mathrm{d}\Phi = -\mathrm{B}\,(\Delta\,\mathrm{OBB'} - \Delta\,\mathrm{OAA'})$$

$$\mathrm{d}\Phi = -\mathrm{B}\left(\frac{1}{2}\mathrm{R}_2\,.\,\mathrm{ds}_2 - \frac{1}{2}\mathrm{R}_1\,.\,\mathrm{ds}_1\right)$$

$$\mathrm{d}\Phi = -\mathrm{B}\left(\frac{1}{2}\mathrm{R}_2{}^2.\,\mathrm{d}\theta - \frac{1}{2}\mathrm{R}_1{}^2.\,\mathrm{d}\theta\right)$$

$$\frac{\mathrm{d}\Phi}{dt} = -\frac{B}{2}\frac{\mathrm{d}\theta}{dt}\left(R_2{}^2 - R_1{}^2\right)$$

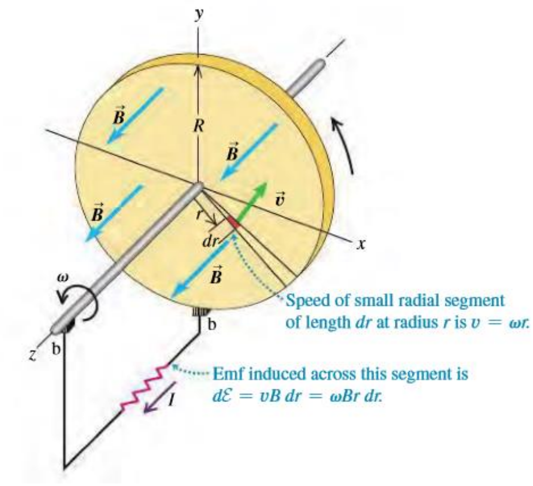
$$\frac{\mathrm{d}\Phi}{dt} = -\frac{B}{2}\,\omega\left(R_2{}^2 - R_1{}^2\right)$$

$$\varepsilon = -\frac{d\Phi}{dt} = \frac{B}{2}\,\omega\left(R_2{}^2 - R_1{}^2\right)$$

untuk cakram pejal

$R_2 = R$ dan $R_2 = 0$

$$\varepsilon = \frac{1}{2}\,B\,\omega\,R^2$$



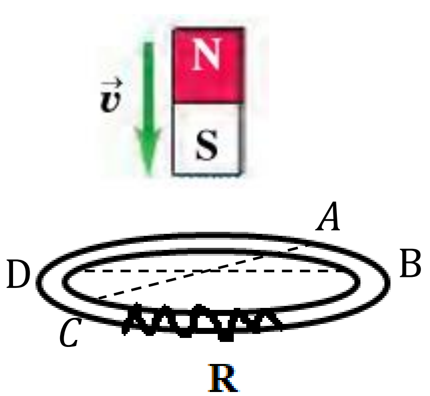
Cara Menentukan Arah Arus Induksi

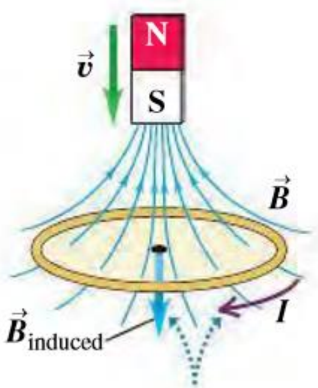
https://www.youtube.com/watch?v=1-aoGz5X_j0

Soal buku hal. 139 no. 8

Sebuah batang magnet dipegang vertical di atas suatu loop horizontal ditunjukkan pada gambar. Kutub selatan magnet batang menghadap loop kawat, kemudian batang magnet dijatuhkan kearah loop. Carilah arah arus yang lewat resistor,

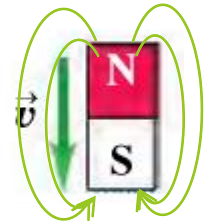
a. Ketika batang magnet jatuh ke loop
b. Setelah batang magnet melewati loop dan menjauhinya

