12 Advanced Physics 2023/24

English Version

Chapter 9

Electromagnetic Induction

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الوحدة 9

الحث الكهرومغناطيسي

Unit 9

Electromagnetic induction

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1. حصص مسجلة لشرح المادة كاملة بالفيديو
2. حصص مسجلة لمراجعة الهيكل وأسئلة السنوات السابقة
3. التواصل مع الأستاذ مباشرة عن طريق الواتساب للإجابة عن الأسئلة والاستفسارات
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تقديم واعداد الأستاذ: علاء الفقيه

Electromagnetic induction

- The phenomenon of electromagnetic induction:

"It is the process of producing an induced electromotive force and an induced electric current in a conductor in a closed circuit by changing the magnetic flux through it."

- Induced Electromotive Force: emf_{ind}

"The electric potential difference generated in a conductor or in a circuit because of a change in the magnetic flux due to the relative movement in a magnetic field."

- Induced current: I_{ind}

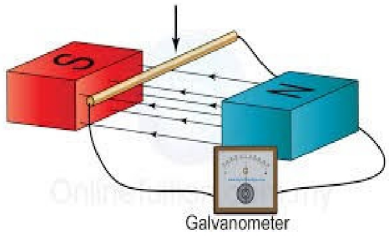
"It is the electrical current generated in a conductor or in a closed circuit because of a change in the magnetic flux due to the relative movement in a magnetic field."

Note: "Induced current continues to be produced in a closed circuit as long as there is a relative motion between the magnet and the circuit."

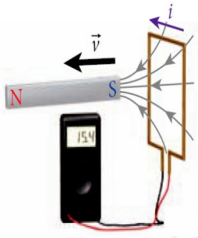
Faraday's experiment:

Move a piece of the wire in a closed circuit connected to a galvanometer between the two poles of a magnet as shown in the figure and Notice:

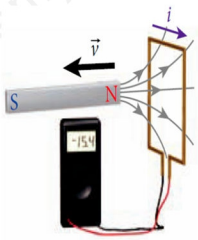
- No current flows if the wire is stationary or moving parallel to its length or parallel to the field lines.
- A current generated in a certain direction when the wire moved upward, cutting the field lines.
- A current generated in the opposite direction when the wire moved downward, cutting the field lines.
- The current itself is generated if the wire stays constant and the magnet is moved downward and upward.



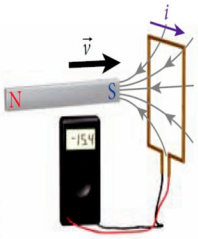
- Move a magnet`s pole relatively to a conducting loop connected to the ammeter, as shown in the figure:



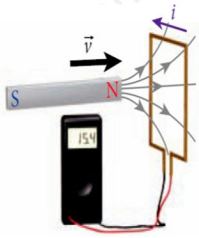
While a south pole is removed away from the loop, a current flows counter-clockwise.



While a north pole is removed away from the loop, a current flows clockwise.



While a south pole is rounded off the loop, a current flows clockwise.



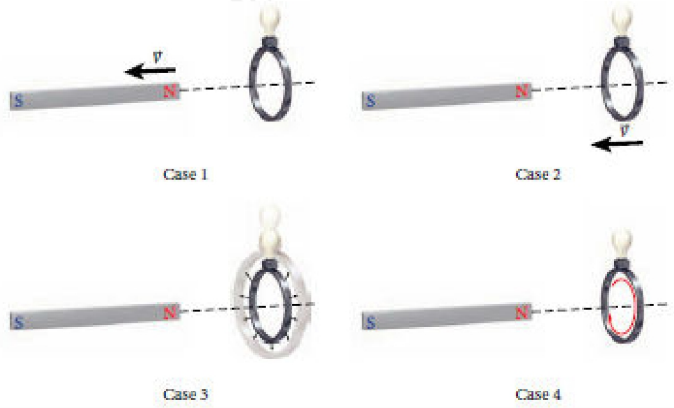
While a north pole is rounded off the loop, a current flows counterclockwise.

Faraday's law of induction

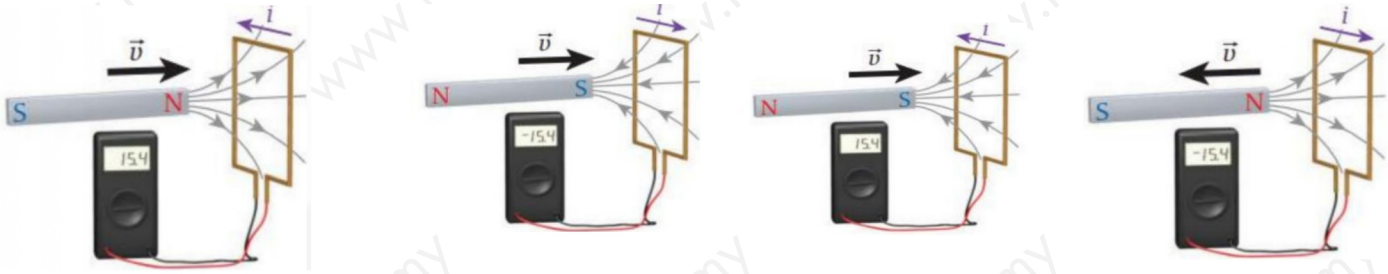
- Faraday's law states that: "A potential difference is induced in a loop when the number of magnetic field lines passing through the loop changes over time."

Example : The four figures show a bar magnet and a low-voltage light bulb connected to the ends of a conducting loop. The plane of the loop is perpendicular to the dotted line. In case 1, the loop is stationary, and the magnet is moving away from the loop. In case 2, the magnet is stationary, and the loop is moving toward the magnet. In case 3, both the magnet and loop are stationary, but the area of the loop is increasing. In case 4, the magnet is stationary, and the loop is rotating about its center. In which of these situations will the light bulb be burning?

a) case 1
b) cases 1 and 2
c) cases 1, 2, and 3
d) cases 1, 2, and 4
e) all four cases



Example : Which of the following figures is incorrect based on Faraday's experiments?



Magnetic flux Φ_B : "represents the total number of magnetic field lines that pass vertically across the area of the loop."

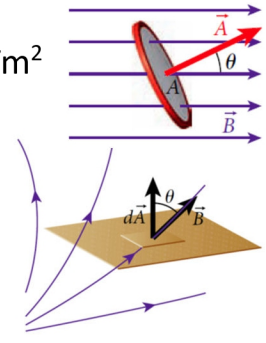
Mathematically, it is "the surface integrity of the magnetic field passing through a differential element of area."

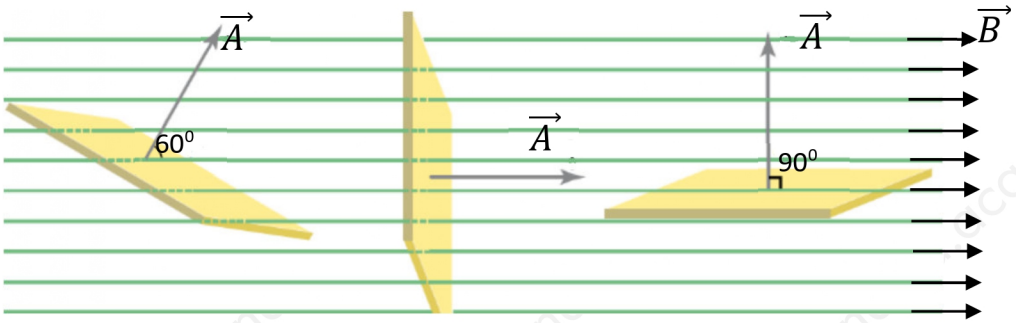
- magnetic flux $\Phi_B = \vec{B} \cdot d\vec{A}$
- The magnetic flux is measured in a unit called Weber Wb where: 1Wb = 1Tm^2

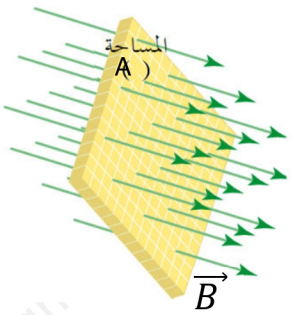
And if the surface is flat and the field is uniform the relationship becomes:

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

Where θ is the angle between $\vec{A}$ and $\vec{B}$







- **Gauss's law of magnetic fields:**

"The total magnetic flux through a closed surface is zero."

$$\oiint \vec{B} \cdot d\vec{A} = 0$$

This is because there are no free magnetic poles, as magnetic poles are always present in northern and southern pairs.

