Imagine a world where there are no electric lights, no trains, no telephones, and no personal computers. It was life before the discovery of electromagnetic induction. A Revolutionary invention as a result of the experiments of Michael Faraday and Joseph Henry.In this chapter, we will study the experiments of electromagnetic induction and their applications. The Experiments of Faraday and Henry The figure shows a coil C1 connected to a galvanometer G. When the North-pole of a bar magnet is pushed towards the coil, the pointer in the galvanometer deflects, indicating the presence of electric current in the coil. The galvanometer does not show any deflection when the magnet is held stationary. When the magnet is pulled away from the coil, the galvanometer shows deflection in the opposite direction, which indicates a reversal of the currents direction. Moreover, when the South-pole of the bar magnet is moved towards or away from the coil, the deflections in the galvanometer are opposite to that observed with the North-pole for similar movements. Further, the deflection is found to be larger when the magnet is pushed towards or pulled away from the coil faster. Instead, when the bar magnet is held fixed and the coil C1 is moved towards or away from the magnet, the same effects are observed. It shows that it is the relative motion between the magnet and the coil that is responsible for the generation of electric current in the coil. Recommended Books Read also: Alternating Current Class 12 Physics Notes Chapter 7 Magnetic Flux Like electric flux, magnetic flux is proportional to the number of magnetic field lines passing through a surface. It is denoted by B. It is a scalar quantity. Mathematically, `\phi_{B}=\vec{B}\vec{A}=BAcos\theta` SI unit of magnetic flux is weber (Wb) (1Wb = 1 tesla-m2). C.G.S. unit of magnetic flux is maxwell. The dimensional formula of magnetic flux is [ML2T-2A-1] Faradays Law of Induction (i) First lawAccording to this law, "The magnitude of the induced emf in a closed loop is equal to the time rate of change of magnetic flux through the loop." `\epsilon=\frac{-d\phi}{dt}` In case of a coil of N turns, induced emf `\epsilon=-N\frac{d\phi}{dt}` (ii) Second Law (Lenz's Law)According to this law, the induced current is in such a direction, so as to oppose its cause. i.e. induced current opposes the change in flux. Read also: General Principles and Processes of Isolation of Elements Class 12 Chemistry Notes Chapter 6 Lenzs Law and Conservation of Energy Lenz's law is in accordance with the law of conservation of energy. As the induced current opposes the change in flux, work has to be done against the opposition offered by the induced current in changing the flux. The work doneappears as electrical energy in the loop. Induced Electric Field An electric field is induced in any region of space in which a magnetic field is changing with time. The induced electric field and magnetic field are at right angles to each other. Consider a particle of charge q0 moving around the ring in a circular path. The work done by the induced electric field in one revolution is W = q0, where is the induced emf. Also work done `W=\int\vec{F}.\vec{dl}``W=q_{0}\int\vec{E}.\vec{dl}``q_{0}\epsilon=q_{0}\int\vec{E}.\vec{dl}``\epsilon=\int\vec{E}.\vec{dl}` By Faraday's law`\epsilon=\frac{-d\phi_B}{dt}``\therefore\int\vec{E}.\vec{dl}=\frac{-d\phi_B}{dt}` Read also: Conceptual Questions for Class 12 Physics Chapter 6 Electromagnetic Induction Eddy Current Even when bulk pieces of conductors are subjected to changing magnetic flux, induced currents are produced in them, these currents are called eddy currents. Eddy currents are undesirable since they heat up the core and dissipate electrical energy in the form of heat. Eddy currents are minimized by using laminations of metal to make a metal core. This arrangement reduces the strength of the eddy currents. Eddy currents are used to advantage in certain applications like: Magnetic braking in trains: Strong electromagnets are situated above the rails in some electricallypowered trains. When the electromagnets are activated, the eddy currents induced in the rails opposethe motion of the train. Electromagnetic damping: Certain galvanometers have a fixed core made of non-magnetic metallicmaterial. When the coil oscillates, the