KK 2916626, Induksi Magnetik
Program Studi S1 Pendidikan IPA

FAKULTAS KEGURUAN DAN ILMU PENDIDIKAN
UNIVERSITAS SEBELAS MARET (UNS)
SURAKARTA

Pertemuan ke-5 (Kelas A) : Selasa, 24 Maret 2020 Pk. 12.40 – 15.00 wib

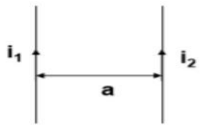
e Learning

INDUKSI ELEKTROMAGNETIK

Dr. Suharno, M.Si

Pendahuluan : Gaya Magnetik

Gaya Lorentz pada Kawat Sejajar



Medan magnet di kawat 1 akibat kawat ke-2 $B_2 = \frac{\mu_0 I_2}{2\pi a}$

Gaya magnet padakawat 2 disebabkanoleh medan B_2(semua yang) $|F_B| = I_1 l_1 |B_2|$

$$|F_B| = \frac{I_1 l_1 \mu_0 I_2}{2\pi a} = \frac{\mu_0 I_1 I_2}{2\pi a} l_1$$

Gaya pada kawat 1 yang disebabkan oleh kawat 2 $F_1 = \frac{\mu_0 I_1 I_2}{2\pi a} l_1$

Gaya pada kawat 2 yang disebabkan oleh kawat 1 $F_2 = \frac{\mu_0 I_1 I_2}{2\pi a} l_2$

Gaya / satuan panjang

$$F = \frac{\mu_0}{2\pi} \frac{i_1 i_2}{a} l$$

Kawat yg arah arusnya searah akan tarik-menarik.
Kawat yang arusnya berlawanan arah akan tolak-menolak

TUGAS 1:

In Figure P30.17, the current in the long, straight wire is $I_1 = 5.00$ A, and the wire lies in the plane of the rectangular loop, which carries 10.0 A. The dimensions are $c = 0.100$ m, $a = 0.150$ m, and $\ell = 0.450$ m. Find the magnitude and direction of the net force exerted on the loop by the magnetic field created by the wire.

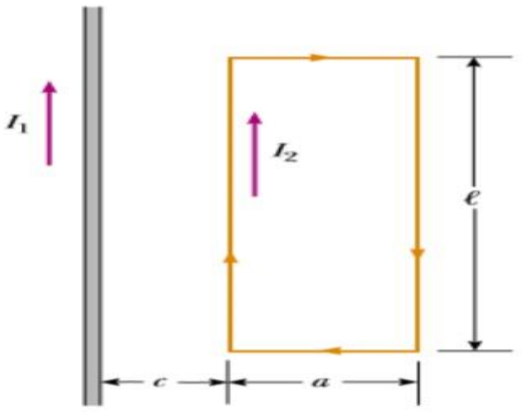


Figure P30.17

EXAMPLE 30.8 Magnetic Flux Through a Rectangular Loop

A rectangular loop of width a and length b is located near a long wire carrying a current I (Fig. 30.21). The distance between the wire and the closest side of the loop is c. The wire is parallel to the long side of the loop. Find the total magnetic flux through the loop due to the current in the wire.

Solution From Equation 30.14, we know that the magnitude of the magnetic field created by the wire at a distance r from the wire is

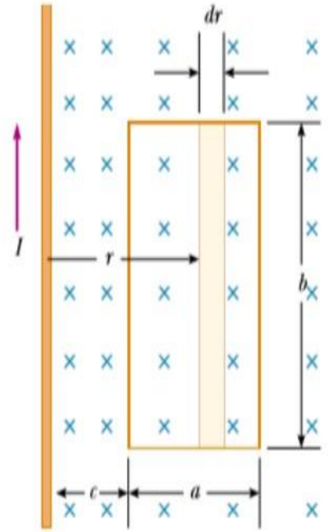


Figure 30.21 The magnetic field due to the wire carrying a current I is not uniform over the rectangular loop.

$$B = \frac{\mu_0 I}{2\pi r}$$

The factor $1/r$ indicates that the field varies over the loop, and Figure 30.21 shows that the field is directed into the page. Because **B** is parallel to $d\mathbf{A}$ at any point within the loop, the magnetic flux through an area element dA is

$$\Phi_B = \int B\,dA = \int \frac{\mu_0 I}{2\pi r}\,dA$$

(Because B is not uniform but depends on r, it cannot be removed from the integral.)