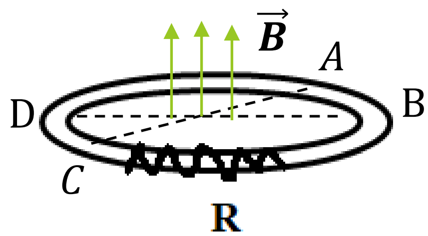


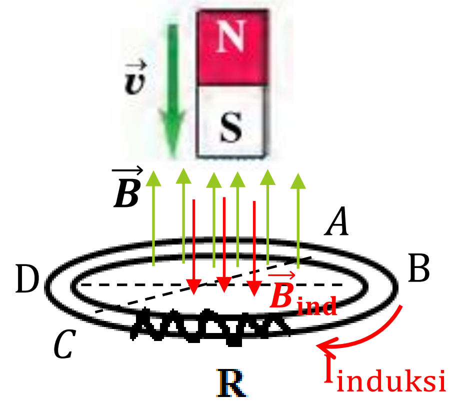


Penyelesaian:

a. Ketika batang magnet jatuh ke loop

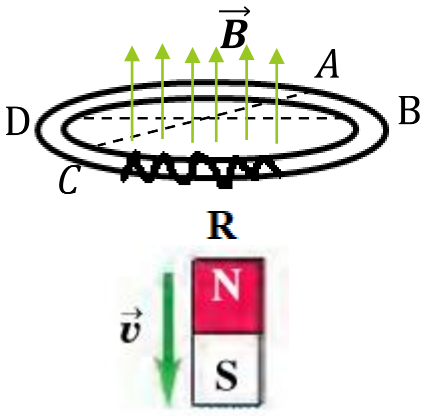


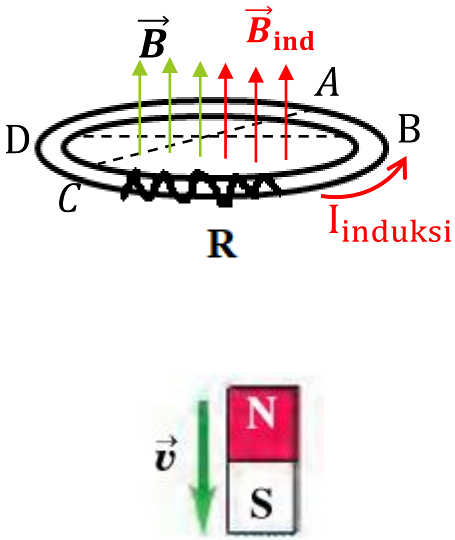




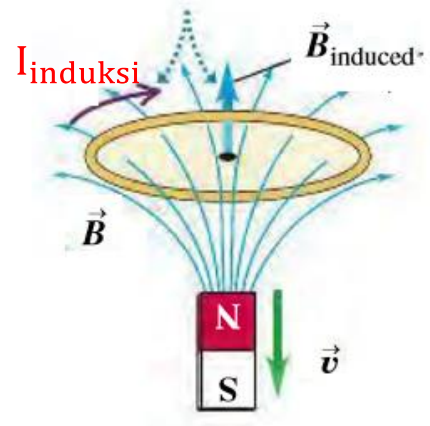
Saat awal (posisi magnet masih jauh), maka medan magnet yang menembus cincin masih kecil dimisalkan 3 buah anak panah berwarna biru dg arah ke atas. Semakin mendekat, maka medan magnet semakin besar dimisalkan menjadi 6 buah anak panah warna biru dengan arah ke atas. Prinsipnya jumlah medan magnet awal dan akhir harus sama, sehingga agar tetap sama dengan awal maka timbul 3 medan magnet induksi dengan arah ke bawah (berwarna merah) yang dinamakan sebagai $B_{induksi}$ sehingga arah arus induksinya dari B ke C

b. Setelah batang magnet melewati loop dan menjauhinya





Saat awal (posisi magnet dekat), maka medan magnet yang menembus cincin nilainya besar memisalkan 6 buah anak panah berwarna biru yang arahnya ke atas. Semakin menjauh, maka medan magnet semakin kecil dimisalkan menjadi 3 buah anak panah warna biru dengan arah ke atas. Prinsipnya jumlah medan magnet awal dan akhir harus sama, sehingga untuk mengimbanginya timbul medan magnet induksi dengan arah ke atas (3 anak panah berwarna merah) yang dinamakan sebagai $B_{induksi}$ sehingga arah arus induksinya dari C ke B



Problem:

Two closed loops A and C are close to a long wire carrying a current I (Fig. 2).

