Maxwell's Law and History of electro magnetism

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Physics Group Project
History of electromagnetism and Maxwell's law
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Introduction
Electromagnetism is a branch of Physics, that deals with the electromagnetic force that occurs between electrically charged particles. The electromagnetic force is one of the four fundamental forces and exhibits electromagnetic fields such as magnetic fields, electric fields, and light. It is the basic reason electrons are bound to the nucleus and are responsible for the complete structure of the nucleus. Maxwell was the first person to calculate the speed of propagation of electromagnetic waves, which was the same as the speed of light and came to the conclusion that EM waves and visible light are similar.

These are the set of partial differential equations that form the foundation of classical electrodynamics, electric circuits and classical optics along with Lorentz force law. These fields highlight modern communication and electrical technologies.

1 Maxwell's law

LaTeX $\vec{D}.d\bar{s} = Q_{enclosed}$ $||(1)$ Any closed system will have multiple surfaces but a single volume.Thus,the above surface integral can be converted in to a volume integral by taking the divergence of the same vector.

Thus,mathematically it is LaTeX $\bar{D}.d\bar{s} = \iiint \bigtriangledown.\vec{D}d\vec{v}\,| - (2)$

Thus,by combining (1) and (2) we get LaTeX $\iiint \bigtriangledown.\vec{D}d\vec{v} = Q_{enclosed}$ |–(3) Charges in a closed surface will be distributed over its volume.Thus,the volume charge density can be defined as LaTeX $\rho v = \frac{dQ}{dv}$ measured using c/m3

On rearranging, we get LaTeX $dQ = \rho v dv$ on integrating the above equation, we get LaTeX $Q = \iiint \rho v dv\, || - (4)$ The charge enclosed with in a closed surface is given by volume charge density over that volume. By substituting (4) in (3) we get LaTeX $\iiint \bigtriangledown.Ddv = \iiint \rho v dv$

Cancelling the volume integral both sides we arrive at Maxwell's first equation. LaTeX $\Rightarrow \bigtriangledown.Ddv = \rho v$

Maxwell second equation Maxwell second equation is based on Gauss law on magneto statics. Gauss law on magneto statics states that "closed surface integral of magnetic flux density is always equal to total scalar magnetic flux enclosed with in that surface of any shape or size lying in any medium" Mathematical it is expressed as LATEX $\vec{B}.ds = \phi_{enclosed}$ |–(1) Hence we can conclude that magnetic flux can not be enclosed with in a closed surface of any shape. LATEX $\vec{B}.ds = 0$ |||(2) Applying the Gauss divergence theorem to equation (2),we can convert it (surface integral) to volume integral by taking the divergence of the same vector. LATEX $\vec{B}.ds = \iiint \nabla.\vec{B}dv$ ||–(3)

substituting the equation (3)in(2)we get- LATEX $\iiint \nabla.\vec{B}dv = 0 || - (4)$

To satisfy the above equation either LATEX $\iiint dv = 0$ or LATEX $\nabla.\vec{B} = 0$ The volume of any body or object can never be zero.

Thus we arrive at Maxwell's second equation LATEX $\nabla.\vec{B} = 0$

where, LATEX $\vec{B} = \mu\bar{H}$ Is the flux density. LATEX $\Rightarrow \nabla.\vec{H} = 0$

solonoidal vector is obtained when the divergence of a vector is zero.Irrotational vector is obtained when the cross product is zero.