To integrate, we first express the area element (the tan region in Fig. 30.21) as $dA = b\,dr$. Because r is now the only variable in the integral, we have

$$\Phi_B = \frac{\mu_0 I b}{2\pi} \int_c^{a+c} \frac{dr}{r} = \frac{\mu_0 I b}{2\pi} \ln r \Big|_c^{a+c}$$

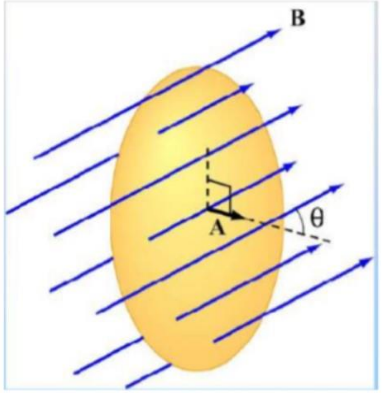
$$= \frac{\mu_0 I b}{2\pi} \ln\left(\frac{a+c}{c}\right) = \frac{\mu_0 I b}{2\pi} \ln\left(1 + \frac{a}{c}\right)$$

Exercise Apply the series expansion formula for $\ln(1 + x)$ (see Appendix B.5) to this equation to show that it gives a reasonable result when the loop is far from the wire relative to the loop dimensions (in other words, when $c \gg a$).

Answer $\Phi_B \to 0$.

Hukum Gauss Magnetik

Analog dengan Fluks Listrik (Hukum Gauss)



(1) **B** Uniform

$$\Phi_B = B_{\perp}A = BA\cos\theta = \vec{\mathbf{B}}\cdot\vec{\mathbf{A}}$$

(2) **B** Non-Uniform

$$\Phi_B = \int_S \vec{\mathbf{B}}\cdot d\vec{\mathbf{A}}$$

Animasi 8.2

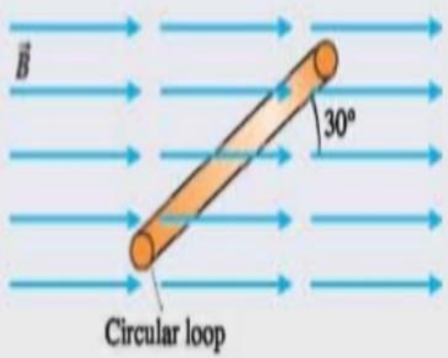
EXAMPLE 34.4 A circular loop in a magnetic field

FIGURE 34.15 is an edge view of a 10-cm-diameter circular loop in a uniform 0.050 T magnetic field. What is the magnetic flux through the loop?

SOLVE Angle θ is the angle between the loop's area vector $\vec{A}$, which is perpendicular to the plane of the loop, and the magnetic field $\vec{B}$. In this case, $\theta = 60°$, not the 30° angle shown in the figure. Vector $\vec{A}$ has magnitude $A = \pi r^2 = 7.85 \times 10^{-3}\ \text{m}^2$. Thus the magnetic flux is

$$\Phi_m = \vec{A}\cdot\vec{B} = AB\cos\theta = 2.0 \times 10^{-4}\ \text{Wb}$$

FIGURE 34.15 A circular loop in a magnetic field.



TUGAS 2:

FIGURE Q34.4 shows four different circular loops that are perpendicular to the page. The radius of loops c and d is twice that of loops a and b. The magnetic field is the same for each. Rank in order, from largest to smallest, the magnetic fluxes Φ_a to Φ_d. Some may be equal. Explain.

