

Magnetism

Course for BSc 2nd Semester General

Subject : Physics

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Magnetism at School

According to the syllabus you know all the basic definitions at school.

Magnetic field

potential

Magnetic moments

Torques

Actually it is a course on magnetic effect of electric current

Lorentz force law

- Force on a static charge q in a electric field $\vec{E}$ is, $q \vec{E}$
- Force on a moving charge q with velocity $\vec{v}$ in a magnetic field $\vec{B}$ is $q\vec{v} \times \vec{B}$
- Total Force $\vec{F}$ on a moving charge in a electromagnetic field is,

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

This is known as the Lorentz force.

This force law is universal i.e. it is valid for any electromagnetic field and velocity.

- Magnetic force is always perpendicular to the velocity of the charge, hence no work is done by this force. Unit of magnetic field is *tesla, T*.

A moving charge **experiences magnetic force in a magnetic field**
and can generate magnetic field.

stationary charges generate steady E-field.

steady currents generate steady B-field.

Biot-Savart's law

In 1820 Oersted discovered the action of electric current on a magnetic needle.

In the same year Biot-Savart formulated a law regarding the interaction current element and magnetic pole. Using this formula one can obtain Magnetic field due to any shape of current carrying conductor.

Currents which arise due to the motion of charges are the source of magnetic fields.

When charges move in a conducting wire and produce a current i , the magnetic field at any point P due to the current can be calculated by adding up the magnetic field contributions, $d\vec{B}$, from small segments of the wire $d\vec{s}$

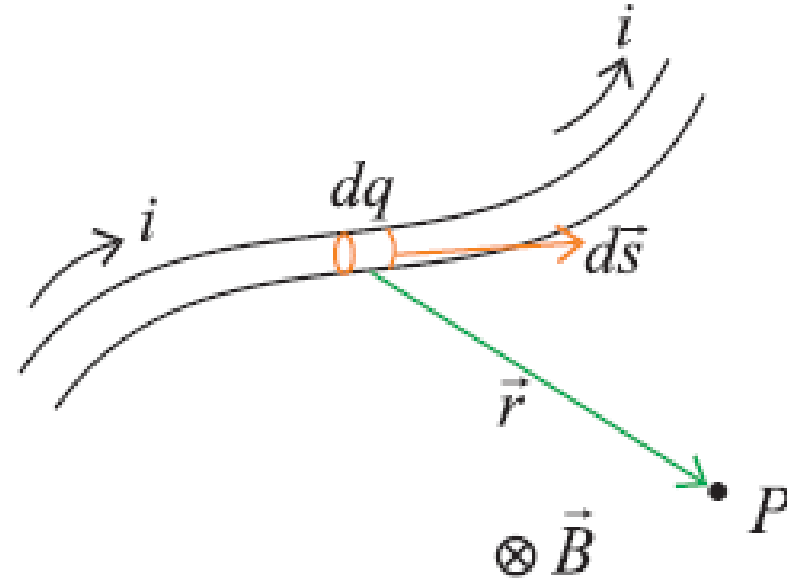
The magnetic field, $d\vec{B}$ for the small segment $d\vec{s}$ can be expressed by Biot-Savart law as,

$$d\vec{B} = \frac{\mu_0}{4\pi} \frac{id\vec{s} \times \vec{r}}{r^3}$$

The total magnetic field, $\vec{B}$ for the wire is,

where μ_0 is permeability of free space and its value is $4\pi \times 10^{-7} \text{ Tm/A}$

$$\vec{B} = \int d\vec{B} = \frac{\mu_0}{4\pi} \int_{\text{wire}} \frac{id\vec{s} \times \vec{r}}{r^3}$$



Application of Biot-Savart's law

Biot-Savart Law is to magnetic field as Coulomb's Law is to electric field.

Basic element of E-field: Electric charges dq

Basic element of B-field: Current element $id\vec{s}$

Determination of magnetic field for

a straight conductor

circular coil and

solenoid carrying current.

Force between two straight current carrying wires.

Magnetic field of a straight conductor

Biot-Savart Law:
$$d\vec{B} = \frac{\mu_0}{4\pi} \frac{id\vec{s} \times \vec{r}}{r^3}$$

The fig clearly shows that

$$\begin{aligned} |d\vec{s} \times \vec{r}| &= dz r \sin\phi \\ &= dz r \sin(\pi - \phi) \\ &= dz r \frac{d}{r} = ddz \end{aligned}$$

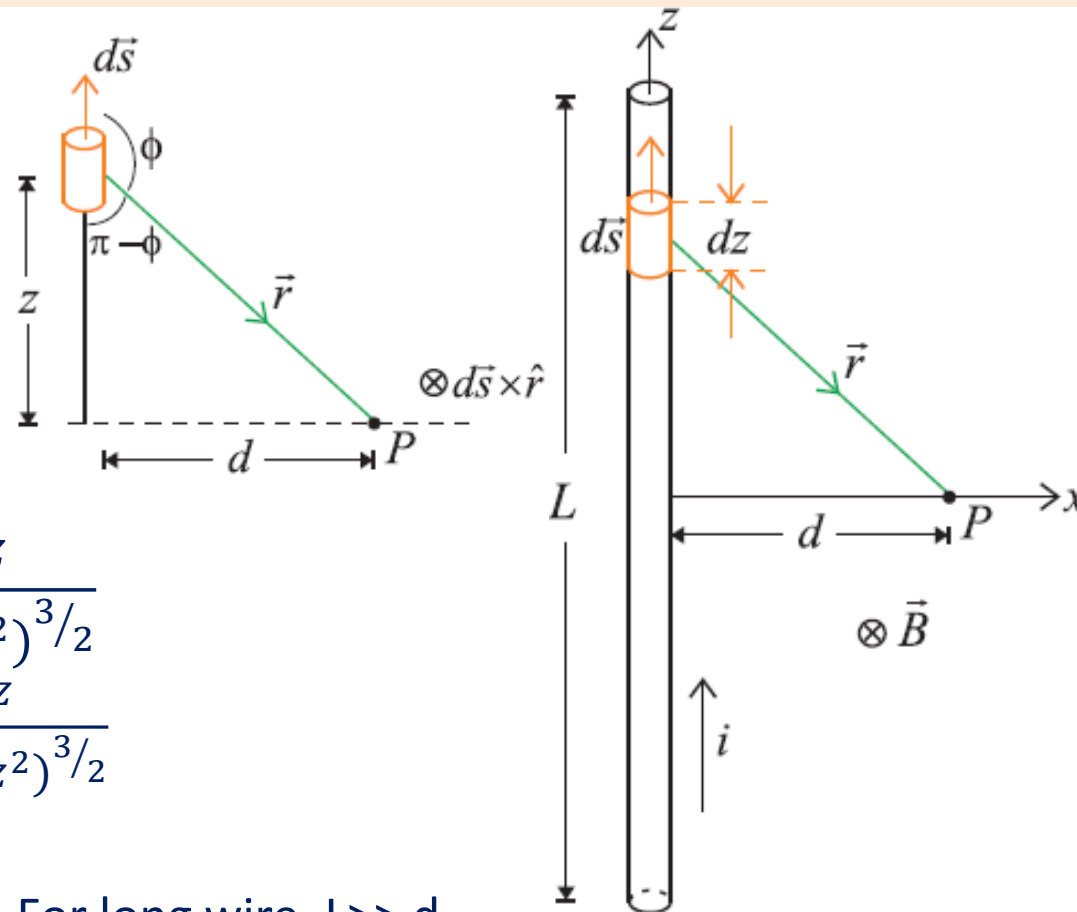
$$\therefore |d\vec{B}| = \frac{\mu_0}{4\pi} \frac{id dz}{r^3} = \frac{\mu_0 i}{4\pi} \frac{d dz}{(d^2 + z^2)^{3/2}}$$