eddy currents generated in the core oppose the motion and bringthe coil to rest quickly.Induction furnace: Induction furnace can be used to produce high temperatures. A high-frequency alternating current is passed througha coil that surrounds the metals to be melted. The eddy currents generated in the metals produce hightemperatures sufficient to melt them.Electric power meters: The shiny metal disc in the electric power meter rotates dueto the eddy currents. Electric currents are induced in the disc by magnetic fields produced by sinusoidallyvarying currents in a coil. Self Inductance Self-inductance is the property of a coil, by which an induced emf is developed in itself due to a change in the strength of the current flowing through the coil itself. Let a current 'i' flows through the inductor. Due to this current, a flux is linked with it such that `\phi\propto i``\phi=Li` L is called the inductance ofself-inductance of the coil. The induced emf is given by`\epsilon=\frac{-d\phi}{dt}` `\epsilon=\frac{-Ldi}{dt}` SI unit of inductance is henry (H). (i). Self Inductance of a solenoidLet a current 'i' be flowing through the solenoid. There is a uniform magnetic field B = 0ni in its core. The total flux linked with the solenoid is `\phi=(\mu_{0}ni)\times A\times N``\phi=\mu_{0}ni\times \pi r^2\times (nl)``\phi=\mu_{0}n^{2}\pi r^{2}l\times i``L=\mu_{0}n^{2}\pi r^{2}l` ......[`\phi=Li`] (ii). Energy Stored in an InductorLike a capacitor stores energy in the form of an electric field, an inductor stores energy in the form of a magnetic field. Let a current 'i' be flowing through an inductor of inductance L. As the current increase a rate `V_{AB}=L\frac{di}{dt}``Power=Vi``\frac{dW}{dt}=(L\frac{di}{dt})i``dW=Lidi``W=\frac{1}{2}Li^2` Mutual Inductance The phenomenon by which an induced emf is produced in one coil due to a change in the strength of the current flowing through another coil is called mutual induction. When a current i flows through one of the coils, a flux is linked with another coil such that `\phi\propto i``\phi=Mi` The constant M is called the coefficient of mutual inductance between the coils. `\epsilon=\frac{-d\phi}{dt}``\epsilon=\frac{-Mdi}{dt}` .....[`\phi=Mi`] SI unit of mutual inductance is henry (H). AC Generator An ac generator converts mechanical energy into electrical energy. It consists of a coil mounted on a rotor shaft. The axis of rotation of the coil is perpendicular to the direction of the magnetic field. The coil (called thearmature) is mechanically rotated in the uniform magnetic field by some external means. The rotation of the coil causes the magnetic flux through it to change, so an emf is induced in the coil. The ends of the coil are connected to an external circuit by means of slip rings and brushes. When the coil is rotated with a constant angular speed , the angle between the magnetic field vector B and the area vector A of the coil at any instant t is = t. As a result, the effectivearea of the coil exposed to the magnetic field lines changes with time, and the flux at any time t is `\phi_{B}=BA cos\theta``\phi_{B}=BA cost` From Faradays law, the induced emf for the rotating coil of N turns is, then,`\epsilon=-N\frac{d\phi_{B}}{dt}``\epsilon=-NBA\frac{d}{dt}(cos\omega t)` Thus, the instantaneous value of the emf is`\epsilon=NBA\omega sin\omega t` If we denote NBA as 0,`\epsilon=\epsilon_{0}sin\omega t` The direction of the current changes periodically and therefore the current is called alternating current (ac). Summary Electricity and magnetism are interrelated.Scientists Oersted and ampere demonstrated experimentally that moving charges (currents)produce a magnetic field.In a closed circuit, electric currents are induced so as to oppose the changing magnetic flux.Lenzs law is in accordance with the law of conservation of energy.The motional emf can be discussed independently from Faradays law by using Lorentz forceon moving charges.Moving charges in a static field and static charges in a time-varying field seem to be the symmetricsituation for Faradays law.The motion of a copper plate is damped when it is allowed to oscillate between the magneticpole pieces, this is because eddy current loops are induced in the bulk of the conductor.Eddy current losses can be minimized by having slot cuts in the bulk of the conductor, therebycutting