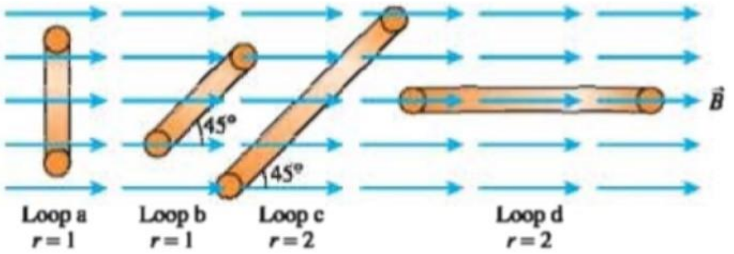


FIGURE Q34.4

TUGAS 3:

II A 2.0-cm-diameter solenoid passes through the center of a 6.0-cm-diameter loop. The magnetic field inside the solenoid is 0.20 T. What is the magnetic flux through the loop when it is perpendicular to the solenoid and when it is tilted at a 60° angle?

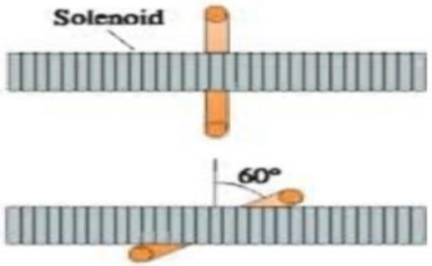


FIGURE EX34.5

Hukum Faraday

$$\mathcal{E} = -N\frac{d\Phi_B}{dt}$$

Cara untuk Menginduksi GGL

$$\mathcal{E} = -N\frac{d}{dt}(BA\cos\theta)$$

Kuantitas yang berubah terhadap waktu:
1. Besar B
2. Luas A yang dilingkupi loop
3. Sudut θ antara B dan normal loop

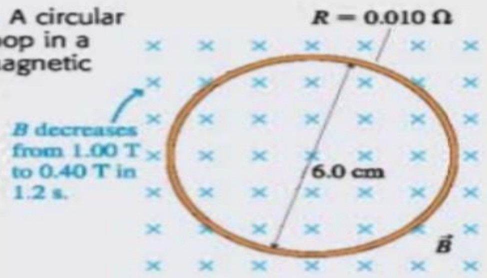
EXAMPLE 34.8 Electromagnetic induction in a loop

A patient having an MRI scan has neglected to remove a copper bracelet. The bracelet is 6.0 cm in diameter and has a resistance of 0.010 Ω. The magnetic field in the MRI solenoid is directed along the person's body from head to foot; the bracelet is perpendicular to $\vec{B}$. As a scan is taken, the magnetic field in the solenoid decreases from 1.00 T to 0.40 T in 1.2 s. What are the magnitude and direction of the current induced in the bracelet?

MODEL Assume that B decreases linearly with time.

VISUALIZE FIGURE 34.28 shows the bracelet and the applied field looking down along the patient's body. As the applied field decreases, the flux into the loop decreases. To oppose the decreasing flux, the field from the induced current must be in the direction of the applied field. Thus, from the right-hand rule, the induced current in the bracelet must be clockwise.

FIGURE 34.28 A circular conducting loop in a decreasing magnetic field.



SOLVE The magnetic field is perpendicular to the plane of the loop, hence $\theta = 0°$ and the magnetic flux is $\Phi_m = AB = \pi r^2 B$. The radius of the loop doesn't change with time, but B does. According to Faraday's law, the magnitude of the induced emf is

$$\mathcal{E} = \left|\frac{d\Phi_m}{dt}\right| = \pi r^2\left|\frac{dB}{dt}\right|$$

The rate at which the magnetic field changes is

$$\frac{dB}{dt} = \frac{\Delta B}{\Delta t} = \frac{-0.60\ \text{T}}{1.2\ \text{s}} = -0.50\ \text{T/s}$$

dB/dt is negative because the field is decreasing, but all we need for Faraday's law is the absolute value. Thus

$$\mathcal{E} = \pi r^2\left|\frac{dB}{dt}\right| = \pi(0.030\ \text{m})^2(0.50\ \text{T/s}) = 0.0014\ \text{V}$$

TUGAS 4:

FIGURE Q34.9 shows a bar magnet, a coil of wire, and a current meter. Is the current through the meter right to left, left to right, or zero for the following circumstances? Explain.

a. The magnet is inserted into the coil.
b. The magnet is held at rest inside the coil.
c. The magnet is withdrawn from the coil.