$$\therefore B = \int_{-L/2}^{L/2} dB = \frac{\mu_0 id}{4\pi} \int_{-L/2}^{L/2} \frac{dz}{(d^2 + z^2)^{3/2}}$$

$$B = \frac{\mu_0 i}{4\pi d} \frac{z}{(d^2 + z^2)^{1/2}} \Big|_{-L/2}^{L/2}$$

$$\therefore B = \frac{\mu_0 i}{4\pi d} \frac{L}{(d^2 + \frac{L^2}{4})^{1/2}}$$

$E = \frac{\lambda}{2\pi\epsilon_0 d}$ for an infinite long line of charge



For long wire, $L \gg d$

$$(d^2 + \frac{L^2}{4})^{-1/2} \approx \left(\frac{L^2}{4}\right)^{-1/2} = \frac{2}{L}$$

$\therefore B = \frac{\mu_0 i}{2\pi d}$ direction of B determined from *right-hand screw rule*

Magnetic field for a circular loop

For every current element $id\vec{s}_1$, generating a magnetic field $d\vec{B}_1$ at point P, there is an opposite current element $id\vec{s}_2$ generating B-field $d\vec{B}_2$ so that $d\vec{B}_1 \sin \alpha = -d\vec{B}_2 \sin \alpha$

$\therefore$ Only vertical component of B-field needs to be considered at point P.

$$\therefore dB = \frac{\mu_0}{4\pi} \frac{ids}{r^2} \quad [\because d\vec{s}_1 \perp \vec{r}]$$

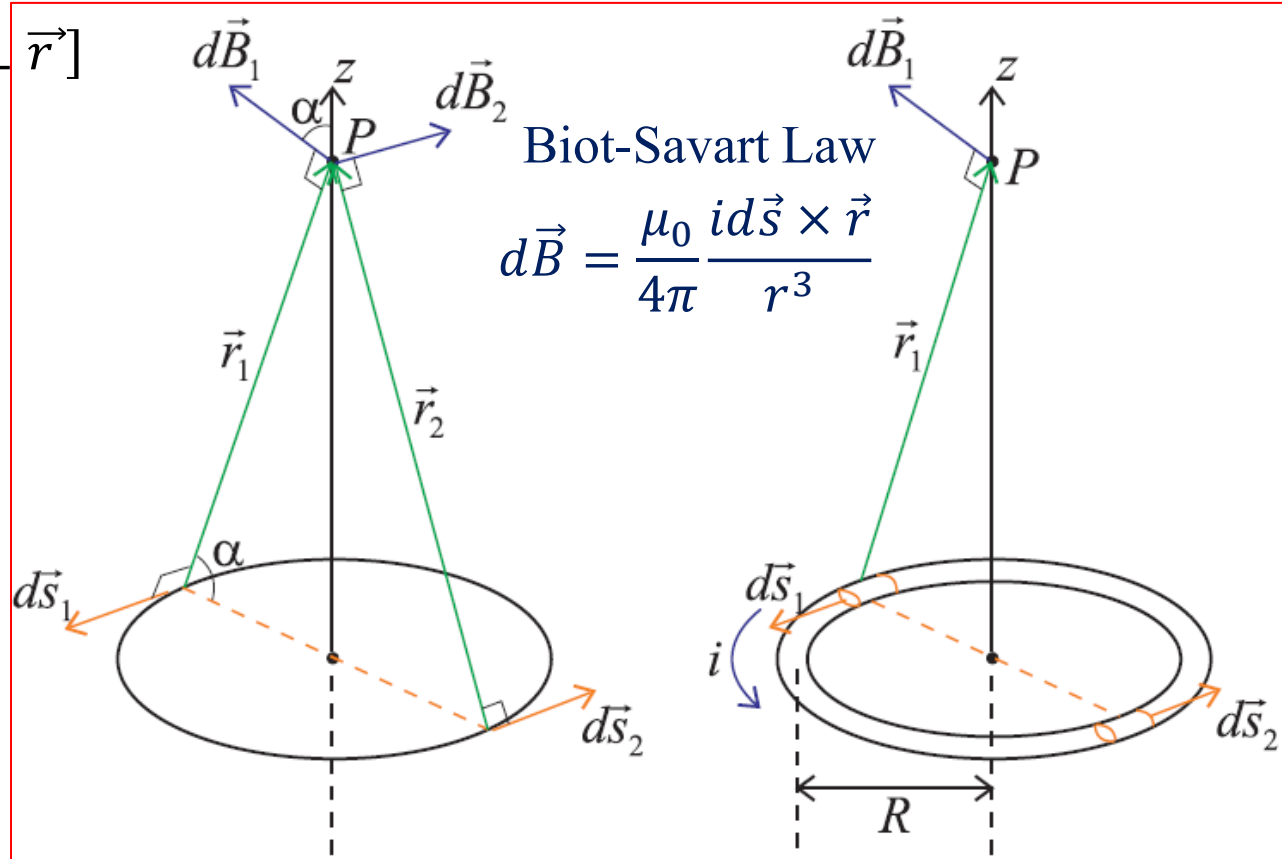
$\therefore$ B-field at point P:

$$B = \int_{\text{around circuit}} dB \cos \alpha$$

$$\therefore B = \int_0^{2\pi} \frac{\mu_0}{4\pi} \frac{i \cos \alpha ds}{r^2}$$

$$= \frac{\mu_0}{4\pi} \frac{iR}{r^3} \int_0^{2\pi} R d\theta$$

$$= \frac{\mu_0}{4\pi} \frac{iR 2\pi R}{r^3}$$



$$\therefore B = \frac{\mu_0 i R^2}{2r^3}$$

$$B = \frac{\mu_0 i R^2}{2(R^2 + z^2)^{3/2}}$$

direction of B determined from *right-hand screw rule*

Field at different positions for a circular loop

Field at center of loop:

$$z=0$$

$\therefore$

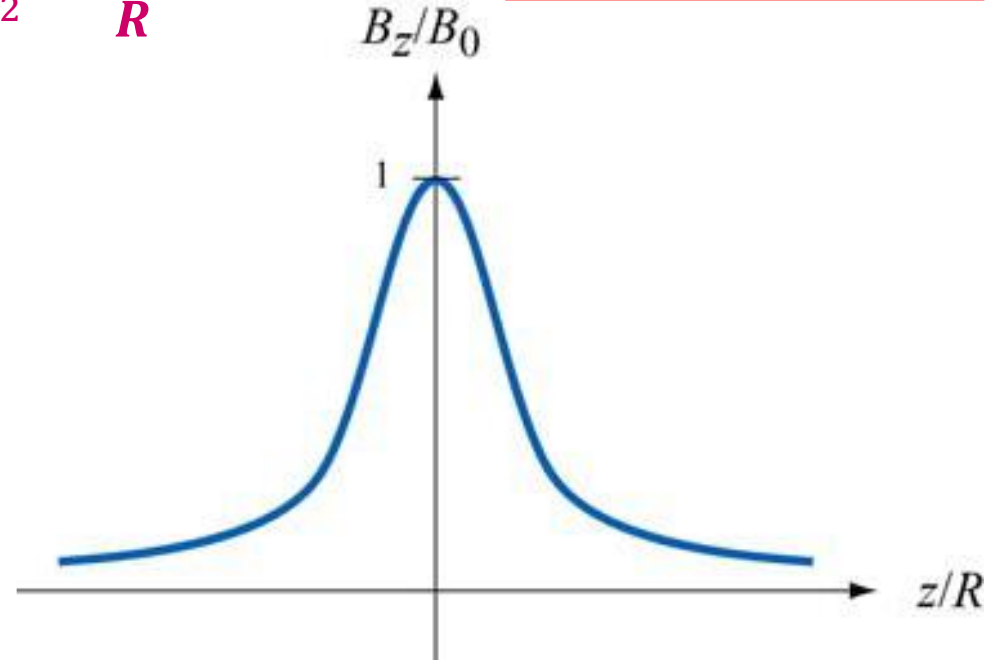
$$\mathbf{B} = \frac{\mu_0 i R^2}{2(R^2)^{3/2}} = \frac{\mu_0 i}{R}$$

$$\mathbf{B} = \frac{\mu_0 i R^2}{2(R^2 + z^2)^{3/2}}$$

Field far from the loop:

$$z \gg R$$

$$\mathbf{B} = \frac{\mu_0 i R^2}{2z^3 \left(\frac{R^2}{z^2} + 1\right)^{3/2}} \cong \frac{\mu_0 i R^2}{2z^3} \propto \frac{1}{z^3}$$



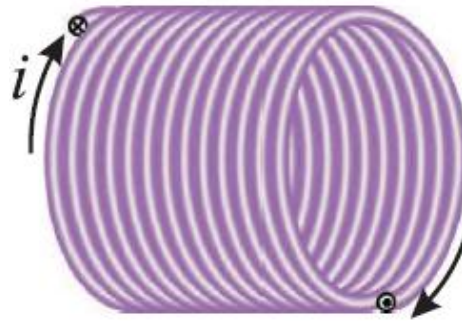
E-field for an electric dipole:
$$E = \frac{p}{4\pi\epsilon_0 x^3}$$

$\therefore$ A circular current loop is also called a magnetic dipole.

Magnetic field for a solenoid carrying current

Consider a solenoid of length L consisting of N turns of wire.

Let, n = Number of turns per unit length = N/L

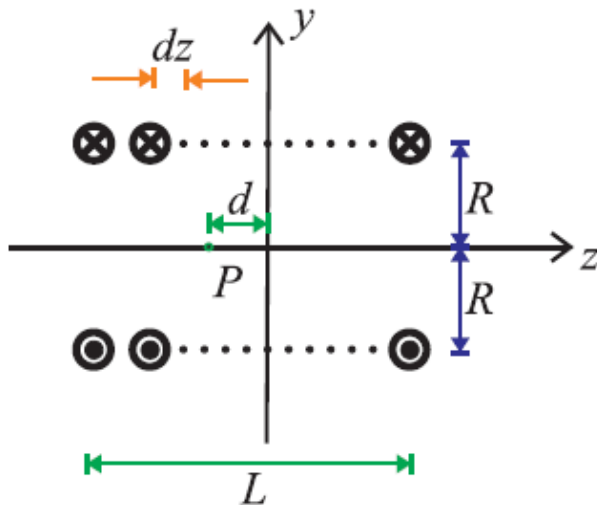


Solenoid

$\approx$



Tightly-packed coils of wire



We will evaluate B-field at distance d from the center of the solenoid:

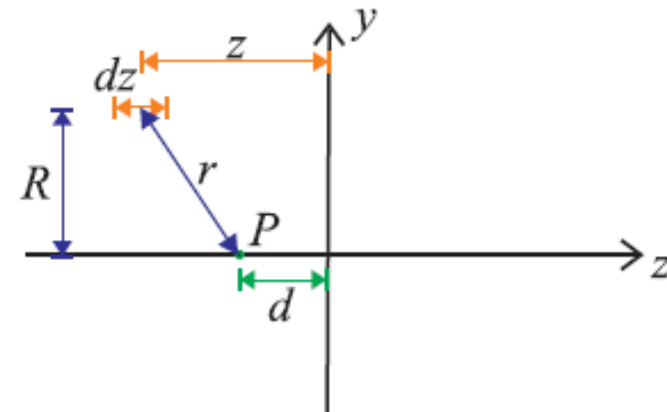
For a segment of length dz , number of current turns = ndz