(a) Find the direction (clockwise or counter clockwise) of the current induced in each loop if I is steadily decreasing.

(b) While I is decreasing, what is the direction of the net force that the wire exerts on each loop? Explain how you obtain your answer

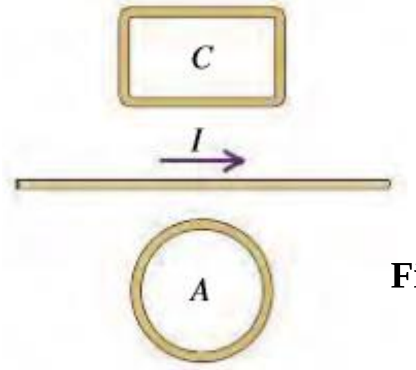
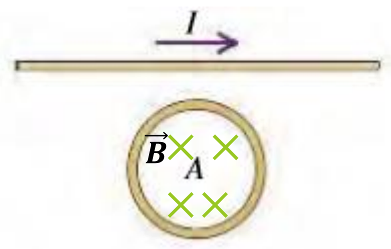


Fig. 2

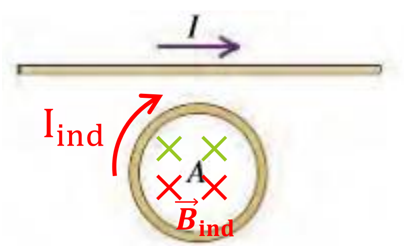
SOLUTION

(a) direction of the current induced

Ketika I di turunkan maka pada loop A.



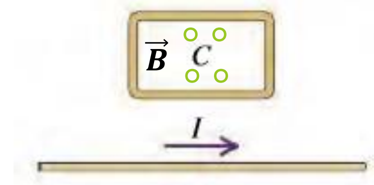
sebelum I diturunkan



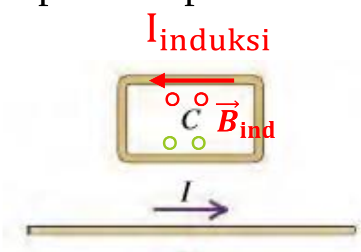
setelah I diturunkan

Pada saat arus I belum diturunkan maka medan magnet yang menembus loop A masih besar dengan arah masuk bidang dimisalkan ada 4 buah medan magnet. Setelah I diturunkan maka ada pengurangan induksi magnet yang menembus loop dimisalkan tinggal 2 buah, sehingga timbul induksi magnet ($B_{induksi}$) arah masuk bidang untuk melawan pengurangan medan magnet tersebut (jumlah sama dg awal), sehingga arah arus induksi pada loop A searah jarum jam.

Ketika I di turunkan maka pada loop C.



sebelum I diturunkan



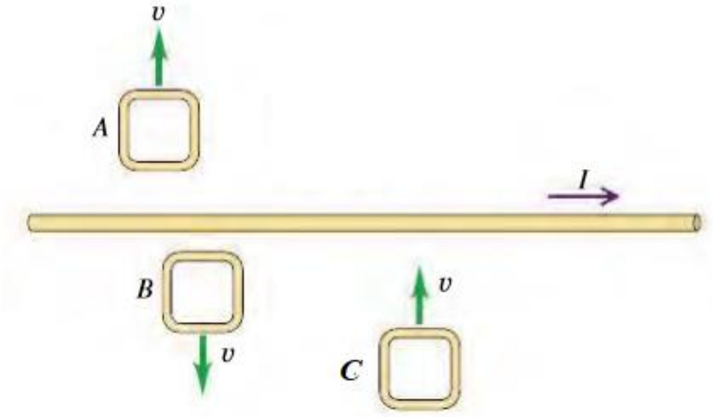
setelah I diturunkan

Pada saat arus I belum diturunkan maka medan magnet yang menembus loop A masih besar dengan arah keluar bidang dimisalkan ada 4 buah medan magnet. Setelah I diturunkan maka ada pengurangan induksi magnet yang menembus loop dimisalkan tinggal 2 buah, sehingga timbul induksi magnet ($B_{induksi}$) arah keluar bidang untuk melawan pengurangan medan magnet tersebut (jumlah sama dg awal), sehingga arah arus induksi pada loop A berlawanan jarum jam.