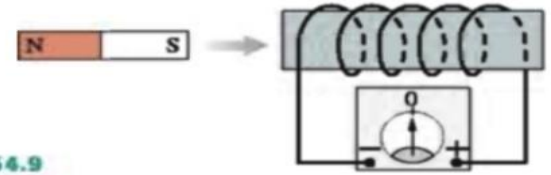


FIGURE Q34.9

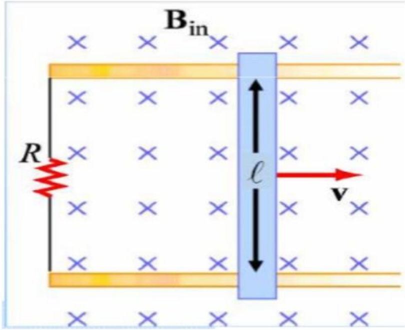
TUGAS 5:

A 5.0-cm-diameter coil has 20 turns and a resistance of 0.50 Ω. A magnetic field perpendicular to the coil is $B = 0.020t + 0.010t^2$, where B is in tesla and t is in seconds.

a. Draw a graph of B as a function of time from $t = 0$ s to $t = 10$ s.
b. Find an expression for the induced current $I(t)$ as a function of time.
c. Evaluate I at $t = 5$ s and $t = 10$ s.

Hukum Faraday : Kawat Konduktor

Batang konduktor ditarik sepanjang dua rel konduktor dalam daerah bermedan magnet uniform B dengan kecepatan konstan **v**



1. Arah arus induksi?
2. Arah resultan gaya?
3. Besar GGL?
4. Besar arus?
5. Daya eksternal yang harus disuplai agar batang bergerak dengan kecepatan konstan **v**?

Animasi 8.6

TUGAS 6:

| The loop in FIGURE EX34.12 is being pushed into the 0.20 T magnetic field at 50 m/s. The resistance of the loop is 0.10 Ω. What are the direction and the magnitude of the current in the loop?

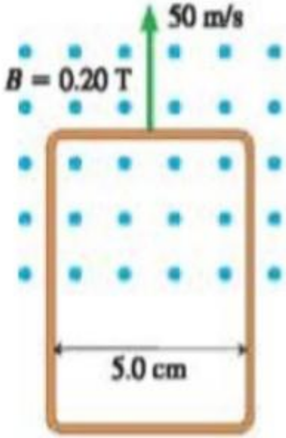


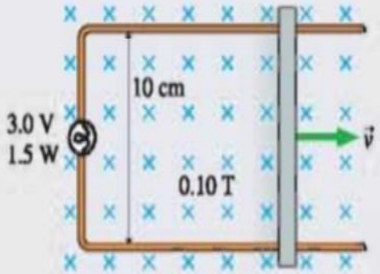
FIGURE EX34.12

EXAMPLE 34.3 Lighting a bulb

FIGURE 34.8 shows a circuit consisting of a flashlight bulb, rated 3.0 V/1.5 W, and ideal wires with no resistance. The right wire of the circuit, which is 10 cm long, is pulled at constant speed v through a perpendicular magnetic field of strength 0.10 T.

a. What speed must the wire have to light the bulb to full brightness?
b. What force is needed to keep the wire moving?

FIGURE 34.8 Circuit of Example 34.3.



MODEL Treat the moving wire as a source of motional emf.

VISUALIZE The direction of the magnetic force on the charge carriers, $\vec{F}_B = q\vec{v} \times \vec{B}$, will cause a counterclockwise (ccw) induced current.