Total current for this segment is $ni dz$

Using the result from one coil, we get B-field from coils of length dz at distance z from center:

$$dB = \frac{\mu_0 n i dz R^2}{2r^3} \quad \text{Now, } r = \sqrt{R^2 + (z - d)^2}$$

$$B = \int_{\text{entire solenoid}} dB$$



..... Magnetic field for a solenoid carrying current

$$B = \frac{\mu_0 n i R^2}{2} \int_{-L/2}^{+L/2} \frac{dz}{[R^2 + (z - d)^2]^{3/2}}$$

After integration we can get

Do the integration as home work

$$B = \frac{\mu_0 n i}{2} \left[\frac{\frac{L}{2} + d}{\sqrt{R^2 + (\frac{L}{2} + d)^2}} + \frac{\frac{L}{2} - d}{\sqrt{R^2 + (\frac{L}{2} - d)^2}} \right]$$

The field is in negative z-direction

For an ideal solenoid $L \gg R$ $\therefore B = \frac{\mu_0 n i}{2} [1 + 1] = \mu_0 n i$

At the end of the solenoid $d = L/2$, hence the 2nd term is zero

$$\therefore B = \frac{\mu_0 n i}{2}$$

Force between two straight current carrying wires

Let two parallel current carrying wires 1 & 2 carrying currents i_1 and i_2 respectively in the same direction. They are separated by a distance d .

From slide 6, the magnetic field on wires 2

for wire 1

$$B_1 = \frac{\mu_0 i_1}{2\pi d} \quad \text{downwards}$$

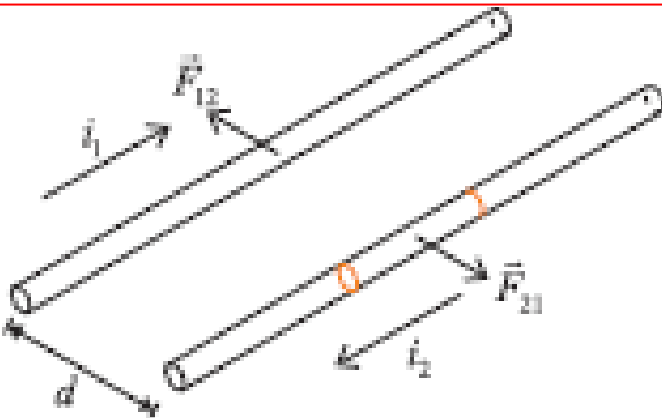
the magnetic field on wires 1 for wire 2

$$B_2 = \frac{\mu_0 i_2}{2\pi d} \quad \text{upwards}$$

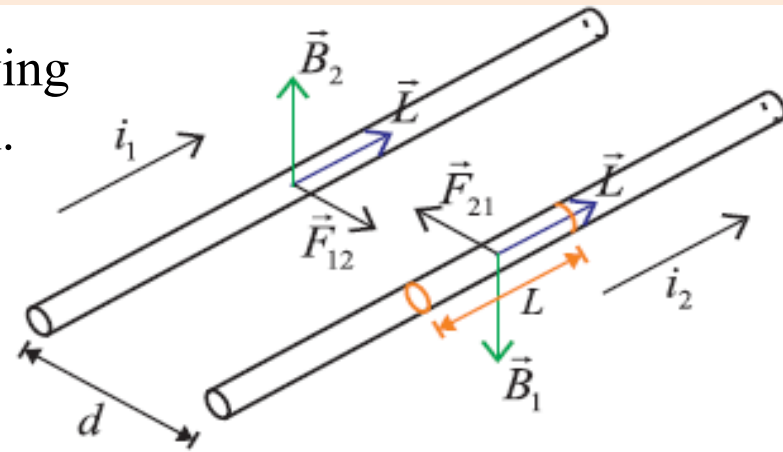
Magnetic force on wires 2 of a segment l for wire 1 $F_{21} = i_2 l \times B_1 = \frac{\mu_0 l i_1 i_2}{2\pi d}$

Similarly, magnetic force on wires 1 of a segment l for wire 2, $F_{12} = i_1 l \times B_2 = \frac{\mu_0 l i_1 i_2}{2\pi d}$

From the figure: for same direction of currents both the wires attracts each others.



In the same fashion, it can be shown that anti-parallel currents repel each other.



The Divergence of B

Biot-Savart law
$$d\vec{B} = \frac{\mu_0}{4\pi} \frac{id\vec{s} \times \vec{r}}{r^3}$$

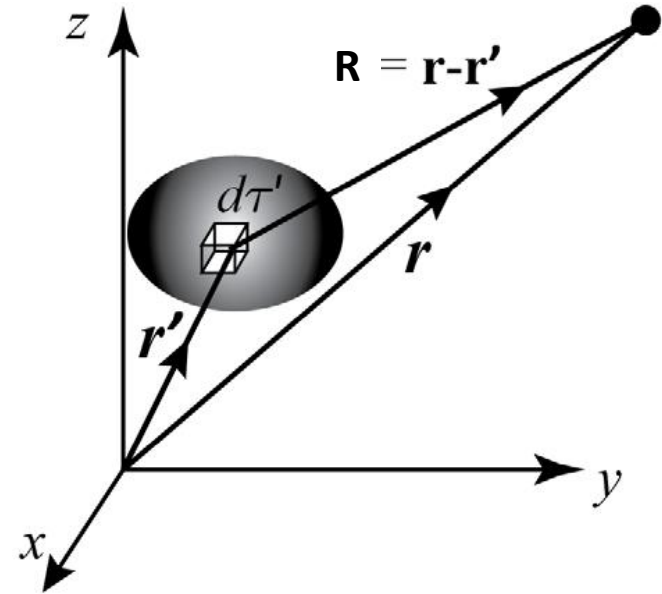
The magnetic field for volume current

$$\vec{B}(R) = \frac{\mu_0}{4\pi} \int_V \frac{J(r') \times \vec{R}}{R^3} d\tau'$$

Taking divergence

$$\nabla \cdot \vec{B} = \frac{\mu_0}{4\pi} \int_V \nabla \cdot \frac{J(r') \times \vec{R}}{R^3} dV$$

Using vector identity $\nabla \cdot (\mathbf{A} \times \mathbf{B}) = \mathbf{B} \cdot (\nabla \times \mathbf{A}) - \mathbf{A} \cdot (\nabla \times \mathbf{B})$



$$\nabla \cdot \vec{B} = \frac{\mu_0}{4\pi} \int_V \frac{\vec{R}}{R^3} \cdot (\nabla \times J(r')) d\tau' - \frac{\mu_0}{4\pi} \int_V J(r') \cdot (\nabla \times \frac{\vec{R}}{R^3}) d\tau'$$

$\nabla \times J(r') = 0$ Since, $J(r')$ doesn't depend on R $\left(\nabla \times \frac{\vec{R}}{R^3} \right) = 0$

$\nabla \cdot \vec{B} = 0$ The divergence of a magnetic field is zero.