(b) Karena arah arus pada sisi kawat yang berdekatan dengan kawat adalah searah maka resultan gaya pada loop menuju kawat lurus

TUGAS

1. The current I in a long, straight wire is constant and is directed toward the right as in Fig. Conducting loops A, B, C, are moving, in the directions shown, near the wire. For each loop, is the direction of the induced current clockwise or counter clockwise, or is the induced current zero?

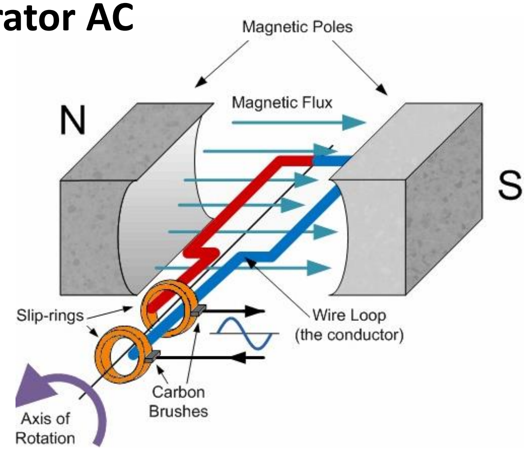


2. Soal di buku halaman 130 no. 5 dan 10

Generator

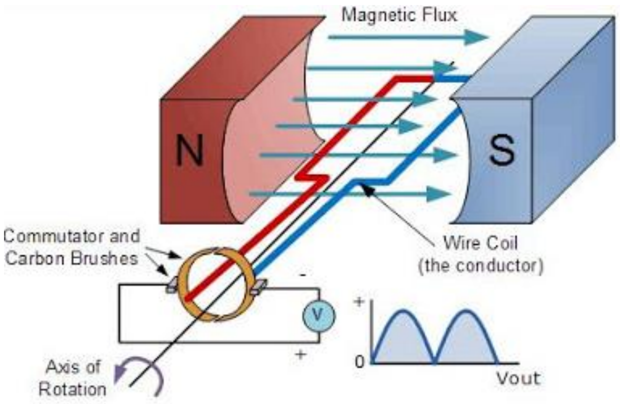
https://www.youtube.com/watch?v=Ylgb8FFMgd4

Generator AC

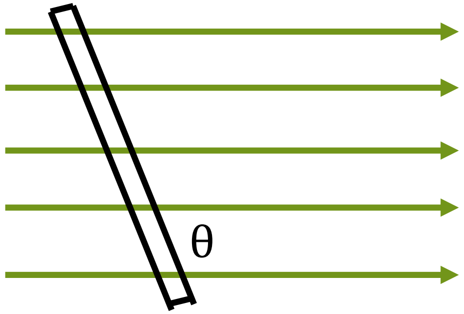


Schematic diagram of an AC generator. An emf is induced in a loop that rotates in a magnetic field.

Generator DC



The alternating emf induced in the loop plotted as a function of time.



θ= ωt

A loop enclosing an area *A* and containing *N* turns, rotating with constant angular speed * in a magnetic field. The emf induced in the loop varies sinusoidally in time.

$$\Phi = \vec{\mathrm{B}}.\vec{\mathrm{A}}$$

$$\Phi = \mathrm{B\ A}\cos\theta$$

$$\varepsilon = -N\frac{d\Phi}{dt}$$

$$\varepsilon = -N\frac{d(\vec{\mathrm{B}}\,.\,\vec{\mathrm{A}})}{dt}$$

$$\varepsilon = -N\frac{d(\mathrm{B\ A}\cos\theta)}{dt}$$

$$\varepsilon = -NBA\frac{d(\cos\omega t)}{dt}$$

$$\varepsilon = -NBA(-\sin\omega t)\omega$$

$$\varepsilon = NBA\omega\sin\omega t$$

$$\varepsilon = \varepsilon_{max}\ \sin\omega t$$

$$\varepsilon_{max} = NBA\omega$$

Induction of Electromotive (GGL Induksi)