SOLVE a. The bulb's rating of 3.0 V/1.5 W means that at full brightness it will dissipate 1.5 W at a potential difference of 3.0 V. Because the power is related to the voltage and current by $P = I\Delta V$, the current causing full brightness is

$$I = \frac{P}{\Delta V} = \frac{1.5\ \text{W}}{3.0\ \text{V}} = 0.50\ \text{A}$$

The bulb's resistance—the total resistance of the circuit—is

$$R = \frac{\Delta V}{I} = \frac{3.0\ \text{V}}{0.50\ \text{A}} = 6.0\ \Omega$$

Equation 34.4 gives the speed needed to induce this current:

$$v = \frac{IR}{lB} = \frac{(0.50\ \text{A})(6.0\ \Omega)}{(0.10\ \text{m})(0.10\ \text{T})} = 300\ \text{m/s}$$

You can confirm from Equation 34.6 that the input power at this speed is 1.5 W.

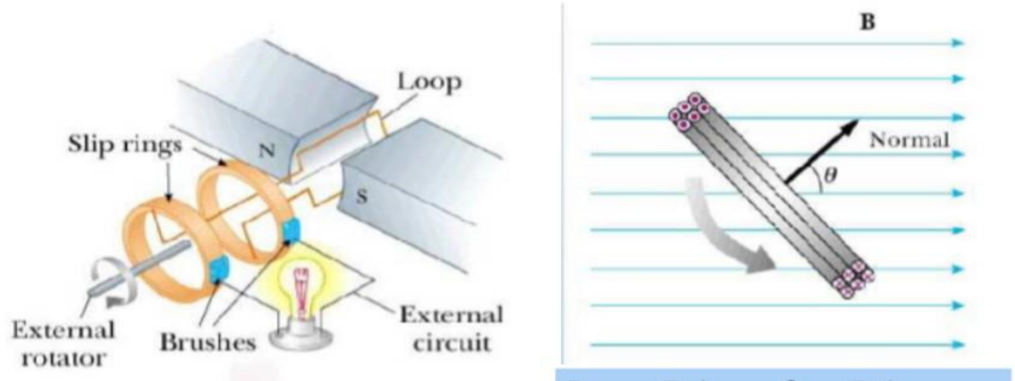
b. From Equation 34.5, the pulling force must be

$$F_{pull} = \frac{vl^2B^2}{R} = 5.0 \times 10^{-3}\ \text{N}$$

You can also obtain this result from $F_{pull} = P/v$.

ASSESS Example 34.1 showed that high speeds are needed to produce significant potential difference. Thus 300 m/s is not surprising. The pulling force is not very large, but even a small force can deliver large amounts of power $P = Fv$ when v is large.

Generator



$$\Phi_B = BA\cos\theta = BA\cos\omega t$$

$$\mathcal{E} = -N\frac{d\Phi_B}{dt} = -NAB\frac{d}{dt}(\cos\omega t) = NAB\omega\sin\omega t$$

TUGAS 7:

In a 250-turn automobile alternator, the magnetic flux in each turn is $\Phi_B = (2.50 \times 10^{-4}\ \mathrm{T\cdot m^2})\cos(\omega t)$, where ω is the angular speed of the alternator. The alternator is geared to rotate three times for each engine revolution. When the engine is running at an angular speed of 1 000 rev/min, determine (a) the induced emf in the alternator as a function of time and (b) the maximum emf in the alternator.

EXAMPLE 31.9 emf Induced in a Generator

An ac generator consists of 8 turns of wire, each of area A = 0.090 0 m², and the total resistance of the wire is 12.0 Ω. The loop rotates in a 0.500-T magnetic field at a constant frequency of 60.0 Hz. (a) Find the maximum induced emf.

Solution First, we note that $\omega = 2\pi f = 2\pi(60.0\ \mathrm{Hz}) = 377\ \mathrm{s^{-1}}$. Thus, Equation 31.11 gives

$$\mathcal{E}_{max} = NAB\omega = 8(0.090\,0\ \mathrm{m^2})(0.500\ \mathrm{T})(377\ \mathrm{s^{-1}}) = \boxed{136\ \mathrm{V}}$$

(b) What is the maximum induced current when the output terminals are connected to a low-resistance conductor?