Magnetic flux through any close surface is always zero, whether or not any current within the surface.

$\nabla \cdot \vec{E} = \rho/\epsilon_0$ Magnetic monopole doesn't exist, hence no source of magnetic flux

Magnetic vector potential

$\nabla \cdot \vec{B} = 0$ From vector identity, we know divergence of curl of a vector is zero

Hence, we can define magnetic field $\mathbf{B}$ as $\mathbf{B} = \nabla \times \mathbf{A}$ $\nabla \cdot \mathbf{B} = \nabla \cdot \nabla \times \mathbf{A} = 0$

$\mathbf{A}$ is known as magnetic vector potential

HW: What is the dimension and unit of $\mathbf{A}$?

As $\mathbf{B}$ is a physical quantity, $\nabla \times \mathbf{A}$ is also so. However, the divergence of the vector potential has no physical meaning and consequently we are at liberty to specify its divergence as per our wish. This freedom to choose a vector potential whose curl is $\mathbf{B}$ and whose divergence can be conveniently chosen is called by mathematicians as a choice of a gauge .

If ψ is a scalar function any transformation of the type $\mathbf{A} \longrightarrow \mathbf{A} + \nabla \psi$ gives the same magnetic field as curl of a gradient is identically zero. The transformation above is known as gauge invariance.

The popular gauge $\nabla \cdot \mathbf{A} = 0$ is known as Coulomb gauge

Magnetic vector potential

Biot-Savart's law for magnetic field due to a current element $\vec{dl}$

$$d\vec{B} = \frac{\mu_0 I}{4\pi} \frac{\vec{dl} \times \hat{r}}{r^2} = -\frac{\mu_0 I}{4\pi} \vec{dl} \times \nabla\left(\frac{1}{r}\right)$$

may be used to obtain an expression for the vector potential. Since the element $\vec{dl}$ does not depend on the position vector of the point at which the magnetic field is calculated, we can write $d\vec{B} = \frac{\mu_0 I}{4\pi} \nabla \times \left(\frac{\vec{dl}}{r}\right)$

the change in sign is because $\nabla\left(\frac{\vec{dl}}{r}\right) = \nabla(1/r) \times \vec{dl}$.

Thus the contribution to the vector potential from the element $\vec{dl}$ is $d\vec{A} = \frac{\mu_0 I}{4\pi r} \vec{dl}$

The expression is to be integrated over the path of the current to get the vector potential for the system

$$\vec{A} = \frac{\mu_0 I}{4\pi} \int \frac{\vec{dl}}{r}$$

The Curl of B

The magnetic field produced by a volume current

$$\mathbf{B}(\mathbf{r}) = \frac{\mu_0}{4\pi} \int \frac{\mathbf{J}(\mathbf{r}') \times \hat{\mathbf{r}}}{r^2} d\tau'$$

$$\mathbf{r} = (x - x')\hat{\mathbf{x}} + (y - y')\hat{\mathbf{y}} + (z - z')\hat{\mathbf{z}}$$

Take the curl of the above magnetic field (with respect to the unprimed coordinates)

$$\nabla \times \mathbf{B}(\mathbf{r}) = \frac{\mu_0}{4\pi} \int \nabla \times \left(\frac{\mathbf{J}(\mathbf{r}') \times \hat{\mathbf{r}}}{r^2} \right) d\tau'$$

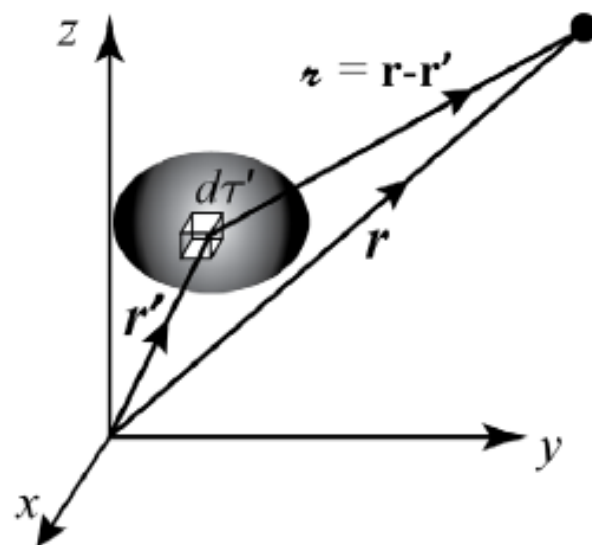
$$\nabla \times (\mathbf{A} \times \mathbf{B}) = (\mathbf{B} \cdot \nabla)\mathbf{A} - (\mathbf{A} \cdot \nabla)\mathbf{B} + \mathbf{A}(\nabla \cdot \mathbf{B}) - \mathbf{B}(\nabla \cdot \mathbf{A})$$

$$\nabla \times \left(\frac{\mathbf{J}(\mathbf{r}') \times \hat{\mathbf{r}}}{r^2} \right) = \left(\frac{\hat{\mathbf{r}}}{r^2} \cdot \nabla \right) \mathbf{J}(\mathbf{r}') - (\mathbf{J}(\mathbf{r}') \cdot \nabla) \frac{\hat{\mathbf{r}}}{r^2} + \mathbf{J}(\mathbf{r}') \left(\nabla \cdot \frac{\hat{\mathbf{r}}}{r^2} \right) - \frac{\hat{\mathbf{r}}}{r^2} (\nabla \cdot \mathbf{J}(\mathbf{r}'))$$

$$\nabla \cdot \mathbf{J}(\mathbf{r}') = \mathbf{0} \text{ since } \mathbf{J}(\mathbf{r}') \text{ does not depend on } \mathbf{r}$$

$$\left(\frac{\hat{\mathbf{r}}}{r^2} \cdot \nabla \right) \mathbf{J}(\mathbf{r}') = \mathbf{0} \text{ since } \mathbf{J}(\mathbf{r}') \text{ does not depend on } \mathbf{r}$$

$$\nabla \times \mathbf{B}(\mathbf{r}) = \frac{\mu_0}{4\pi} \int \mathbf{J}(\mathbf{r}') \left(\nabla \cdot \frac{\hat{\mathbf{r}}}{r^2} \right) d\tau' - \frac{\mu_0}{4\pi} \int (\mathbf{J}(\mathbf{r}') \cdot \nabla) \frac{\hat{\mathbf{r}}}{r^2} d\tau'$$