the eddy current loops.The magnetic potential energy of the inductor at any instant depends upon the strength of the current flowing in the inductor at that instant. It does not depend upon the manner in which the current is changing.Magnetic flux linkage through a surface is proportional to the number of field lines passingthrough it.The induced emf is equal to the negative of the time rate of change of magnetic flux.The self-inductance is numerically equal to the magnetic flux when the unit current is flowing inthe coil.The self-inductance of a coil is numerically equal to the emf induced across the ends of the coilwhen the rate of change of current is 1 A/s.An induced charge is numerically equal to the change in magnetic flux if the resistance of thecircuit is unity.Magnetic flux is a scalar quantity as it is the scalar product of the magnetic field and area (vector).The mutual inductance of two coils is numerically equal to emf induced across one coil when the rate of change of current in the other coil is 1 A/s. Read also Mutual inductance is the main operating principle of generators, motors and transformers. Any electrical device having components that tend to interact with another magnetic field also follows the same principle. The interaction is usually brought about by a mutual induction where the current flowing in one coil generates a voltage in a secondary coil.Download Complete Chapter Notes of Electromagnetic Induction Download NowTable of Contents What Is Mutual Inductance?When two coils are brought in proximity to each other, the magnetic field in one of the coils tends to link with the other. This further leads to the generation of voltage in the second coil. This property of a coil which affects or changes the current and voltage in a secondary coil is called mutual inductance. Changing I1 produces changing magnetic flux in coil 2.In the first coil of N1 turns, when a current I1 passes through it, magnetic field B is produced. As the two coils are closer to each other, a few magnetic field lines will also pass through coil 2.\(\begin{array}{l}{{\phi }_{21}}\to\ \text{magnetic flux in one turn of coil 2 due to current}\ I_1.\end{array} \)If we vary the current with respect to time, then there will be an induced emf in coil 2.\(\begin{array}{l}{{\varepsilon }_{ind}}=-\frac{d\phi }{dt}\end{array} \) [According to Faradays law] \(\begin{array}{l}{{\varepsilon }_{21}}=-{{N}_{2}}\frac{d{{\phi }_{21}}}{dt}\end{array} \) \(\begin{array}{l}{{\varepsilon }_{21}}=-{{N}_{2}}\frac{d}{dt}\left(\overline{B}.\,\overline{A} \right)\end{array} \)The induced emf in coil 2 is directly proportional to the current that passes through coil 1. \(\begin{array}{l}{{N}_{2}}\,{{\phi }_{21}}\propto {{I}_{1}}\end{array} \) \(\begin{array}{l}{{N}_{2}}\,{{\phi }_{21}}={{M}_{21}}{{I}_{1}}.(1)\end{array} \)The constant of proportionality is called mutual inductance. It can be written as\(\begin{array}{l}{{M}_{21}}=\frac{{{N}_{2}}{{\phi }_{21}}}{{{I}_{1}}}.(2)\end{array} \)The SI unit of inductance is henry (H)\(\begin{array}{l}1H=\frac{1(\text{Tesla}).1\left({{m}^{2}} \right)}{1\,\,A}\end{array} \)In a similar manner, the current in coil 2, I2, can produce an induced emf in coil 1 when I2 varies with respect to time. Then,\(\begin{array}{l}{{\varepsilon }_{12}}=-{{N}_{1}}\frac{d{{\phi }_{12}}}{dt}\end{array} \) \(\begin{array}{l}{{N}_{1}}{{\phi }_{12}}\propto {{I}_{2}}\end{array} \) \(\begin{array}{l}{{N}_{1}}{{\phi }_{12}}={{M}_{12}}{{I}_{2}}.(3)\end{array} \) \(\begin{array}{l}{{M}_{12}}=\frac{{{N}_{1}}{{\phi }_{12}}}{{{I}_{2}}}.(4)\end{array} \)This constant of proportionality is another mutual inductance. Changing I2 produces changing magnetic flux in coil 1. Reciprocity TheoremExperiments and calculations that combine Amperes law and Biot-Savarts law confirm that the two constants, M21 and M12, are equal in the absence of material medium between the two coils.M12 = M21 (5)This property is called reciprocity, and by using the reciprocity theorem, we can simply write the mutual inductance between two coils as,\(\begin{array}{l}{{\text{M}}_{12}}\text{=}\,{{\text{M}}_{21}}\equiv \text{M}\end{array} \)EMF of Mutual InductanceConsidering the mutual inductance between the two coils we just discussed, we defined mutual inductance M21 of coil 2 with respect to 1 as,\(\begin{array}{l}{{\text{M}}_{21}}\text{=}\,\frac{{{N}_{2}}{{\phi }_{21}}}{{{I}_{1}}}\end{array} \) \(\begin{array}{l}{{\text{M}}_{21}}{{I}_{1}}={{N}_{2}}{{\phi }_{21}}\end{array} \)If I1 changes with time,\(\begin{array}{l}{{M}_{21}}\frac{d{{I}_{1}}}{dt}={{N}_{2}}\frac{d{{\phi }_{21}}}{dt}.