Solution From Equation 27.8 and the results to part (a), we have

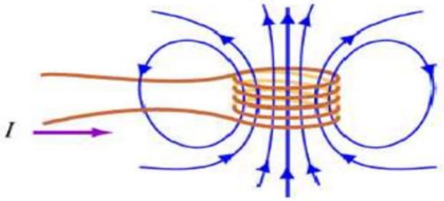
$$I_{max} = \frac{\mathcal{E}_{max}}{R} = \frac{136\ \mathrm{V}}{12.0\ \Omega} = \boxed{11.3\ \mathrm{A}}$$

Exercise Determine how the induced emf and induced current vary with time.

Answer $\mathcal{E} = \mathcal{E}_{max}\sin\omega t = (136\ \mathrm{V})\sin 377t$; $I = I_{max}\sin\omega t = (11.3\ \mathrm{A})\sin 377t$.

Indukstansi

Induktansi Diri



Sebuah koil dialiri arus listrik.
Arus konstan!
Arus berubah thd waktu!

$$\varepsilon_L = -N\frac{d\Phi_B}{dt} = -N\frac{d}{dt}\iint \vec{\mathbf{B}}\cdot d\vec{\mathbf{A}}$$

$$\varepsilon_L = -L\frac{dI}{dt} \qquad L = \frac{N\Phi_B}{I}$$

Secara fisis, Induktansi L adalah ukuran dari sebuah "resistansi" induktor untuk merubah arus; semakin besar L, semakin kecil laju perubahan arus.

29

TUGAS 8:

A coil of 15 turns and radius 10.0 cm surrounds a long solenoid of radius 2.00 cm and 1.00×10^3 turns per meter (Fig. P31.10). If the current in the solenoid changes as $I = (5.00\text{ A})\sin(120t)$, find the induced emf in the 15-turn coil as a function of time.

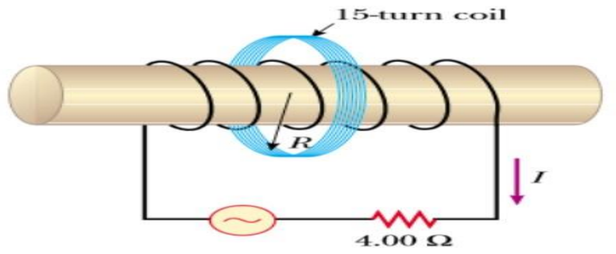


Figure P31.10

EXAMPLE 32.2 Calculating Inductance and emf

(a) Calculate the inductance of an air-core solenoid containing 300 turns if the length of the solenoid is 25.0 cm and its cross-sectional area is 4.00 cm².

Solution Using Equation 32.4, we obtain

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

$$= (4\pi \times 10^{-7}\ \mathrm{T\cdot m/A})\frac{(300)^2(4.00\times 10^{-4}\ \mathrm{m^2})}{25.0\times 10^{-2}\ \mathrm{m}}$$

$$= 1.81\times 10^{-4}\ \mathrm{T\cdot m^2/A} = \boxed{0.181\ \mathrm{mH}}$$

(b) Calculate the self-induced emf in the solenoid if the current through it is decreasing at the rate of 50.0 A/s.

Solution Using Equation 32.1 and given that $dI/dt = -50.0$ A/s, we obtain

$$\varepsilon_L = -L\frac{dI}{dt} = -(1.81\times 10^{-4}\ \mathrm{H})(-50.0\ \mathrm{A/s})$$

$$= \boxed{9.05\ \mathrm{mV}}$$

TUGAS 9: The current in a 90.0-mH inductor changes with time as $I = t^2 - 6.00t$ (in SI units). Find the magnitude of the induced emf at (a) $t = 1.00$ s and (b) $t = 4.00$ s. (c) At what time is the emf zero?

EXAMPLE 32.5 The Coaxial Cable

Coaxial cables are often used to connect electrical devices, such as your stereo system and a loudspeaker. Model a long coaxial cable as consisting of two thin concentric cylindrical conducting shells of radii a and b and length ℓ, as shown in Figure 32.11. The conducting shells carry the same current I in opposite directions. Imagine that the inner conductor carries current to a device and that the outer one acts as a return path carrying the current back to the source. (a) Calculate the self-inductance L of this cable.