Q1: Calculate the magnetic flux across a surface of (0.2 m2) immersed in a magnetic field of (0.4) T if the area vector A is:

a- Perpendicular to B b- Same direction with B c- Make angle 60 with B d- Make angle of 135 with B.

Q2 : A magnetic field of (5) T affects a surface of (6m2) parallel to the area vector, if the magnetic field strength becomes (10) T, calculate the change in magnetic flux.

- **Example :**

In the adjacent figure, a coil has 12 turns in a uniform magnetic field of 0.5 T, so if the coil is removed from the field within 0.2 s

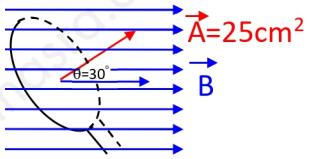
1- How much induced potential difference during the expulsion of the coil?

$\Phi_i = ABCos\theta \Rightarrow \Phi_i = 25 \times 10^{-4} \times 0.5 \times Cos30° = 1.1 \times 10^{-3} T.m^2$

$\Phi_f = 0 \quad \Rightarrow \Delta\Phi = 0 - 1.1 \times 10^{-3} = -1.1 \times 10^{-3} T.m^2$

$\Delta V_{ind} = -N\frac{\Delta\Phi}{\Delta t} \Rightarrow$

$\Delta V_{ind} = -12 \times \frac{-1.1\times10^{-3}}{0.2} = 0.066\ V$



2- If the coil is entered into the field through 0.2 s so that the plane of the coil is perpendicular to the field as it is inserted, then how much induced potential difference?

$\Phi_i = 0 \quad \Rightarrow \quad \Phi_f = 25 \times 10^{-4} \times 0.5 \times Cos0° = 1.25 \times 10^{-3}\ T.m^2$

$\varepsilon = -N\frac{\Delta\Phi}{\Delta t} \quad \Rightarrow \varepsilon = -12 \times \frac{(1.25 \times 10^{-3} - 0)}{0.2} = -0.075\ V$

- **Mathematical form of Faraday's Law:**

Faraday's law of induction is expressed by: $\Delta V_{ind} = -\frac{d\Phi_B}{dt}$ And in the case of a of N loop

$\Delta V_{ind} = -N\frac{d\Phi_B}{dt}$

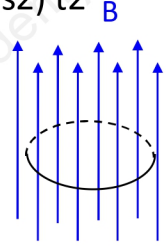
The flux can be changed by changing the magnetic field, changing the area, or changing the angle between

$\vec{A}$ and $\vec{B}$. Then the induced potential difference given by the flux derivative is:

$$\boldsymbol{\Delta V_{ind} = -NAcos\theta\frac{dB}{dt}} \qquad \boldsymbol{\Delta V_{ind} = -NBcos\theta\frac{dA}{dt}} \qquad \boldsymbol{\Delta V_{ind} = -NAB\frac{dcos\theta}{dt} = +NAB\omega Sin\theta}$$

Example:

In the adjacent figure there is a coil of 20 turns and a radius of 4 cm in a magnetic field whose magnitude changes with time according to the equation: B (t) = 0.5 (T) +0.004 (T / s2) t2



1- What is the amount of induced potential difference in the coil in terms of time?

$\Delta V_{ind} = -NA\frac{dB}{dt} \Rightarrow \Delta V_{ind} = -20(\pi 0.04^2)\frac{d(0.5+0.004t^2)}{dt} \Rightarrow |\Delta V_{ind}| = 0.008\ t$

2- How much induced potential difference in the coil at t = 8 s?

$|\Delta v_{ind}| = 0.008t \quad \Rightarrow \quad |\Delta v_{ind}| = 0.008 \times 8 \quad \Rightarrow \quad |\Delta v_{ind}| = 0.064\ v$

Q3: A loop with an area of $0.4m^2$ and a resistance of 19 Ω is placed in such a way that its level is perpendicular to a magnetic field whose amount varies according to the equation($B = 0.2t^3 - 0.5t + 2$), calculate :

1- The induced current when t=2s?
2- The magnetic flux at t=0?

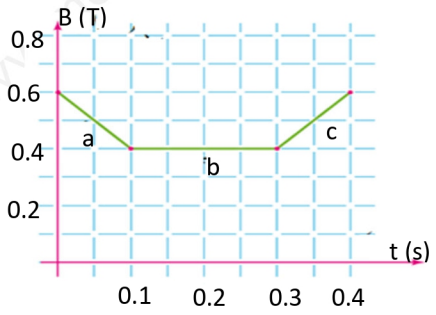
Q4 : A coil in the form of a square with a side length of 20 cm, consisting of (50) turns, and its resistance is (4 Ω), placed in a magnetic field corresponding to its area vector. If the magnetic field changes regularly from (0) to (2) Tesla within (two seconds), calculate:

1- The induced electromotive force generated in a coil.
2- The inductive current in the circuit.

Q5: A coil with a number of turns (100) turns. Calculate the induced potential difference if the magnetic flux increases at a rate of (5wb/s).

Q6: According to the adjacent drawing that shows the change of the magnetic field that penetrates a circularly coil. If you know that the number of turns in the coil is (2000) turns, and the cross-sectional area of the coil is (80 cm2) and the direction of the field is parallel to the area vector, calculate:

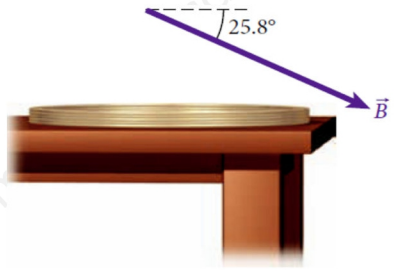
1- The change in magnetic flux in cases (a, b, c).
2- The average induced potential difference in (a, b, c).
3- Represent graphically the relationship between (ΔV_{ind}) and (t) in the periods (a, b, c).



Q7: A coil whose number of turns is 5000 turns is immersed in a uniform magnetic field, so the magnetic flux is 0.6 Tesla Calculate:

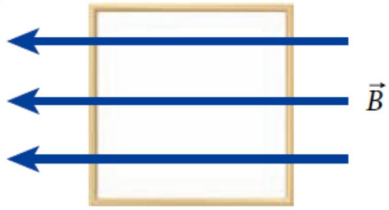
1- The induced potential difference in the coil when the direction of the magnetic field reverses within 0.2 seconds
2- The induced potential difference in the coil when the magnetic field vanished in 0.1 second (B=0)
3- The $\frac{\Delta\Phi_B}{\Delta t}$ when $\Delta V_{\_ind}$=100V

Q8: A circular coil of wire with 20 turns and a radius of 40.0 cm is laying flat on a horizontal table as shown in the figure. There is a uniform magnetic field extending over the entire table with a magnitude of 5.00 T and directed to the north and downward, making an angle of 25.8° with the horizontal. What is the magnitude of the magnetic flux through the coil.?.