The Curl of B

$$\nabla \times \mathbf{B}(\mathbf{r}) = \frac{\mu_0}{4\pi} \int \mathbf{J}(\mathbf{r}') \left(\nabla \cdot \frac{\hat{\mathbf{r}}}{r^2} \right) d\tau' - \frac{\mu_0}{4\pi} \int (\mathbf{J}(\mathbf{r}') \cdot \nabla) \frac{\hat{\mathbf{r}}}{r^2} d\tau'$$

$$\nabla \cdot \frac{\hat{\mathbf{r}}}{r^2} = 4\pi \delta^3(\mathbf{r})$$

$$\nabla \times \mathbf{B}(\mathbf{r}) = \mu_0 \mathbf{J}(\mathbf{r}) - \frac{\mu_0}{4\pi} \int (\mathbf{J}(\mathbf{r}') \cdot \nabla) \frac{\hat{\mathbf{r}}}{r^2} d\tau'$$

$$-(\mathbf{J}(\mathbf{r}') \cdot \nabla) \frac{\hat{\mathbf{r}}}{r^2} = (\mathbf{J}(\mathbf{r}') \cdot \nabla') \frac{\hat{\mathbf{r}}}{r^2}$$

$$= (\mathbf{J}(\mathbf{r}') \cdot \nabla') \left[\frac{(x-x')}{r^3} \hat{\mathbf{x}} + \frac{(y-y')}{r^3} \hat{\mathbf{y}} + \frac{(z-z')}{r^3} \hat{\mathbf{z}} \right]$$

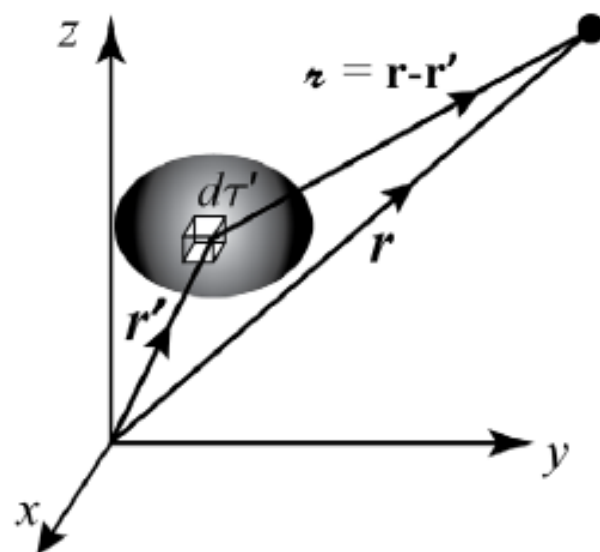
$$(\mathbf{J}(\mathbf{r}') \cdot \nabla') \frac{(x-x')}{r^3} = \nabla' \cdot \left[\frac{(x-x')}{r^3} \mathbf{J} \right] - \frac{(x-x')}{r^3} (\nabla' \cdot \mathbf{J}) = \nabla' \cdot \left[\frac{(x-x')}{r^3} \mathbf{J} \right]$$

$$\nabla \cdot (f\mathbf{A}) = f(\nabla \cdot \mathbf{A}) + (\mathbf{A} \cdot \nabla)f$$

Magnetostatics implies steady current. So $\nabla' \cdot \mathbf{J} = -\frac{d\rho}{dt} = 0$

$$\int_{Vol} \nabla' \cdot \left[\frac{(x-x')}{r^3} \mathbf{J} \right] d\tau' = \oint_{surf} \left[\frac{(x-x')}{r^3} \mathbf{J} \right] \cdot d\mathbf{a} = 0$$

For large enough integration volume, all the currents are inside.
So $\mathbf{J} = 0$ at the surface.



The Curl of B

$$\nabla \times \mathbf{B}(\mathbf{r}) = \frac{\mu_0}{4\pi} \int \mathbf{J}(\mathbf{r}') \left(\nabla \cdot \frac{\hat{\mathbf{r}}}{r^2} \right) d\tau' - \frac{\mu_0}{4\pi} \int (\mathbf{J}(\mathbf{r}') \cdot \nabla) \frac{\hat{\mathbf{r}}}{r^2} d\tau'$$

$$\nabla \cdot \frac{\hat{\mathbf{r}}}{r^2} = 4\pi\delta^3(\mathbf{r})$$

$$\nabla \times \mathbf{B}(\mathbf{r}) = \mu_0 \mathbf{J}(\mathbf{r}) - \frac{\mu_0}{4\pi} \int (\mathbf{J}(\mathbf{r}') \cdot \nabla) \frac{\hat{\mathbf{r}}}{r^2} d\tau'$$

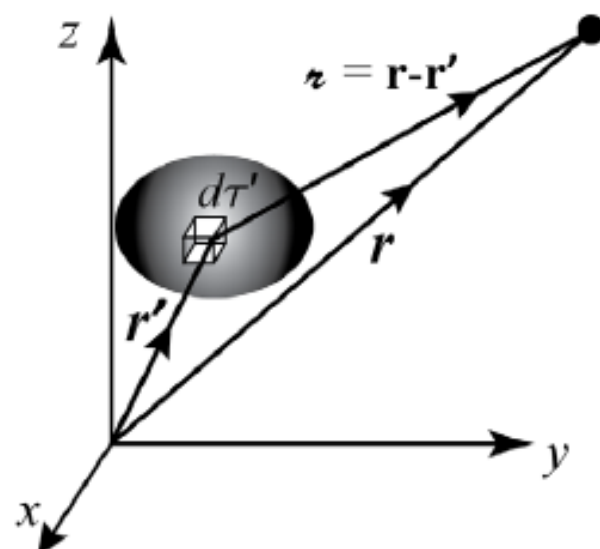
$$\int_{Vol} \nabla' \cdot \left[\frac{(x - x')}{r^3} \mathbf{J} \right] d\tau' = \oint_{surf} \left[\frac{(x - x')}{r^3} \mathbf{J} \right] \cdot d\mathbf{a} = 0$$