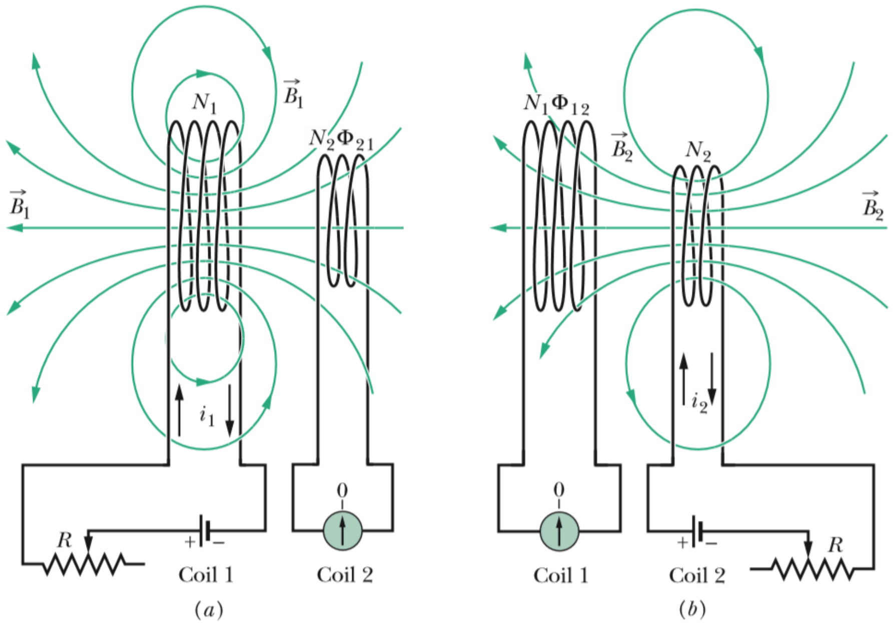
NURRISMA PUSPITASARI

POKOK BAHASAN

- Induktansi Timbal Balik
- Induktansi Diri
- Energi Pada Konduktor
- Rapat Energi Pada Induktor
- Hukum Lentz
- Pembahasan Tugas

Induktansi Timbal Balik

Dua kumpran masing masing dialiri arus listrik I_1 dan I_2 seperti ditunjukkan pada Gambar



Pada gambar (a) ketika kumparan 1 dialiri arus maka B_1 akan menembus kumparan 2, sebaliknya Ketika kuparan 2 (gambar b) dialiri arus maka B_2 akan menembus kumparan 1, sehingga:

$$\Phi_{21} = B_1 A_2$$

$$\Phi_{12} = B_2 A_1$$

Pada kumparan 1

Φ_{12}= fluks pada kawat 1 oleh kawat 2

Φ_{12}= k_2 I_2

$$\varepsilon_1 = -N_1 \frac{d\Phi_{12}}{dt}$$

$$\varepsilon_1 = -N_1 \frac{d(k_2 I_2)}{dt}$$

$$\varepsilon_1 = -N_1 k_2 \frac{dI_2}{dt}$$

dengan

$$M = N_1 k_2$$

$$\varepsilon_1 = -M \frac{dI_2}{dt}$$

Pada kumparan 2

Φ_{21}= fluks pada kawat 2 oleh kawat 1

$\Phi_{21} = k_1 I_1$

$$\varepsilon_2 = -N_2 \frac{d\Phi_{21}}{dt}$$

$$\varepsilon_2 = -N_2 \frac{d(k_1 I_1)}{dt}$$

$$\varepsilon_2 = -N_2 k_1 \frac{dI_1}{dt}$$

dengan,

$$M = N_2 k_1$$

$$\varepsilon_2 = -M \frac{dI_1}{dt}$$

Pada GGL 1 (ε_1)

$$\varepsilon_1 = -N_1 \frac{d\Phi_{12}}{dt}$$

$$-M \frac{dI_2}{dt} = -N_1 \frac{d\Phi_{12}}{dt}$$

$$MI_2 = N_1 \Phi_{12}$$

$$M = \frac{N_1 \Phi_{12}}{I_2}$$

Pada GGL 2 (ε_1)