Q9: When a magnet in an MRI is abruptly shut down, the magnet is said to be quenched. Quenching can occur in as little as 20.0 s. Suppose a magnet with an initial field of 1.20 T is quenched in 20.0 s, and the final field is approximately zero. Under these conditions, what is the average induced potential difference around a conducting loop of radius 1.00 cm (about the size of a wedding ring) oriented perpendicular to the field?

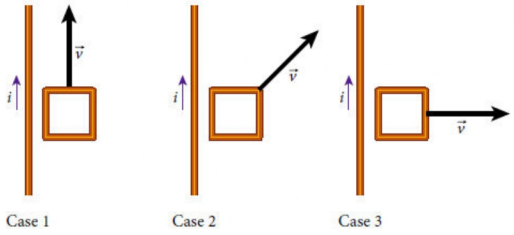
Q10: A metal loop has an area of 0.100 m2 and is placed flat on the ground. There is a uniform magnetic field pointing due west, as shown in the figure. This magnetic field initially has a magnitude of 0.123 T, which decreases steadily to 0.075 T during a period of 0.579 s. Find the potential difference induced in the loop during this time.



Q11: Choose the correct answer:

1- A long wire carries a current, i, as shown in the figure. A square loop moves in the same plane as the wire as indicated. In which cases will the loop have an induced current?

a) cases 1 and 2
b) cases 1 and 3
c) cases 2 and 3
d) None of the loops will have an induced current.



2- A solenoid with 200 turns and a cross-sectional area of 60 cm^2 has a magnetic field of 0.60 T along its axis. If the
field is confined within the solenoid and changes at a rate of 0.20 T/s, the magnitude of the induced potential difference in the solenoid will be

a) 0.0020 V. b) 0.02 V. c) 0.001 V. d) 0.24 V.

3- Which of the following will induce a current in a loop of wire in a uniform magnetic field?

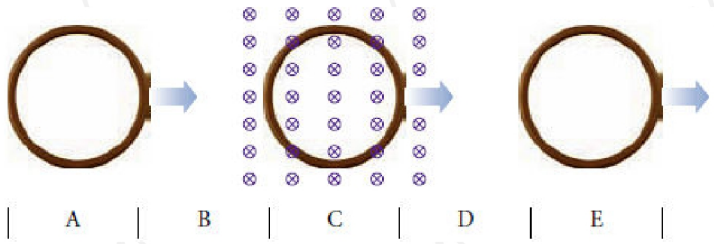
a) decreasing the strength of the field
b) rotating the loop about an axis parallel to the field
c) moving the loop within the field
d) all of the above

4- Faradays Law of Induction states

a) that a potential difference is induced in a loop when there is a change in the magnetic flux through the loop.
b) that the current induced in a loop by a changing magnetic field produces a magnetic field that opposes this change in magnetic field.
c) that a changing magnetic field induces an electric field.
d) that the inductance of a device is a measure of its opposition to changes in current flowing through it.

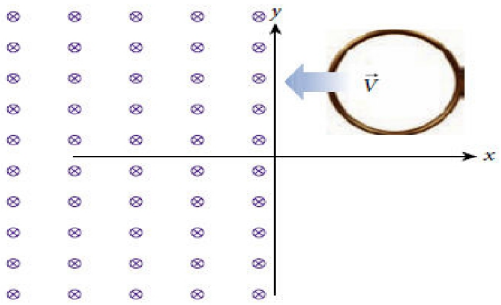
5- A conducting ring is moving from left to right through a uniform magnetic field, as shown in the figure. In which
regions is there an induced current in the ring?

a) regions B and D
b) regions B, C, and D
c) region C
d) regions A through E



6- A circular loop of wire moving in the xy-plane with a constant velocity in the negative x-direction enters a uniform magnetic field, which covers the region in which $x < 0$, as shown in the figure. The surface normal vector of the loop points in the direction of the magnetic field. Which of the following statements is correct?

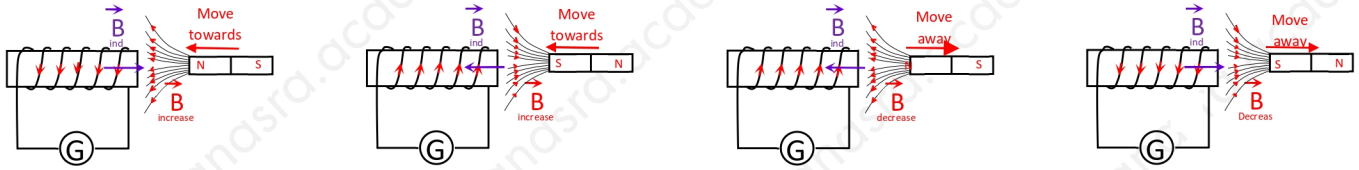
a) The induced potential difference in the loop is at a maximum as the edge of the loop just enters the region with the magnetic field.
b) The induced potential difference in the loop is at a maximum when one fourth of the loop is in the region with the magnetic field.
c) The induced potential difference in the loop is at a maximum when the loop is halfway into the region with the magnetic field.
d) The induced potential difference in the loop is constant from the instant the loop starts to enter the region with the magnetic field.



7- Awire loop is placed in a uniform magnetic field (0.5T) , the magnetic field decrease to be zero with a constant rate during a period of (0.25s) , if the average potential difference induced in the loop is (1.24V) what is the radius of the loop ?

a- 0.18m b- 0.22m c- 0.44m d- 0.92m

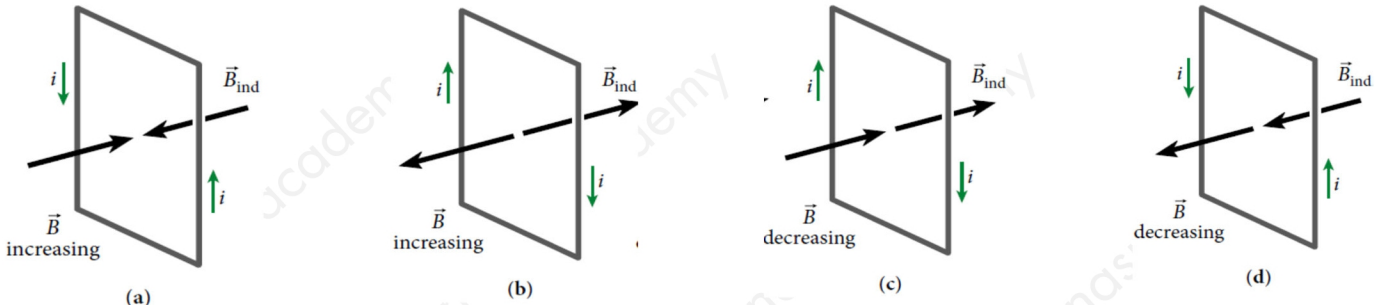
- **Lenz's law:** Used to determine the direction of the induced current in a loop or coil.
  "An induced current will have a direction such that the magnetic field due to the induced current opposes the change in the magnetic flux that induces the current."



Notes:

*The induced current creates in the coil a like magnetic pole if the source magnet increases the flux Φ.

*The induced current creates in the coil an opposite magnetic pole if the source magnet decreases the flux Φ.



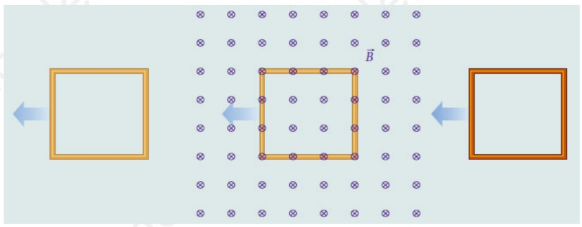
An increasing magnetic field pointing to the right induces a current that creates a magnetic field pointing to the left.