(6)\end{array} \)According to Faradays law of induction,\(\begin{array}{l}{{\varepsilon }_{ind}}=-\frac{d\phi }{dt}\end{array} \)Thus, induced emf in coil 2 due to the current in coil 1 is given by\(\begin{array}{l}{{\varepsilon }_{2}}=-{{M}_{21}}\frac{d{{I}_{1}}}{dt}.(7)\end{array} \)Similarly, induced emf in coil 1 due to changing current in coil 2 can be given as,\(\begin{array}{l}{{\varepsilon }_{1}}=-{{M}_{12}}\frac{d{{I}_{2}}}{dt}.(8)\end{array} \)From experiments (equation (5),M21 = M12 = MTherefore, \(\begin{array}{l}{{\varepsilon }_{1}}=-M\frac{d{{I}_{2}}}{dt}\,\,\,\,\,\,{{\varepsilon }_{2}}=-M\frac{d{{I}_{1}}}{dt}\end{array} \)The coefficient of mutual induction mutual inductance depends only on the geometrical factor of the two coils, such as the number of turns and radii of two coils and on the properties of a material medium, such as the magnetic permeability of the medium surrounding the coils.Also Read: Electromagnetic Induction How to Find Mutual Inductance?Steps to find mutual inductance (M).(i) Assume current in one of the coils (say I1 in coil 1)(ii) Deduce the expression for the magnetic field in the neighbouring coil (2) due to I1.(iii) Write the flux linkage equation.\(\begin{array}{l}{{N}_{2}}{{\phi }_{2}}=M{{I}_{1}}..(9)\end{array} \)(iv) Obtain the magnetic flux linked,\(\begin{array}{l}{{N}_{2}}\left({{\phi }_{2}} \right)={{N}_{2}}\left({{B}_{1}}.\,{{A}_{2}} \right)..(10)\end{array} \)(v) Compare the above two equations and find mutual inductance, M.Mutual Inductance Problems(1) Mutual induction between circular coils. Consider two circular coils (closely packed) coaxially placed to each other. The coil with a larger radius has N1 turns, and that with a smaller radius has N2 turns. Also, assume that R1>> R2.The above-mentioned calculation is the same for the following case as well.Mutual inductance of two concentric coplanar loops.Mutual induction between two solenoids. Mutual Inductance of a Coaxial Solenoid Consider two coaxial solenoids, of which the outer solenoid S2 has radius r2, and N2 turns, whereas the inner solenoid S1 has radius r1 and N1 turns. Both the solenoids are of equal length.When there is a current I2 in the solenoid S2, the magnetic induction due to I2 is given by,\(\begin{array}{l}{{B}_{2}}={{\mu }_{0}}{{n}_{2}}{{I}_{2}}={{\mu }_{0}}\frac{{{N}_{2}}}{l}{{I}_{2}}.\end{array} \)The corresponding flux linkage with solenoid S1 is,\(\begin{array}{l}{{N}_{1}}{{\phi }_{12}}={{N}_{1}}{{B}_{2}}.\,{{A}_{1}}\end{array} \) \(\begin{array}{l}{{N}_{1}}{{\phi }_{12}}={{N}_{1}}{{\mu }_{0}}\frac{{{N}_{2}}}{l}{{I}_{2}}.\,\pi r_{1}^{2}.(11)\end{array} \)Also, \(\begin{array}{l}{{N}_{1}}{{\phi }_{12}}={{M}_{12}}{{I}_{2}}.(12)\end{array} \)On comparing (11) and (12),\(\begin{array}{l}{{M}_{12}}=\frac{{{\mu }_{0}}{{N}_{1}}{{N}_{2}}\pi \,\,r_{1}^{2}}{l}\end{array} \)Similarly, when a current I1 is set up through S1, then the magnetic flux linked in S2 is given by,\(\begin{array}{l}{{N}_{2}}{{\phi }_{21}}={{M}_{21}}{{I}_{1}}.(13)\end{array} \)Note that the magnetic flux due to current I1 in S1 is assumed to be confined only inside the solenoid S1. Also, the solenoids are very long compared to their radii, and the flux linkage in S2 is\(\begin{array}{l}{{N}_{2}}{{\phi }_{21}}={{N}_{2}}\left({{B}_{1}}\,.\,\,{{A}_{1}} \right)\end{array} \) (Area confined within S1.) \(\begin{array}{l}{{N}_{2}}{{\phi }_{21}}={{N}_{2}}{{\mu }_{0}}\frac{{{N}_{1}}}{l}.\,{{I}_{1}}\,.\,\,\pi \,r_{1}^{2}.(14)\end{array} \)From (13) and (14),\(\begin{array}{l}{{M}_{21}}={{\mu }_{0}}\frac{{{N}_{1}}{{N}_{2}}}{l}\,\pi \,\,r_{1}^{2}={{M}_{12}}=M\end{array} \)Example Problem: Calculate the mutual inductance between a solenoid of length l and cross-sectional area A with N1 turns, and a circular coil of N2 turns that is wound at the centre of the solenoid. Solution:(i) Assume current I1 in the solenoid. The magnetic field B at its centre is given by\(\begin{array}{l}B={{\mu }_{0}}n\,i={{\mu }_{0}}\frac{{{N}_{1}}}{l}{{I}_{1}}\end{array} \)(ii) Magnetic flux linked with the small coil of area A is due to magnetic field B, then,\(\begin{array}{l}{{N}_{2}}{{\phi }_{21}}={{N}_{2}}\left(B.