1.1 Maxwell's third equation

This equation is derived from Faraday's law of electromagnetic induction. It states that "when ever they are n-turns of conducting coil in a closed path placed in a time-varying magnetic field,an alternating electromotive force gets induced in each coil." When two coils with N number of turns,A primary coil and a secondary coil.The primary coil is connected to an alternating current source,and the secondary coil is connected in a closed loop and is placed at a small distance from the primary coil.When an AC current passes the primary coil,an alternating electromotive force gets induced in the secondary coil. Mathematical it is expressed as Alternating emf, LATEX $emf_{alt} = -N\frac{d\phi}{dt}$ ||–(1) where, N is the number of turns in a coil. o is the scalar magnetic flux. The negative signs indicates that the induced emf always oppose the time varying magnetic flux. Let N=1 LATEX $\Rightarrow emf_{alt} = -\frac{d\phi}{dt} || - (2)$ Here the scalar magnetic flux can be replaced by LATEX $\phi = \iint \vec{B}.d\vec{s}$||–(3) substitute equation (3) in (2) LATEX $emf_{alt} = -\frac{d}{dt}\iint \vec{B}.d\vec{s}$ which is a partial differential equation given by LATEX $emf_{alt} = \iint -\frac{\delta\vec{B}}{\delta t}.d\vec{s}$|||–(4) The alternating electromotive force induced in a coil is basically a closed path LATEX $\Rightarrow emf_{alt} = \oint \vec{E}.d\vec{l} || - (5)$ substituting the equation (5) in (4) we get LATEX $\Rightarrow \oint \vec{E}d\vec{l} = \iint -\frac{\delta\vec{B}}{\delta t}.d\vec{s}$|–(6) The closed line integral can be converted in to surface integral using Stokes theorem. Which states that the "closed integral of any vector field is always is equal to the surface integral of the curl of the same vector field." LATEX $\Rightarrow \oint \vec{E}d\vec{l} = \iint \left(\nabla \times \vec{E}\right).d\vec{s}$ |||(7) Substituting equation (7) in (6) LATEX $\Rightarrow \iint \left(\nabla \times \vec{E}\right)d\vec{s} = \iint -\frac{\delta\vec{B}}{\delta t}.d\vec{s}$ |||(8) The surface integral can be cancelled on both sides.Thus we arrive at Maxwell's third equation LATEX $\nabla \times \vec{E} = -\frac{\delta\vec{B}}{\delta t}$ Hence we can conclude that the time varying magnetic field will always produce an electric field.

1.2 Maxwell's fourth equation

It is based on Ampere's circuit law.

Ampere's circuit law states that "The closed line integral of magnetic field vector is always equal to the total amount of scalar electric field enclosed with in the path of any shape," which means the current flowing along the wire(which is a scalar quantity) is equal to the magnetic field vector (which is a vector quantity) Mathematical it can be written as LATEX $\oint \vec{H}.d\vec{l} = I_{enclosed}$|–(1)

Any closed path of any shape or size will occupy on surface area.

Thus L.H.S of equation (1) can be converted in to surface integral using stokes theorem,which states that "closed line integral of any vector is always equal to the surface integral of the curl of the same vector field. LATEX $\oint \vec{H}.d\vec{l} = \iint \left(\nabla \times \vec{H}\right).d\vec{s}| - (2)$ Substituting equation (2) in (1) we get, LATEX $\iint \left(\nabla \times \vec{H}\right).d\vec{l} = I_{enclosed}||(3)$

Here, LATEX $\iint \left(\nabla \times \vec{H}\right).d\vec{l}\, is\ a\ vector\ quantity\ and\ I_{enclosed}\ isascalarquantity.$ is a vector quantity and this scalar quantity in to the LATEX $\vec{J} = \frac{I}{s}\hat{a}N\ measured\ using\ (A/m^2)$ measured using LATEX $\vec{J} = \frac{I}{s}\hat{a}N\ measured\ using\ (A/m^2)$ therefore , LATEX $\vec{J} = \frac{dI}{ds}$ Thus the scalar quantity is converted in to vector quantity.Substituting equation (4) in to (3) we get, LATEX $\Rightarrow \iint \left(\nabla \times \vec{H}\right).d\vec{l} = \iint \vec{J}.d\vec{s}$ |||(5) In the above equation R.H.S and L.H.S both contain surface integral. Hence we can cancel it.