An increasing magnetic field pointing to the left induces a current that creates a magnetic field pointing to the right.

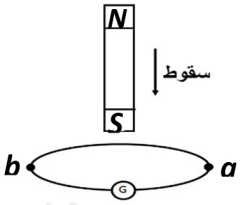
A decreasing magnetic field pointing to the right induces a current that creates a magnetic field pointing to the right.

A decreasing magnetic field pointing to the left induces a current that creates a magnetic field pointing to the left.

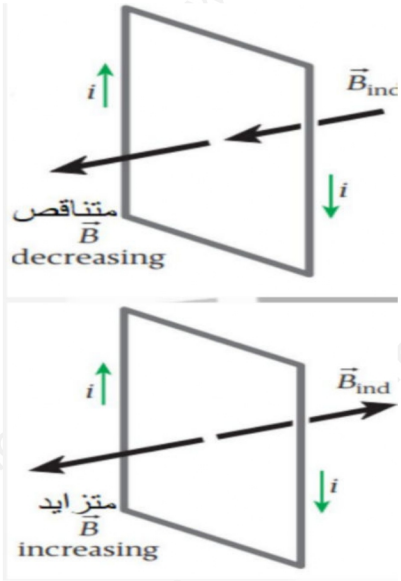
Q12: A square conducting loop with very small resistance is moved at constant speed from a region with no magnetic field through a region of constant magnetic field and then into a region with no magnetic field, as shown in the figure. As the loop enters the magnetic field, what is the direction of the induced current? As the loop leaves the magnetic field, what is the direction of the induced current?

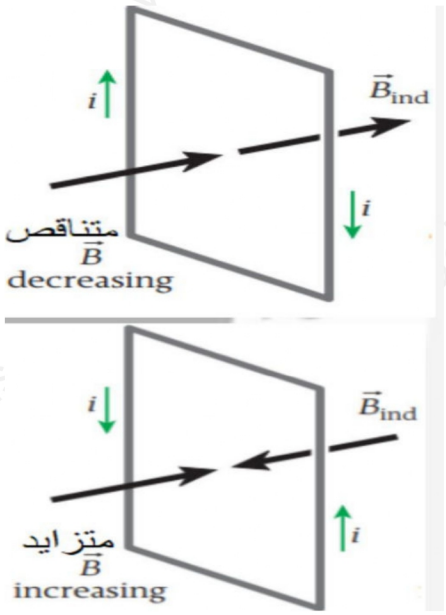


Q13: Determine the direction of the induced current through loop a b during the entry and exit of the magnet:



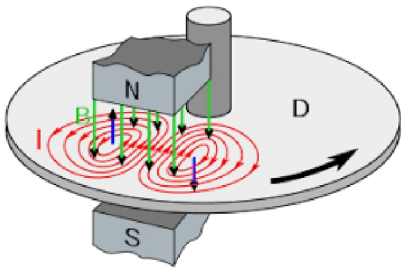
Q14:
Which of the following diagrams is not correct according to Lenz's Law?





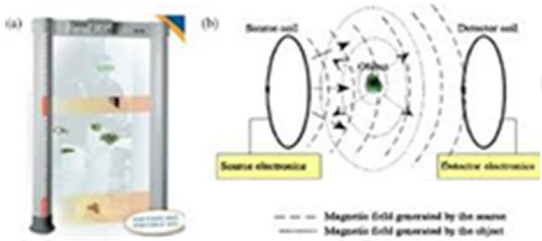
- **Eddy currents:**
  "Currents are induced in a piece of metal due to the circulation of their free electrons by the influence of a magnetic field causing change in magnetic flux."

Induced eddy currents are generated when metal pieces move within a variable magnetic field, and according to Linz's law, variable magnetic flux induces currents that tend to resist the change in magnetic flux. These induced currents produce induced magnetic fields that resist the external magnetic field that produced the currents, slowing the movement of metal pieces.



* One of the disadvantages of eddy currents is the high temperature inside the metal piece, and to reduce that, the piece is divided into segments isolated from each other.
*Positive practical applications of eddy currents include induction furnaces used in metal melting as well as train brakes.

- **Metal detector:**



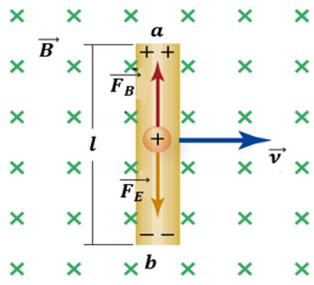
- It consists of a transmitter coil that sends an alternating current and the receiver coil measures the current sent.
- When a piece of metal passes between the transmitter and receiver, Induced eddy currents are generated and according to Linz`s law it will resist the change in the current that causes it.
- Eddy currents result in a decrease in the current value measured by the receiving coil.

Eddy currents can be used to convert the kinetic energy of the **train wheels** to thermal energy, which **slows down the speed** of the train.

*** Traffic lights:**

A rectangular wire loop hidden in the asphalt acts as a transmitter coil and a receiver coil at the same time. The metal body of the car creates the eddy currents that cause the lack of current which the transmitter measures, this automatically turns the signal to green after some delay time interval.

Induced potential difference in a straight wire moving in a magnetic field:(ΔV_{ind})



Interpretation of the generation of inductive potential difference in a conductor:

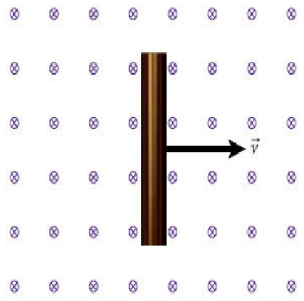
When the wire is moved, the free electrons move with it, affected by a magnetic force and moving to the end of the wire b, which arises Electric field so the Electrons are affected by an electric force in the opposite direction, and the transfer of electrons continues until the two forces are balanced, So a difference in the voltage occurs.

$$F_E = F_B \quad \Rightarrow \quad qE = qv_\perp B \quad \Rightarrow \quad \frac{\Delta V_{ind}}{\ell} = Bv_\perp \quad \Rightarrow \quad \Delta V_{ind} = B\ell v_\perp$$

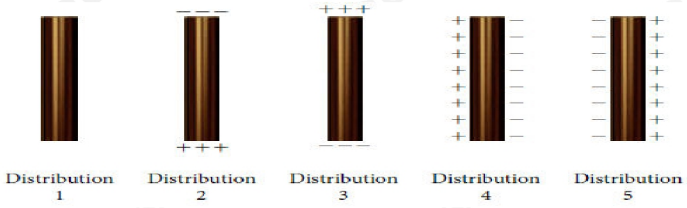
- **Calculate amount (ΔV_{ind}):**

The amount of inductive potential difference (inductive momentum) depends on both the magnetic field B and the length of the wire portion that is exposed to the field ℓ and the vertical speed vehicle on the field $v_\perp = v \sin\theta$ and is given by the equation: $\Delta V_{ind} = B\ell v_\perp$

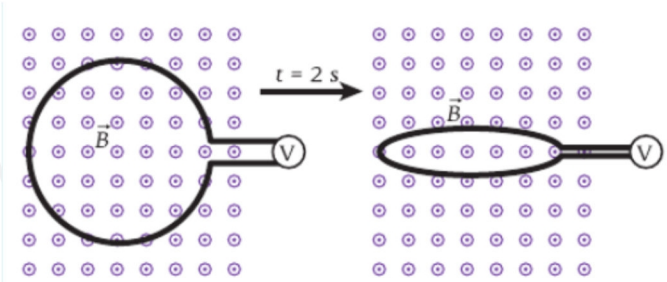
Q15: A metal bar is moving with constant velocity v through a uniform magnetic field pointing into the page, as shown in the figure. Which of the following most accurately represents the charge distribution on the surface of the metal bar?



a) distribution 1
b) distribution 2
c) distribution 3
d) distribution 4
e) distribution 5



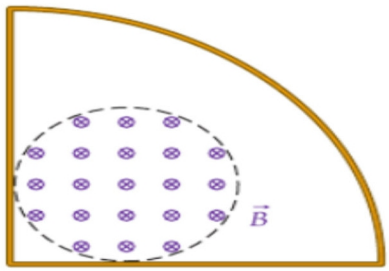
Q16: A wire loop is placed in a uniform magnetic field. Over a period of (2s) , the loop is shrunk . Which statement about the induced potential difference is correct?



a- There will be some induced potential difference.
b- There will be no induced potential difference because the magnetic flux does not change.
c- There will be no induced potential difference because the loop is not closed.
d- There will be no induced potential difference because the loop is shrinking.