\,A \right)\end{array} \) \(\begin{array}{l}{{N}_{2}}{{\phi }_{21}}={{N}_{2}}.\,{{\mu}_{0}}\frac{{{N}_{1}}}{l}{{I}_{1}}\,.\,\,A.(a)\end{array} \)(iii) \(\begin{array}{l}{{N}_{2}}{{\phi }_{21}}=M\,{{I}_{1}}.(b)\end{array} \)Equating (a) and (b),\(\begin{array}{l}M={{\mu }_{0}}\frac{{{N}_{1}}{{N}_{2}}}{l}A\end{array} \)Applications of Mutual InductanceThe principle of mutual inductance is followed in various electronic devices. Some of them are as follows:Motors Note the inductors (Lf and La) in the dc motor circuit that are mutually inducted.Transformer Also Read: TransformerGeneratorsThe induced EMG in a generator by electromagnetic induction is shown below. The direction of induced emf is given by Lenz law. When an electrical component (coil) is interacting or being influenced by the magnetic field in the neighbouring component, mutual inductance arises. The current flowing in one coil induces an emf in the neighbouring coil.Solved Problems:1. Two circular coils can be arranged in any of the three situations in the figure. The mutual inductance will be(a) maximum in the situation (C)(b) maximum in the situation (B)(c) maximum in the situation (A)(d) Same in all situationsSolution:The mutual inductance will be maximum when maximum field lines due to one coil pass through the other. In such a situation, the magnetic flux linked will be maximum.Therefore, in situation A, both coils are parallel to each other. Hence, more flux will be linked. Therefore, the mutual inductance will be larger.2. Two coaxial coils are very close to each other, and their mutual inductance is 5 mH. If a current (50 A) sin 500 t is passed in one of the coils, then find the peak value of induced emf in the secondary coil.(a) 50V (b) 500V (c) 125V (d) 250VSolution:Given:\(\begin{array}{l}i=50\,\sin 500t\end{array} \)emf of mutual induction is given by\(\begin{array}{l}\varepsilon =-M\frac{di}{dt}\end{array} \) \(\begin{array}{l}=-\left(5\times {{10}^{-3}} \right)\frac{d}{dt}\left(50\sin 500t \right)\end{array} \) \(\begin{array}{l}=-5\times {{10}^{-3}}\times 50\cos 500t\times 500\end{array} \) \(\begin{array}{l}\varepsilon =-125\cos 500t\end{array} \)The peak value is 125V. Option c is correct.As the coil is stationary in a uniform magnetic field, there is no change in magnetic flux generated. Hence, there is no induced emf in the coil.We know that the mutual inductance is directly proportional to the permeability of the medium surrounding the coils. When the permeability of the medium is increased by inserting a sheet of iron, then the mutual inductance between the coils also increases.As we know that acceleration due to gravity does not depend on the mass of the falling objects, the glass ball will reach the ground first. Because, being an insulator, glass is not affected by the earths magnetic field. Hence, there is no induced emf in the glass ball. Whereas in a copper ball, emf induced by the earths magnetic field will affect the fall of the ball. Thus, it falls slower.Mutual inductance between two coils is affected by the following:Area of cross-sectionNumber of turns in each coilSpace between the two coilsPermeability of medium between the two coilsLength (in the case of the solenoid)When the separation between the coils is increased, the magnetic flux linked with the secondary coil decreases. Therefore, the mutual inductance of the pair of coils decreases.When there is an increase in the number of turns of each coil, mutual inductance increases.Mutual inductance can be used in transformers, generators and electric motors. Put your understanding of this concept to test by answering a few MCQs. Click Start Quiz to begin! Select the correct answer and click on the Finish buttonCheck your score and answers at the end of the quiz Visit BYJUS for all JEE related queries and study materials 0 out of 0 arewrong 0 out of 0 are correct 0 out of 0 are Unattempted View Quiz Answers and Analysis We know that electric currents can be induced in closed coils when subjected to varying magnetic fields. This phenomenon of inducing current or emf in a coil by changing magnetic fields is called the electromagnetic induction or EMI.We also know that if a current flows through any coil, whether the current is