$$\varepsilon_2 = -N_2 \frac{d\Phi_{21}}{dt}$$

$$-M \frac{dI_1}{dt} = -N_2 \frac{d\Phi_{21}}{dt}$$

$$MI_1 = N_2 \Phi_{21}$$

$$M = \frac{N_2 \Phi_{21}}{I_1}$$

M = Induktansi Saling

Induktansi Diri

$$N_1 = N_2 = N$$

$$I_1 = I_2 = I$$

$$\Phi_{12} = \Phi_{21} = \Phi$$

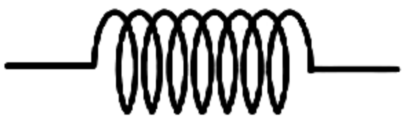
$$M = L = N \frac{\Phi}{I}$$

Hukum Lenz

$$\varepsilon = -L \frac{dI}{dt}$$

L= induktansi induktor (Henry)

simbol



L

Energi yang tersimpan

$$\varepsilon = -L\frac{dI}{dt}$$

Daya :

$$P = \varepsilon I$$

$$P = L\,I\,\frac{dI}{dt}$$

$$\frac{dW}{dt} = L\,I\,\frac{dI}{dt}$$

$$W = \int_0^I L\,I dI$$

$$\boxed{W = \frac{1}{2}L\,I^2}$$

Rapat Energi Induktor

$$u_B = \frac{\text{Energi}}{\text{volume}}$$

$$u_B = \frac{\frac{1}{2}L\,I^2}{Al}$$

$$u_B = \frac{\frac{1}{2}N\frac{\Phi}{I}I^2}{Al}$$

$$B = \frac{\mu_0 IN}{l}$$

$$u_B = \frac{\frac{1}{2}N\frac{B\cancel{A}}{\cancel{I}}\cancel{I^2}}{\cancel{A}l}$$

$$I = \frac{Bl}{\mu_0 N}$$

$$u_B = \frac{1}{2}\frac{NB}{l}\frac{Bl}{\mu_0 N}$$

$$\boxed{u_B = \frac{B^2}{2\mu_0}}$$

Soal buku hal. 139 no. 12:

Sebuah solenoida yang terdiri 500 lilitan Panjangnya 8 cm. Bila arus dalam solenida ini naik dari 0 sampai 2,5 A dalam waktu 0,35 s, besarnya ggl yang terinduksi adalah 0,05 volt. (Asumsi: solenoida sangat panjang) Carilah:

a. Induktansi solenoida

b. Luas penampang solenoida

Penyelesaian:

a. Induktansi solenoida

$$\varepsilon = -L\frac{dI}{dt}$$

$$\varepsilon = -L\frac{\Delta I}{\Delta t}$$

Karena dilihat besarnya maka tanda negative dihilangkan

$$0{,}05 = L\frac{(2{,}5 - 0)}{0{,}35}$$

$$0{,}05 = L\frac{(2{,}5 - 0)}{0{,}35}$$

$$L = \frac{0{,}05 \times 0{,}35}{2{,}5}$$

$$L = 7\mathrm{mH}$$

b. Luas penampang solenoida

$$L = N\frac{\Phi}{I}$$

$$L = N\frac{BA}{I} = N\frac{\frac{\mu_0 IN}{l}A}{I}$$

$$L = \frac{\mu_0 N^2 A}{l}$$

$$A = \frac{Ll}{\mu_0 N^2}$$

$$A = \frac{7 \times 10^{-3} \times 8 \times 10^{-2}}{4\pi \times 10^{-7} \times 500^2}$$

$$A = \frac{5{,}6 \times 10^{-3}}{\pi}\mathrm{m}^2 = \frac{56}{\pi}\mathrm{cm}^2$$

Pembahasan Tugas:

1. The current I in a long, straight wire is constant and is directed toward the right as in Fig. Conducting loops A, B, C, are moving, in the directions shown, near the wire. For each loop, is the direction of the induced current clockwise or counter clockwise, or is the induced current zero?