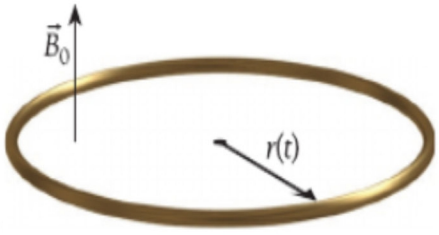
Q17: In 1996, the Space Shuttle Columbia deployed a tethered satellite on a wire out to a distance of 20 km. The wire was oriented perpendicular to the Earth's magnetic field at that point, and the magnitude of the field was $B = 5.1 \cdot 10^{-5}$ T. Columbia was traveling at a speed of 7.6 km/s. What was the potential difference induced between the ends of the wire?

Q18: The conducting loop in the shape of a quarter circle shown in the figure has a radius of 10.0 cm and resistance of 0.200 Ω. The magnetic field strength within the dotted circle of radius 3.00 cm is initially 2.00 T. The magnetic
field strength then decreases from 2.00 T to 1.00 T in 2.00 s. Find
(a) the magnitude and (b) the direction of the induced current in the lo



Q19: A supersonic aircraft with a wingspan of 10.0 m is flying over the north magnetic pole (in a magnetic field of
magnitude 0.500 G perpendicular to the ground) at a speed of three times the speed of sound. What is the potential difference between the tips of the wings? Assume that the wings are made of aluminum.

Q20: An elastic circular conducting loop expands at a constant rate over time such that its radius is given by
r(t) = r0 + vt, where r0 = 0.100 m and v = 0.0150 m/s. The loop has a constant resistance of R = 12.0 Ω and is placed in a uniform magnetic field of magnitude B_0 = 0.750 T, perpendicular to the plane of the loop, as shown in the
figure. Calculate the direction and the magnitude of the induced current, i, at t = 5.00 s.



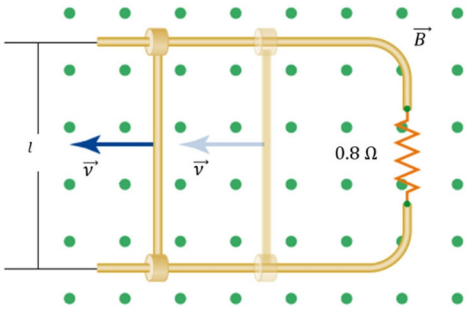
Q21: A straight conductor of length (40 cm) perpendicular to a uniform magnetic field (2) Tesla, if it moves at a constant speed (80 cm/s) perpendicular to its length and to the magnetic field, calculate:

1- The average induced potential difference.

2- The induced current generated through the conductor.

3- The power consumed by the external resistance.

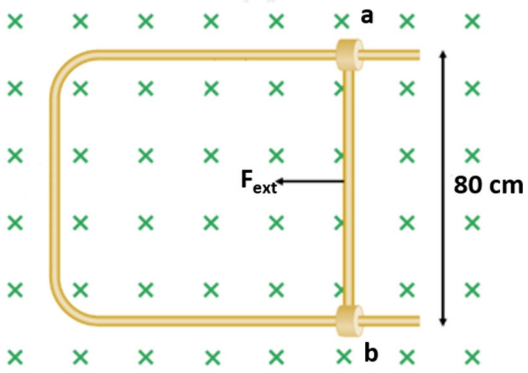
4- If the conductor is parallel to the magnetic field, what happens to (i_{ind} andΔv_{ind}).



Q22: When moving the conductor (a b) at a constant speed (50 m/s) as in the figure, and if the resistance of the rail and the conductor together is (20) ohms, calculate: (note that B = 2 T)

1- ΔV_{ind}

2- i_{ind}



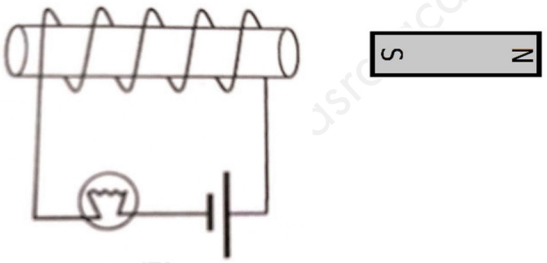
Q23: What happens to the bulb lighting in the following cases :

a- When the magnet moves towards the coil.

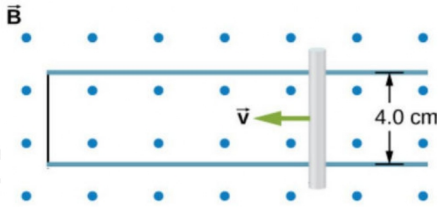
Decrease instantaneously

b- When the magnet moves away from the coil.

Increasing instantaneously



Q24:



The conducting rod shown in the figure, is pulled horizontally through a uniform magnetic field of strength (B=0.65T) with a constant velocity. If the induced potential difference between the ends of the rod equals to (0.32V). What is the velocity of the rod?

a- 12.3 m/s b- 0.08 m/s c- 2.08 m/s d- 9.81 m/s

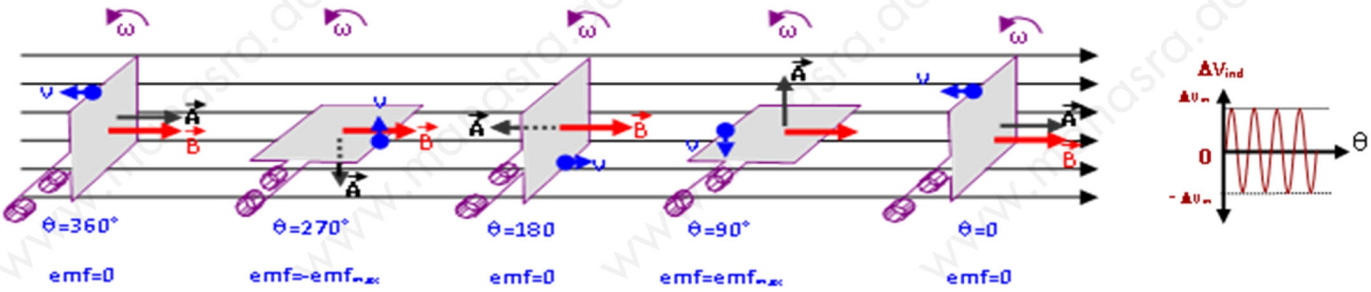
- **Generators and electric motors:**

  Generator : "It is a device that converts kinetic energy into electrical energy."

  Electric motor: "It is a device that converts electrical energy into kinetic energy.