So,

$$\frac{\mu_0}{4\pi} \int (\mathbf{J}(\mathbf{r}') \cdot \nabla) \frac{\hat{\mathbf{r}}}{r^2} d\tau' = 0$$

$$\boxed{\nabla \times \mathbf{B}(\mathbf{r}) = \mu_0 \mathbf{J}(\mathbf{r})}$$

Ampere's Law



For large enough integration volume, all the currents are inside.
So $\mathbf{J} = 0$ at the surface.

Ampere's circuital law

It states that the line integral of magnetic field around any closed loop is proportional to the total current passing through any surface that is bounded by the closed loop:

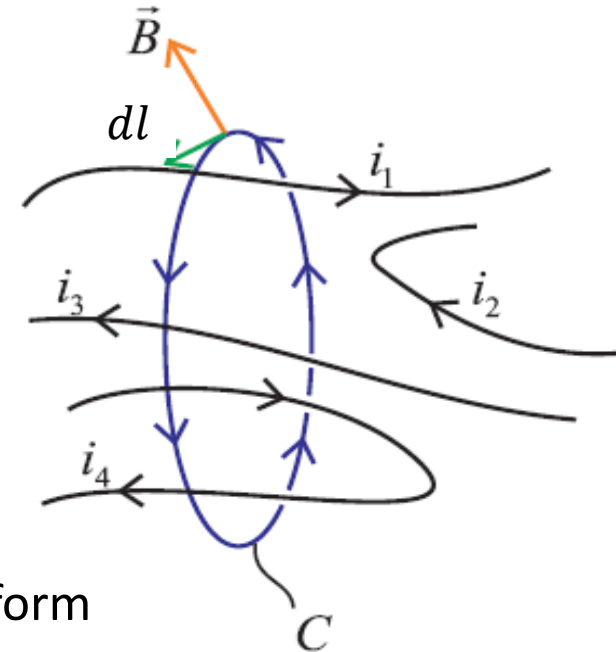
$$\oint_C \vec{B} \cdot d\vec{l} = \mu_0 i \quad \oint_C \vec{B} \cdot d\vec{l} = \mu_0(i_1 - i_3 + i_4 - i_2)$$

Using Stokes theorem

$$\oint_C \vec{B} \cdot d\vec{l} = \mu_0(i_1 - i_3)$$

$$\oint_C \vec{B} \cdot d\vec{l} = \oiint_S \vec{\nabla} \times \vec{B} \cdot d\vec{S} = \mu_0 i = \mu_0 \oiint_S \vec{J} \cdot d\vec{S}$$

$$\vec{\nabla} \times \vec{B} = \mu_0 \vec{J} \quad \text{Ampere's circuital law in differential form}$$



Ampere's law is used for calculating magnetic field, by following the procedure:

- (1) Draw an Amperian loop using symmetry arguments.
- (2) Find the current enclosed by the Amperian loop.
- (3) Calculate the line integral around the closed loop.
- (4) Equate with both sides and solve for B.

Application of Ampere's circuital law

Magnetic field of a straight conductor

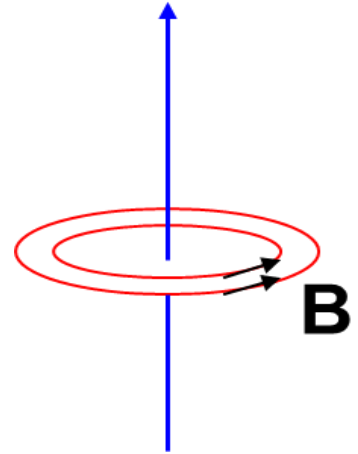
We have to find Magnetic field B at distance r from the wire

Let's draw a circle of radius r

From Ampere's circuital law

$$\therefore B 2\pi r = \mu_0 i \quad \therefore \boxed{B = \frac{\mu_0 i}{2\pi r}}$$

$$\oint_C B \cdot dl = \mu_0 i$$



Magnetic field for cylindrical conductor of Radius R at a distance r ; a) $r > R$ & b) $r < R$:

For outside the conductor $r > R$ Magnetic field is same as straight conductor

$$\therefore \boxed{B = \frac{\mu_0 i}{2\pi r}} \quad \text{For } r > R$$

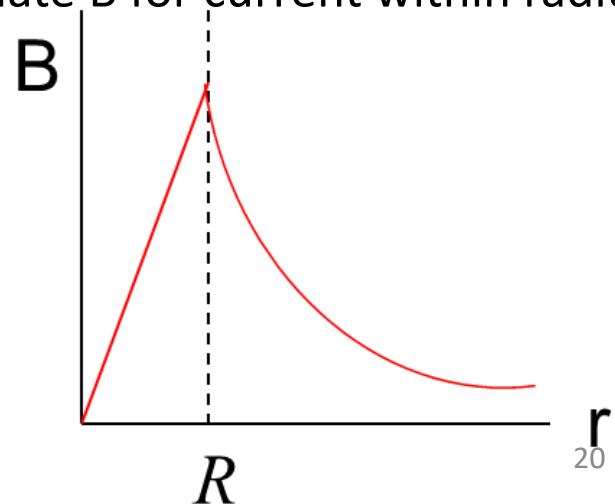
For inside the conductor $r < R$, here we have to calculate B for current within radius r

Here current density is $\frac{i}{\pi R^2}$

$$\therefore B 2\pi r = \mu_0 i \frac{\pi r^2}{\pi R^2}$$

$$\therefore \boxed{B = \frac{\mu_0 i r}{2\pi R^2}}$$

For $r < R$



... Application of Ampere's circuital law

Magnetic field due to long current carrying solenoid

Magnetic field B will be perpendicular to I

We consider a rectangular loop $abcd$ on the solenoid and we will find B for this loop