Thus, we arrive at Maxwell's fourth equation LaTeX $\vec{J} = \bigtriangledown \times \vec{H}$ ||(6) We can conclude that the current density vector is a curl of the static magnetic field vector. on applying the time varying field (differentiating by time) we get, LaTeX $\bigtriangledown \times \vec{J} = \frac{\delta \rho v}{\delta t}$ |||(7) Apply divergence on both sides of equation (6) LaTeX $\bigtriangledown . \left(\bigtriangledown \times \vec{H} \right) = \bigtriangledown \times \vec{J}$ This divergence of the curl of any vector will always be zero. LaTeX $\bigtriangledown . \vec{G} = - \bigtriangledown . \vec{J}$|–(10) Substituting equation (6) in 10 we get, LaTeX $\bigtriangledown . \vec{G} = \frac{\delta \rho v}{\delta t}$|–(11) BY Maxwell's first equation, LaTeX $\rho v = \bigtriangledown . \vec{D}$

Substituting the value of PV by equation (11) we get, LaTeX $\bigtriangledown . \vec{G} = \frac{\delta(\bigtriangledown . \vec{D})}{\delta t}$|–(12) Here LaTeX $\frac{\delta}{\delta t}$ *is time varient and* is time variant and space variant.Both are independent to each other.Thus on rearranging equation (12) we get, LaTeX $\bigtriangledown . \vec{G} = \bigtriangledown . \frac{\delta(\vec{D})}{\delta t}$ Thus canceling the like terms we get, LaTeX $\vec{G} = \frac{\delta \vec{D}}{\delta t} = \vec{J}_D$|–(13) Substituting them in LaTeX $\left(\bigtriangledown \times \vec{H} \right) = \vec{J} + \vec{G}$ This is an insulating current flowing in the dielectric medium between two conductors. Hence Maxwell's fourth equation will be LaTeX $\Rightarrow \left(\bigtriangledown \times \vec{H} \right) = \vec{J} + \vec{J}_D$ or LaTeX $\Rightarrow \left(\bigtriangledown \times \vec{H} \right) = \vec{J} + \frac{\delta \vec{D}}{\delta t}$

1.3 Gauss law

This law describes the nature of the electric field around electric charges.The law is expressed in-terms of electric charge density and electric charge density.

1.4 Gauss's magnetism law

This law states that the divergence of the electric flux density D equals the volume of electric charge density. The second equation states the divergence of the magnetic flux density is null.

1.5 Faraday's law

Faraday was a scientists whose experiment set up led to Faraday's law. The experiment is not very complex.When a battery is disconnected,no electric flows through the wire.Hence no magnetic flux is induced in the iron (magnetic core).The iron acts like a magnetic field that flows easily in a magnetic material.The purpose of the core is to form a path of the flow of magnetic flux.

1.6 Ampere's law

The law shows the relationship between the flow of electric current and the magnetic field around it. Suppose the wire carries a current I, the current produces a magnetic field that surrounds the wire.

1.7 History of electromagnetism

In physics, electromagnetism is an interaction that occurs between particles with electric charge via electromagnetic fields. The electromagnetic force is one of the four fundamental forces of nature. It is the dominant force in the interactions of atoms and molecules. Electromagnetism can be thought of as a combination of electrostatics and magnetism, two distinct but closely intertwined phenomena. Electromagnetic forces occur between any two charged particles, causing an attraction between particles with opposite charges and repulsion between particles with the same charge, while magnetism is an interaction that occurs exclusively between charged particles in relative motion. These two effects combine to create electromagnetic fields in the vicinity of charge particles, which can exert accelerate other charged particles via the Lorentz force. At high energy, the weak force and electromagnetic force are unified as a single electroweak force.The electromagnetic force is responsible for many of the chemical and physical phenomena observed in daily life. The electrostatic attraction between atomic nuclei and their electrons holds atoms together. Electric forces also allow different atoms to combine into molecules, including the macro molecules such as proteins that form the basis of life. Meanwhile, magnetic interactions between the spin and angular momentum magnetic moments of electrons also play a role in chemical reactivity; such relationships are studied in spin chemistry. Electromagnetism also plays a crucial role in modern technology: electrical energy production, transformation and distribution, light, heat, and sound production and detection, fiber optic and wireless communication, sensors, computation, electrolysis, electroplating and mechanical motors and actuators.