AC generator (continuously variable driving force generator):

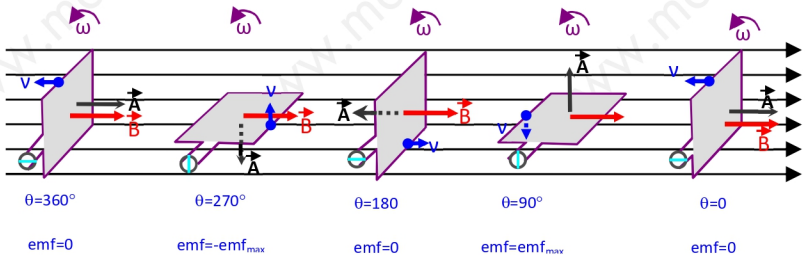
The coil rotates and cuts its field lines, and the magnetic flux that passes the coil continuously changes by changing the angle θ, so we get a continuously Variable induced driving force, given by: $\Delta V_{ind} = N\omega AB \sin\theta$ $(where\ \omega = 2\pi f)$

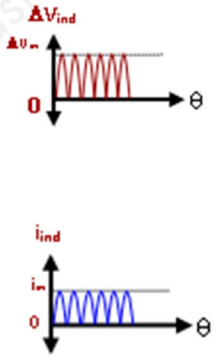


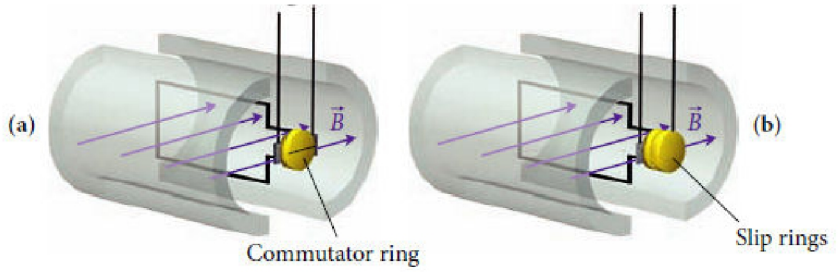
DC generator

The ends of the coil are connected to the outer circuit by two halves of a metal ring between them, a dielectric called the reflector, this causes the Unidirectional pocket potential difference ($V = V_{max} \sin\theta$)to pass between the ends of the generator

The circuit is a Unidirectional pocket current $I = I_{max} \sin\theta$ illustrated by a curve as shown in the figure.

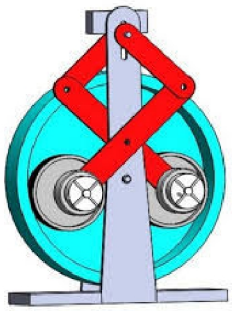






(a) A simple direct-current (DC) generator/motor.
(b) A simple alternating-current (AC) generator/motor.

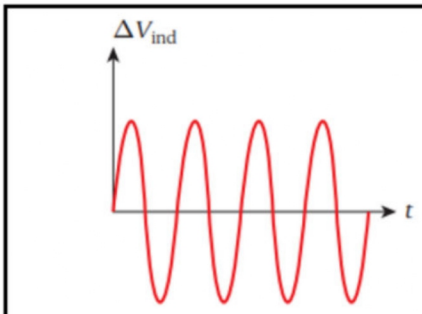
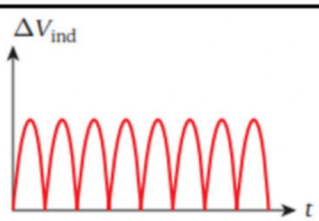
Regenerative Braking:



One of the advantages of hybrid cars is that they are using regenerative braking, as they take benefit of the reverse motion while breaking at running an electric generator, that generates electrical energy used to recharge the battery, partially recovering energy, which increases fuel efficiency.

Q25:

The figure shows two graphs representing the induced potential difference as a function of time for two generators. Which of the following rows indicates the correct type of generator under each graph?

		
A	a simple alternating-current generator مولد بسيط للتيار المتردد	a simple direct-current generator مولد بسيط للتيار المستمر
B	a simple alternating-current generator مولد بسيط للتيار المتردد	a simple alternating-current generator مولد بسيط للتيار المتردد
C	a simple direct-current generator مولد بسيط للتيار المستمر	a simple direct-current generator مولد بسيط للتيار المستمر
D	a simple direct-current generator مولد بسيط للتيار المستمر	a simple alternating-current generator مولد بسيط للتيار المتردد

Q26: When can we use the equation ($\Delta Vind = \omega ABsin\theta$) to find the induced potential difference?

a- A and B are constant. b- A, B and θ are constant
c- B and θ are constant d-A and θ are constant.

Q27: Which of the following is not correct about the generator and motors?

a- The motors transform kinetic energy into electric energy
b- Generators and motors contain loops in a magnetic field
c- Generators and motors are applications of electromagnetic induction
d- Generator that produces alternating voltages and the resulting alternating current is also called an alternators

Q28: A simple generator consists of a loop rotating inside a constant magnetic field.
If the loop is rotating with frequency f, the magnetic flux is given by $\Phi(t) = BA \cos(2\pi ft)$.
If B = 1.00 T and A = 1.00 m^2, what must the value of "f" be for the maximum induced potential difference to be 110. V?

Q29: A motor has a single loop inside a magnetic field of magnitude 0.87 T. If the area of the loop is 300. cm^2, find the maximum angular speed possible for this motor when connected to a source of emf providing 170 V.

Q30: Your friend decides to produce electrical power by turning a coil of 1.00×10^5 circular loops of wire around an axis parallel to a diameter in the Earth's magnetic field, which has a local magnitude of 0.300 G. The loops have a radius of 25.0 cm.

a) If your friend turns the coil at a frequency of 150.0 Hz, what peak current will flow in a resistor, R = 1500. Ω, connected to the coil?

b) The average current flowing in the coil will be 0.7071 times the peak current. What will be the average power obtained from this device

Induced electric field (E_{ind})

From our study to calculate the potential difference, we found that:

$\Delta V = \oint \vec{E} \cdot d\vec{S}$ And from Faraday's law: $\Delta V = -\frac{d\Phi}{dt}$

By combining the two equations, we obtain: $\oint \vec{E} \cdot d\vec{S} = -\frac{d\Phi}{dt}$

- Which means that the variable magnetic flux generates an electric field calculated from that relationship and applied to any closed path in a variable magnetic field even if there is no conductor in the path. (The direction of(E_{ind}) is in the same direction of (i_{ind}).

Q31:

For a positive charge moving in a circular path in an electric field, the induced potential difference can be expressed as:($\Delta V_{ind} = 2\pi x E$) . What does x represent?

a- The magnitude of the charge.
b- Induced electric field.
c- The radius of the circular path.
d- Induced electric current.

Inductance of a Solenoid:

The total magnetic flux through a solenoid formed of N turns and carrying a current i through it is $\Phi_{tot} = N\Phi_B$ Where $\Phi_B = \vec{B} \cdot d\vec{A}$ ($\Phi_B = ABcos0 = AB$) and It is directly proportional to the intensity of the current passing through the coil: ($N\Phi_B = Li$) .

Where L is a fixed amount per coil called the coil-induction coefficient of the coil and is measured in a unit called Henry H where: $1H = \frac{T.m2}{A}$ = Wb/A

The coefficient of self-induction of any coil depends on its engineering specifications and the coil in the circuit is called an inductor.