increasing, or decreasing, the coil opposes the change in the currents strength passing through it. This means supplying varying current is necessary.So, if we use two coils in place of one, what type of phenomenon will occur here?Well, mutual inductance takes place between these two coils.About the Concept of Mutual InductanceTo understand this concept, let us take two coils P and S (Distinct coils) and keep them side-by-side.We connect one coil to the switch, and the other to a galvanometer.As soon as a varying current is generated in coil P, automatically current induces in the coil S.P coil is known as the primary coil, and the S coil in which we see the deflection is the secondary coil.So What Happens Next?Well, the varying current in the P coil generates varying magnetic field lines that pass through both the coils.This means increasing the current; the magnetic field lines increase because of which the flux at the secondary coil increases.When this flux increases, an induced EMF is generated in the coil because of which an induced current starts flowing in it.Therefore, the galvanometer shows a deflection.To find the direction of the magnetic field lines, we curl our fingers of our right hand around the wire, the direction in which the thumb points, is the direction of the magnetic field.We can see that the magnetic field lines are in the direction of the current.If these lines change (because of the changing current), the flux in the secondary coil changes because of which an induced emf and the induced current generates in it.Mutual Inductance DerivationWe know that on increasing the current in the primary coil, the flux in the secondary coil increases.I.e., (2)T I(Image will be uploaded Soon)We are not sure of the number of turns in the S coil. So, to calculate the total flux, we have taken the subscript T in (2)T.On removing the sign of proportionality constant, we get,(2)T = MIWhere M is the constant of proportionality and is called the coefficient of mutual induction or mutual inductance of two coils.The unit of mutual inductance is:M = (2)T /I = \[\frac{Weber}{Ampere}\] = \[\frac{Volt-sec}{Ampere}\] = Henry The unit of M is Henry.If I = 1, (2)T = M x 1 M = (2)TThus the coefficient of mutual inductance of two coils is equal to the amount of flux that generates in one coil because of the current flow in the primary coil.M doesnt depend on (2)T, and I because it is a constant term.However, it depends upon the following factors:Geometry (shape) of the coils,Their separation (or the radius of the coils),The orientation (coils kept parallel or inclined at some angle), andThe medium in which we keep these coils.We know that an EMF is induced in the secondary coil. Now we will apply Faradays law here:e2 = - d(2)T/dt = - d(MI1)/dt(Its because the flux of S coil, i.e., (2)T depends on the current (I1) in the P coil)e2 = - M dI1/dtIf dI1/dt = 1, then M = - e2EMF in the secondary coil generates only when there is a change in the current I1.The coefficient of mutual inductance of two coils is equal to the induced emf in the S coil when the rate of change of current in the P coil is unity.Important Formulas in Mutual Induction1. Coefficient of Coupling (K)The coefficient of coupling of two coils is a measure of the coupling between the two cells. It is given byK = \[\frac{M}{\sqrt{L_{1}L_{2}}}\]Where L1 and L2 are coefficients of the self-inductance of the two coils.The value of K is always < 1.If two coils are arranged in series, then their K = 1, then we can show thatL = L1 + L2 + 2M (When current in two coils is in the same direction), andL = L1 + L2 - 2M (When current in two coils in the opposite directions).2. Mutual Inductance of Two Long Coaxial Solenoids (S1 and S2)M = \[\frac{{\mu_{0}N_{1}N_{2}A}}{l}\]Where 0 = Magnetic constant,N1 and N2 = Total number of turns in a solenoid S1, and S2, respectively,l = Length of the longer solenoid, andA = r2= Cross-sectional area of the inner solenoid.Application of Mutual InductanceMutual inductance is the basic operating principle for the following:TransformersMotorsGeneratorsWhat is Inductance?In the field of electronics and electromagnetic, inductance is a key notion that describes a conductor's tendency to oppose current flow. A magnetic field is created across the conductor by the current flow. The field strength