From Ampere's circuital law $\oint B \cdot dl = \mu_0 i$

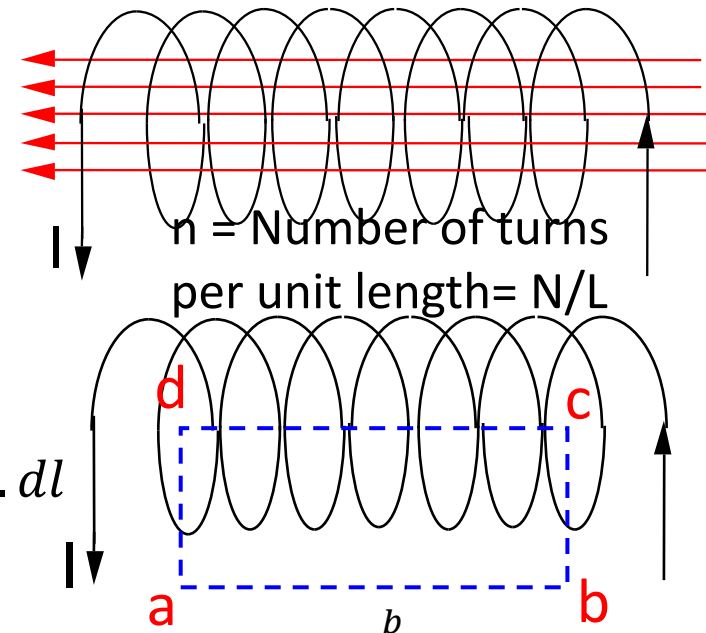
$$\text{Now, } \oint_C B \cdot dl = \int_a^b B \cdot dl + \int_b^c B \cdot dl + \int_c^d B \cdot dl + \int_d^a B \cdot dl$$

Here, bc and da perpendicular to B

$$\therefore \int_b^c B \cdot dl = \int_d^a B \cdot dl = 0 \quad \text{There is no current for the path } ab \quad \therefore \int_a^b B \cdot dl = 0$$

current for the path cd is $(cd) nI$ $\therefore \int_c^d B \cdot dl = \mu_0 (cd) nI$

$$\therefore B(cd) = \mu_0 (cd) nI \quad \therefore \boxed{B = \mu_0 nI}$$



Magnetic field for a Toroid (A circular solenoid)

C is a circle of radius r inside the toroid.

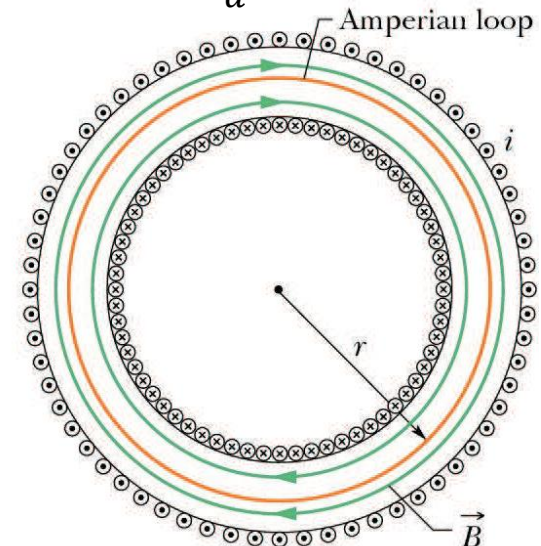
$$\oint_C B \cdot dl = \mu_0 NI \quad \therefore B 2\pi r = \mu_0 2\pi r nI$$

$$\therefore \boxed{B = \mu_0 nI}$$



Magneti

N turns



Magnet

Magnetic pole, region at each end of a magnet where the external magnetic field is strongest.

A bar magnet suspended in Earth's magnetic field orients itself in a north–south direction. The north-seeking pole of such a magnet, is called a north magnetic pole. The south-seeking pole, or any pole similar to it, is called a south magnetic pole. Unlike poles of different magnets attract each other; like poles repel each other.

The [magnetic force](#) between a pole of one long bar magnet and that of another was described by an inverse square law

$$F = \frac{\mu_0}{4\pi} \frac{m_1 m_2}{r^2}$$

Potential and field due to a magnetic dipole.

Magnetic dipole moment.

Force and torque on a magnetic dipole.

(d) Magnetic fields inside matter: Magnetization. Bound currents. The magnetic intensity - H. Linear media. Magnetic susceptibility and Permeability. Brief introduction of dia-, para- and ferro-magnetic materials.

Magnetic dipole

Potential and field due to a magnetic dipole.

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Magnetic fields inside matter: Magnetization. Bound currents. The magnetic intensity - H . Linear media. Magnetic susceptibility and Permeability. Brief introduction of dia-, para- and ferro-magnetic materials.

Electromagnetic Induction

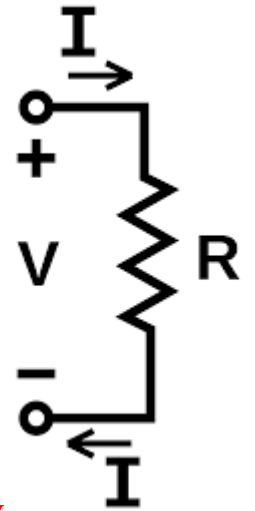
Electromagnetic Induction

4. Ohms law and definition of E.M.F. Faraday's laws of electromagnetic induction, Lenz's law, self and mutual inductance, L of single coil, M of two coils. Energy stored in magnetic field.

Ohms law and E.M.F

Ohm's law: the current through a conductor between two points is directly proportional to the voltage across the two points. $I \propto V$

$$I = V/R$$



The proportional constant is $1/R$, R is known as resistance.

Electromotive force (EMF) is equal to the terminal potential difference when no current flows.

EMF and terminal potential difference (V) are both measured in volts, however they are not the same thing.

The EMF can be written in terms of the internal resistance of the battery (r) where: $\epsilon = I(r+R) = V+Ir$ EMF dimension is given as $M^1L^2T^{-3}I^{-1}$

Electromotive Force	Potential Difference
EMF is defined as the work done on a unit charge	Potential difference is defined as the energy which is dissipated as the unit charge pass through the components
EMF remains constant	Potential difference is not constant
EMF is independent of circuit resistance	The potential difference depends on the resistance between the two points during the measurement
Due to EMF, electric, magnetic, and the gravitational field is caused	Due to the potential difference, the only electric field is induced
It is represented by E	It is represented by V

Faraday's laws of electromagnetic induction

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