The self-induction coefficient of a solenoid is calculated from the relationship:

$L = \mu\, n^2 \ell A$ $\quad (n = \frac{N}{\ell})$ or $L = \frac{\mu\, N^2 A}{\ell}$

n: $Number\ of\ turns\ per\ unit\ length.$
N: Number of turns
A : Cross – sectional area ($A=\pi r^2$)
ℓ: $The\ length\ of\ solenoid$

Example : A solenoid with a length of (0.15m) and (20 turns /cm) and a radius of (2cm). An electric current of (5A) is passing through it. Calculate the inductance of the coil ?.

Q32:

A solenoid inductance is equal (3×10^{-3}H) . Suppose that the length of the solenoid is increased to be three times its original length , and the average cross – section area is reduced to be one fifth of its original radius, while the number of turns not changed .

Calculate the new inductance ?

Q33: What does the unit of inductance Henry (H) equal?

a- A^2m^2/T

b- Am^2/T

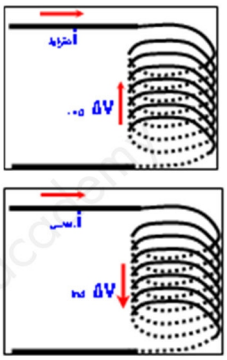
c- Tm^2/A

d- T^2m/A

Self-induction and mutual induction:

Self induction:

"It creates an electric driving force in a coil due to the change in the intensity of the passing current in the coil itself."



Note:

- As the current intensity increases, the flow that passes the file coils increases and a reverse inductive driving force and reverse inductive current is created.
- While decreasing the current intensity, the flow that passes the file coils decreases and a direct inductive drive and a direct inductive current is created.
- Calculates the induced potential difference from the relationship:

$$\Delta V_{ind} = -\frac{dN\Phi_B}{dt} = -L\frac{di}{dt}$$

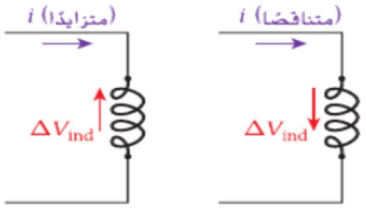
- The negative signal indicates that the inductive current always resists the changes in the original current.

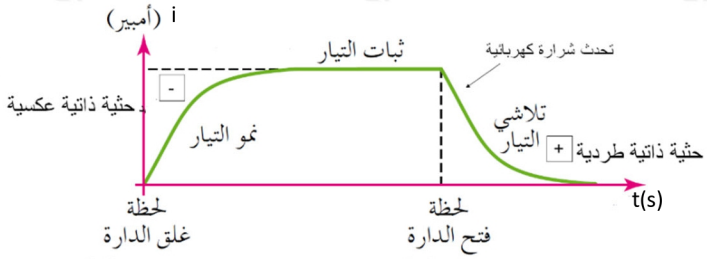
- The self-induction coefficient can be calculated from the relationship:

$$N\Phi_B = Li$$

- In the case of the solenoid from the relationship:

$$L = \mu\, n^2 \ell A \qquad (n = \frac{N}{\ell}) \quad \Rightarrow \quad L = \frac{\mu\, N^2 A}{\ell}$$

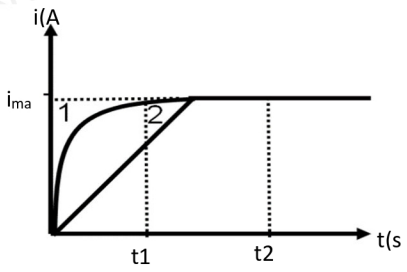




$$\Delta V_{ind,L} = -L\frac{\Delta i}{\Delta t} \qquad L = \frac{\Delta V_{ind,L}}{\frac{\Delta i}{\Delta t}}$$

Note: The self-induction coefficient works to control the growth rate of the current in the coil, so if L is large, the current growth rate is small, i.e. the current grows slowly and takes longer time to reach its maximum value.

When drawing the relationship between current and time for two inductors, we find that L1 <L2 because in the first inductor, reaching the maximum value of the current was faster.



Example: a solenoid with a section area of 2.5 cm^2 and an axis length of 10 cm consisting of 200 folds and inside the core of its magnetic transmittance coefficient 0.004 Tm / A, If the coil has a current of 8 A, then answer the following:

1) **Find the self-induction coefficient of the coil.**

$$L = \frac{\mu N^2 A}{\ell} \quad \Rightarrow \quad L = \frac{0.004 \times 200^2 \times 2.5 \times 10^{-4}}{10 \times 10^{-2}} \quad \Rightarrow \quad L = 0.4\ H$$

2) **Calculate the magnetic flux that passes one coil of the file coils.**

$$L = \frac{N\Phi}{I} \quad \Rightarrow \quad \Phi = \frac{L\ I}{N} \quad \Rightarrow \quad \Phi = \frac{0.4 \times 8}{200} \quad \Rightarrow \quad \Phi = 0.016\ T.m^2$$

3) **How much induced electric driving force in the coil if the current reflected in 0.02 s?**

$$\varepsilon = -L\frac{\Delta I}{\Delta t} \quad \Rightarrow \quad \varepsilon = -0.4\frac{(-8-8)}{0.02} \quad \Rightarrow \quad \varepsilon = 320\ v$$

4) **If the coil itself is divided into two identical sections, how much is the self-induction coefficient for each section?**

The coefficient of induction for each section is reduced to half of the coil coefficient of the original, making L = 0.2 H for each section.

5) **What happens in the original file itself if we multiply the number of folds to double by wrapping another layer of coils over the first and with the same length? How much does it become?**

The self-inductance factor increases to four times its original value, so L = 1.6 H

Q34: A solenoid whose number of turns is (200) turns, its length is (20 cm), and its cross-sectional area is (5 cm^2), calculate:

1- self-induction coefficient of the coil.

2- The induced electric driving force if the passing current is decreasing at a rate of (50 A/s).

Q35: A coil whose self-inductance coefficient (2) Henry is carrying a current of (0.5) ampere, calculate the induced electric driving force if:

1- The circuit was opened and the current disappeared within (0.01 s).
2- If the inductor current reversed within (0.2 s).

The phenomenon of mutual induction:

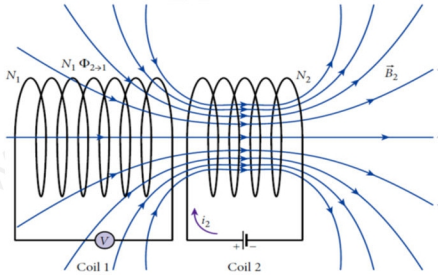
"It creates an induced impulsive force in one of the two circuits due to the change in the intensity of the current in the next circle".

$$\Delta V_{ind,1} = -M\frac{di_2}{dt} \qquad \& \qquad \Delta V_{ind,2} = -M\frac{di_1}{dt}$$

Where M is the coefficient of mutual induction between the two coils and is measured in Henry. It can be calculated from any of the two equations:

$M = N_1\frac{\Phi_{B\ 2\to1}}{i_2}$ (The mutual inductance of coil 2 due coil 1)

$M = N_2\frac{\Phi_{B\ 1\to2}}{i_1}$ (The mutual inductance of coil 1 due coil 2)



$M = \mu\, N_2 n_1 A_1$ $\qquad$ $M = \mu\, N_1 n_2 A_2$

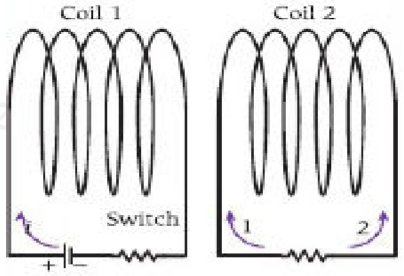
Q36: A short coil with radius R = 10.0 cm contains N = 30.0 turns and surrounds a long solenoid with radius r = 8.00 cm containing n = 60 turns per centimeter. The current in the short coil is increased at a constant rate from zero to i = 2.00 A in a time of t = 12.0 s. Calculate the induced potential difference in the long solenoid while the current is increasing in the short coil.