is determined by the size of the current and changes as the current changes.Types of InductanceThere are two main types of inductance:Self InductanceMutual InductanceHere we will study about Mutual InductionMutual InductanceWhen two coils are brought near together, the magnetic field in one of the coils directs to connect with the other coil, according to the definition of mutual induction. This leads to voltage development in the second coil. A mutual inductance property describes the situation in which one coil influences or alters the voltage and current values in the other coil.Leakage and stray inductance are two negative consequences of mutual inductance. Through the process of electromagnetic induction, when they are released from one coil, they alter the functionality of another element.It has a fairly simple theory that may be grasped by employing two or more coils. In the 18th century, an American scientist named Joseph Henry characterized it. One of the qualities of the coil or conductor utilized in the circuit is this. If the current in one coil fluctuates with time, the EMF will induce in another coil, according to the property inductance. The transformer, for example, is a fundamental example of mutual inductance.The fundamental disadvantage of mutual inductance is that leakage of one coil's inductance might cause the operation of another coil using electromagnetic induction to be disrupted. Electrical screening is essential to reduce leakage.Mutual Inductance FormulaThe formula of two coils is given asM = \[\frac{{\mu_{0}N_{1}N_{2}A}}{l}\]Where 0= permeability of free space = 410-2 = permeability of the soft iron coreN1= turns of coil 1N2= turns of coil 2A= cross-sectional area in m2L = length of the coil in metersThe unit of mutual inductance is kg. m2.s-2.A-2The amount of inductance produces the voltage of one volt due to the rate of change of current of 1 Ampere/second.Joseph Henry, a scientist from the United States, coined the term to describe the phenomenon of two coils. Mutual inductance is the main operating principle of generators, motors and transformers. Any electrical device having components that tend to interact with another magnetic field also follows the same principle. The interaction is usually brought about by a mutual induction where the current flowing in one coil generates a voltage in a secondary coil.Download Complete Chapter Notes of Electromagnetic Induction Download NowTable of Contents What Is Mutual Inductance?When two coils are brought in proximity to each other, the magnetic field in one of the coils tends to link with the other. This further leads to the generation of voltage in the second coil. This property of a coil which affects or changes the current and voltage in a secondary coil is called mutual inductance. Changing I1 produces changing magnetic flux in coil 2.In the first coil of N1 turns, when a current I1 passes through it, magnetic field B is produced. 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It can be written as\(\begin{array}{l}{{M}_{21}}=\frac{{{N}_{2}}{{\phi }_{21}}}{{{I}_{1}}}.(2)\end{array} \)The SI unit of inductance is henry (H)\(\begin{array}{l}1H=\frac{1(\text{Tesla}).1\left({{m}^{2}} \right)}{1\,\,A}\end{array} \)In a similar manner, the current in coil 2, I2, can produce an induced emf in coil 1 when I2 varies with respect to time. Then,\(\begin{array}{l}{{\varepsilon }_{12}}=-{{N}_{1}}\frac{d{{\phi }_{12}}}{dt}\end{array} \) \(\begin{array}{l}{{N}_{1}}{{\phi }_{12}}\propto {{I}_{2}}\end{array} \) \(\begin{array}{l}{{N}_{1}}{{\phi }_{12}}={{M}_{12}}{{I}_{2}}.(3)\end{array} \) \(\begin{array}{l}{{M}_{12}}=\frac{{{N}_{1}}{{\phi }_{12}}}{{{I}_{2}}}.(4)\end{array} \)This constant of proportionality is another mutual inductance. Changing I2 produces changing magnetic flux in coil 1. 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If a current (50 A) sin 500 t is passed in one of the coils, then find the peak value of induced emf in the secondary coil.