Solution To obtain L, we must know the magnetic flux through any cross-section in the region between the two shells, such as the light blue rectangle in Figure 32.11. Ampère's law (see Section 30.3) tells us that the magnetic field in the region between the shells is $B = \mu_0 I/2\pi r$, where r is measured from the common center of the shells. The magnetic field is zero outside the outer shell ($r > b$) because the net current through the area enclosed by a circular path surrounding the cable is zero, and hence from Ampère's law, $\oint \mathbf{B} \cdot d\mathbf{s} = 0$. The magnetic field is zero inside the inner shell because the shell is hollow and no current is present within a radius $r < a$.

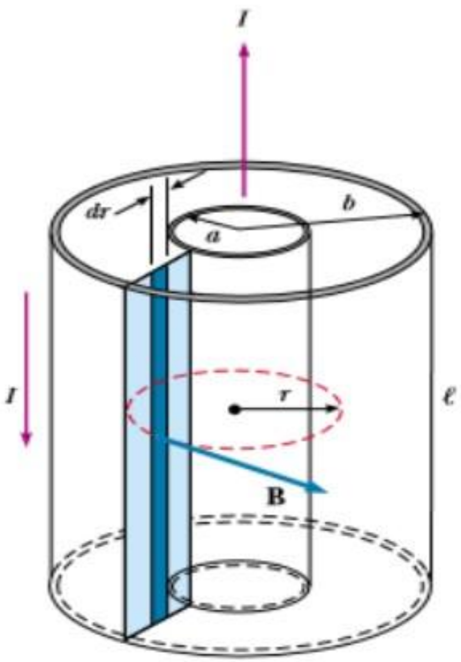


Figure 32.11 Section of a long coaxial cable. The inner and outer conductors carry equal currents in opposite directions.

The magnetic field is perpendicular to the light blue rectangle of length ℓ and width $b - a$, the cross-section of interest. Because the magnetic field varies with radial position across this rectangle, we must use calculus to find the total magnetic flux. Dividing this rectangle into strips of width dr, such as the dark blue strip in Figure 32.11, we see that the area of each strip is $\ell\, dr$ and that the flux through each strip is $B\, dA = B\ell\, dr$. Hence, we find the total flux through the entire cross-section by integrating:

$$\Phi_B = \int B\, dA = \int_a^b \frac{\mu_0 I}{2\pi r}\, \ell\, dr = \frac{\mu_0 I \ell}{2\pi} \int_a^b \frac{dr}{r} = \frac{\mu_0 I \ell}{2\pi} \ln\left(\frac{b}{a}\right)$$

Using this result, we find that the self-inductance of the cable is

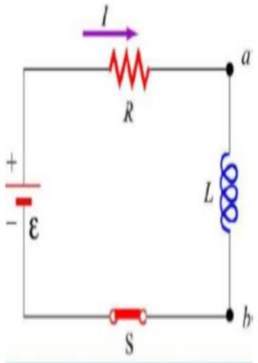
$$L = \frac{\Phi_B}{I} = \frac{\mu_0 \ell}{2\pi} \ln\left(\frac{b}{a}\right)$$

(b) Calculate the total energy stored in the magnetic field of the cable.

Solution Using Equation 32.12 and the results to part (a) gives

$$U = \tfrac{1}{2} L I^2 = \frac{\mu_0 \ell I^2}{4\pi} \ln\left(\frac{b}{a}\right)$$

Energi Tersimpan dalam Induktor



$$\mathcal{E} = +IR + L\frac{dI}{dt}$$

$$I\mathcal{E} = I^2 R + L I \frac{dI}{dt}$$

$$I\mathcal{E} = I^2 R + \frac{d}{dt}\left(\tfrac{1}{2} L I^2\right)$$

Batrei Penyuplai — Resistor Disipasi — Induktor Penyimpan

Terima Kasih dan Selamat Belajar