Electromagnetism has been studied since ancient times. Many ancient civilizations, including the Greeks and the Mayans created wide-ranging theories to explain lightning, static electricity, and the attraction between magnetized pieces of iron ore. However, it wasn't until the late 18Th century that scientists began to develop a mathematical basis for understanding the nature of electromagnetic interactions. In the 18Th and 19Th centuries, prominent scientists and mathematicians such as Coulomb, Gauss and Faraday developed namesake laws which helped to explain the formation and interaction of electromagnetic fields. This process culminated in the 1860s with the discovery of Maxwell's equations, a set of four partial differential equations which provide a complete description of classical electromagnetic fields. Besides providing a sound mathematical basis for the relationships between electricity and magnetism that scientists had been exploring for centuries, Maxwell's equations also predicted the existence of self-sustaining electromagnetic waves. Maxwell postulated that such waves make up visible light, which was later shown to be true. Indeed, gamma-rays, x-rays, ultraviolet, visible, infrared radiation, microwaves and radio waves were all determined to be electromagnetic radiation differing only in their range of frequencies.

In the modern era, scientists have continued to refine the theorem of electromagnetism to take into account the effects of modern physics, including quantum mechanics and relativity. Indeed, the theoretical implications of electromagnetism, particularly the establishment of the speed of light based on properties of the "medium" of propagation (permeability and permittivity), helped inspire Einstein's theory of special relativity in 1905. Meanwhile, the field of quantum electrodynamics (QED) has modified Maxwell's equations to be consistent with the quantize nature of matter. In QED, the electromagnetic field is expressed in terms of discrete particles known as photons, which are also the physical quanta of light. Today, there exist many problems in electromagnetism that remain unsolved, such as the existence of magnetic mono poles and the mechanism by which some organisms can sense electric and magnetic fields.

Originally, electricity and magnetism were considered to be two separate forces. This view changed with the publication of James Clerk Maxwell's 1873 A Treatise on Electricity and Magnetism in which the interactions of positive and negative charges were shown to be mediated by one force. There are four main effects resulting from these interactions, all of which have been clearly demonstrated by experiments:

1.Electric charges attract or repel one another with a force inversely proportional to the square of the distance between them: unlike charges attract, like ones repel. 2.Magnetic poles (or states of polarization at individual points) attract or repel one another in a manner similar to positive and negative charges and always exist as pairs: every north pole is yoked to a south pole. 3.An electric current inside a wire creates a corresponding circumferential magnetic field outside the wire. Its direction (clockwise or counter-clockwise) depends on the direction of the current in the wire. 4.A current is induced in a loop of wire when it is moved toward or away from a magnetic field, or a magnet is moved towards or away from it; the direction of current depends on that of the movement. In April 1820, Hans Christian observed that an electrical current in a wire caused a nearby compass needle to move. At the time of discovery, did not suggest any satisfactory explanation of the phenomenon, nor did he try to represent the phenomenon in a mathematical framework. However, three months later he began more intensive investigations.Soon thereafter he published his findings, proving that an electric current produces a magnetic field as it flows through a wire. The CGS unit of magnetic induction is named in honor of his contributions to the field of electromagnetism.

1.8 Conclusion

Generally An electromagnet is a kind of magnet where the magnetic field is created by an electric current. The uses of electromagnets are given here to help learners understand the topic more effectively. Electromagnets can be considered as a temporary magnet that functions with the help of an electric current. The magnetic strength of an electromagnet can be easily altered by varying the amount of electric current and its polarity can be changed by varying the direction of the electric current. Maxwell's equations integral form explain how the electric charges and electric currents produce magnetic and electric fields. The equations describe how the electric field can create a magnetic field and vice versa.

1.9 Reference

1.10 Google

1.11 Wikipedia

1.12 Grade 8 students book

1.13 From our own previous knowledge

References