(a) 50V (b) 500V (c) 125V (d) 250VSolution:Given:\(\begin{array}{l}i=50\,\sin 500t\end{array} \)emf of mutual induction is given by\(\begin{array}{l}\varepsilon =-M\frac{di}{dt}\end{array} \) \(\begin{array}{l}=-\left(5\times {{10}^{-3}} \right)\frac{d}{dt}\left(50\sin 500t \right)\end{array} \) \(\begin{array}{l}=-5\times {{10}^{-3}}\times 50\cos 500t\times 500\end{array} \) \(\begin{array}{l}\varepsilon =-125\cos 500t\end{array} \)The peak value is 125V. Option c is correct.As the coil is stationary in a uniform magnetic field, there is no change in magnetic flux generated. Hence, there is no induced emf in the coil.We know that the mutual inductance is directly proportional to the permeability of the medium surrounding the coils. When the permeability of the medium is increased by inserting a sheet of iron, then the mutual inductance between the coils also increases.As we know that acceleration due to gravity does not depend on the mass of the falling objects, the glass ball will reach the ground first. Because, being an insulator, glass is not affected by the earths magnetic field. Hence, there is no induced emf in the glass ball. Whereas in a copper ball, emf induced by the earths magnetic field will affect the fall of the ball. Thus, it falls slower.Mutual inductance between two coils is affected by the following:Area of cross-sectionNumber of turns in each coilSpace between the two coilsPermeability of medium between the two coilsLength (in the case of the solenoid)When the separation between the coils is increased, the magnetic flux linked with the secondary coil decreases. Therefore, the mutual inductance of the pair of coils decreases.When there is an increase in the number of turns of each coil, mutual inductance increases.Mutual inductance can be used in transformers, generators and electric motors. Put your understanding of this concept to test by answering a few MCQs. Click Start Quiz to begin! Select the correct answer and click on the Finish buttonCheck your score and answers at the end of the quiz Visit BYJUS for all JEE related queries and study materials 0 out of 0 arewrong 0 out of 0 are correct 0 out of 0 are Unattempted View Quiz Answers and Analysis Mutual inductance is the main operating principle of generators, motors and transformers. Any electrical device having components that tend to interact with another magnetic field also follows the same principle. The interaction is usually brought about by a mutual induction where the current flowing in one coil generates a voltage in a secondary coil.Download Complete Chapter Notes of Electromagnetic Induction Download NowTable of Contents What Is Mutual Inductance?When two coils are brought in proximity to each other, the magnetic field in one of the coils tends to link with the other. This further leads to the generation of voltage in the second coil. This property of a coil which affects or changes the current and voltage in a secondary coil is called mutual inductance. Changing I1 produces changing magnetic flux in coil 2.In the first coil of N1 turns, when a current I1 passes through it, magnetic field B is produced. 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Therefore, the mutual inductance of the pair of coils decreases.When there is an increase in the number of turns of each coil, mutual inductance increases.Mutual inductance can be used in transformers, generators and electric motors. Put your understanding of this concept to test by answering a few MCQs. Click Start Quiz to begin! Select the correct answer and click on the Finish buttonCheck your score and answers at the end of the quiz Visit BYJUS for all JEE related queries and study materials 0 out of 0 arewrong 0 out of 0 are correct 0 out of 0 are Unattempted View Quiz Answers and Analysis Mutual Induction When the flux produced by a variable current in one coil (usually called primary) links with aclosely situated coil (called secondary), there is said to mutual induction. If I2 is the current flowing in the secondary coil, the flux linkages with the primary coil isproportional to the current in the secondary coil. That is, where M12 is the mutual inductance ofthe primary with respect to the secondary. It is also referred to as the coefficient of mutual induction.Similarly, if I1 is the current flowing in the primary coil, the flux linkages with the secondary coilis proportional to the current in the primary coil. That is, where M21 is the mutual inductance of the secondary with respect to the primary. It is also referred to as the coefficient of mutual induction. Mutual Inductance of two circular co-axial concentric coils : Let r1 and r2 (r1