Q37: The figure shows two identical coils. A current is flowing in coil 1 in the direction shown. When the switch is opened in the circuit of coil 1, what happens in coil 2?

a- A current is induced in coil 2 that flows in direction 1.

b- A current is induced in coil 2 that flows in direction 2.

c-No current is induced in coil 2.



Q38:

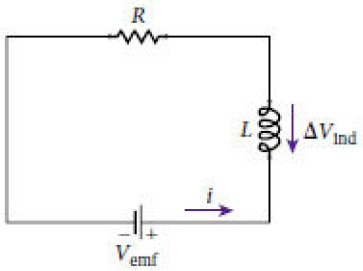
A long solenoid with a circular cross section of radius (r_1=0.05m) and (n=800turns /m) is inside and coaxial with a short coil that has circular cross section of radius (r_2=0.10 m) and (N=7turns). While the current in the long solenoid is increased steadily from (0.003A) to *i* over (0.6millisecond), the potential difference induced in the short coil is (-0.4V)

- Calculate the *current i*

- **RL Circuits:**

If a source of emf is placed in a single-loop circuit containing a resistor with resistance R and an inductor with inductance L, called an RL circuit.

When the switch is closed the increasing current flowing through the inductor creates a self-induced potential difference that tends to oppose the increase in current. As time passes, the change in current decreases, and the opposing self-induced potential difference also decreases. After a long time, the current becomes steady at the value $i_{max} = V_{emf}/R$.



$$V_{emf} = iR + L\, di/dt$$

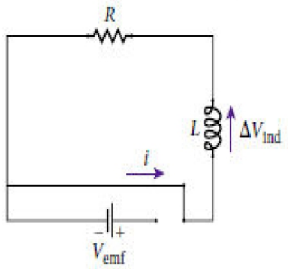
$$i(t) = \frac{V_{emf}}{R}\left(1 - e^{-t/(L/R)}\right).$$

$$i_t = i_{max}\left(1 - e^{-t/(L/R)}\right)$$

Note: Time constant (τ) = L/R

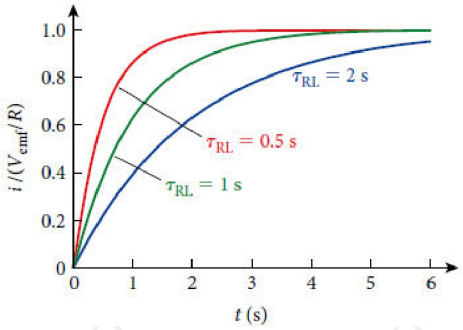
When the switch is closed $t = 0$, the current is zero. For $t \to \infty$, the current is given by $i_{max} = V_{emf}/R$, which is as expected.

When the battery suddenly removed the current decreases gradually until
It reach zero because the decreasing current in the inductor creates
A self-induced potential difference that tends to oppose the decreasing current.

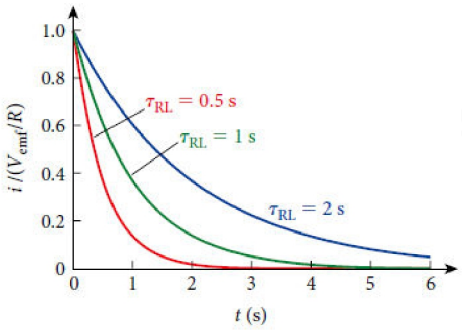


$$L\frac{di}{dt} + iR = 0. \qquad i(t) = i_0 e^{-t/\tau}$$

RL circuits can be used as timers to turn on devices at particular intervals and can also be used to filter out noise.



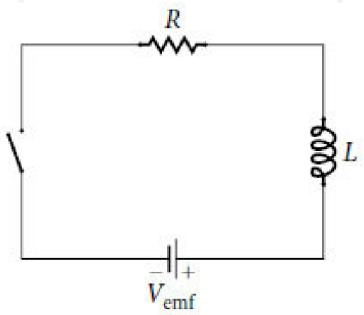
Current as a function of time when a resistor, an inductor, and a source of emf are connected in series.



Current as a function of time when the source of emf is suddenly removed from an RL circuit that has been connected for a long time.

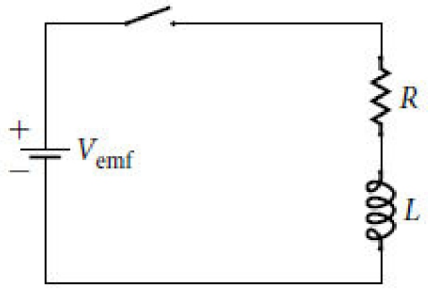
Notes : 1- Immediately after the switch is closed, the inductor is like an open-circuit.
2- After a long time, the inductor acts like a short-circuit. The circuit is in steady state, so the current is no longer changing.

Q39: Consider the RL circuit shown in the figure.
When the switch is closed, the current in the circuit increases exponentially to the value i = Vemf/R.
If the inductor in this circuit is replaced with an inductor having three times the number of turns per unit length,
the time required to reach a current of magnitude 0.9i .
a) increases. b) decreases. c) stays the same.



Q40: Consider an RL circuit with resistance R = 1.00 MΩ and inductance L = 1.00 H, which is powered by a 10.0-V battery.
a) What is the time constant of the circuit?
b) If the switch is closed at time t = 0, what is the current just after that time?
c) what is the current After 2.00 μs?
d) what is the current When a long time has passed?

Q41: In the circuit in the figure, R = 120. Ω, L = 3.00 H, and V_{emf} = 40.0 V. After the switch is closed, how long will it take the current in the inductor to reach 300. mA?



Q42: The current is increasing at a rate of 3.6 A/s in an RL circuit with R = 3.25 Ω and L = 440 mH. What is the potential difference across the circuit at the moment when the current in the circuit is 3.0 A?

Q43: In an RL circuit with a resistance of 21.8Ω and an inductance coefficient of 55.9mH, how long will it take for the current to reach 75 c/o of its maximum value?

- **Energy and energy density of a magnetic field:**

"The energy stored in the magnetic field of the inductor can be calculated from the equation:

$$U_B = \int_0^t P\, dt = \int_0^i Li'\, di' = \frac{1}{2}Li^2$$

$$U_B = \frac{1}{2}\mu n^2 \ell A i^2$$

The instantaneous power of the inductor is :

$$P = V_{emf} i = \left(L\frac{di}{dt} \right) i.$$

Q44: **Choose the most appropriate answer for each sentence of the following:**

1- An emf of 20V is applied to a coil with an inductance of 40mH and a resistance of 0.5Ω. What is the energy stored in the magnetic field when the current reach quarter of its maximum value?

a- 20J B- 4J C- 2J D- 16J

2- Along solenoid has a circular cross section of radius 8.1 cm , a length 0.54 m , and $n=2\times10^4$ (turns/m) . The solenoid is carrying a current of magnitude 4.04×10^{-3} A. How much energy is stored in the magnetic field of the solenoid?

a- 2.11×10^{-7} J b- 6.66×10^{-3} J C- 4.57×10^{-5} J D- 8.91×10^{-6} J

3- If the current in a solenoid is doubled, then the energy stored in the solenoid:

a- Increase by a factor of 4 b- decrease by a factor of 4 c- Increase by a factor of 2

4- A long solenoid with inductance 1.2H carries a current i. It stores 375J of energy. What is current (i)?

a- 25 A B- 5 A C- 1.8 A D- 18 A