Saint John Baptist De La Salle Catholic School

A.A, Ethiopia

Physics First Group Assignment for Grade 10 Students

Grade:10^{th}
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Contents

You may notice that the name of sir Hans Christian Oersted is at some places referred as "Hans Christian **Ørsted**" or vice versa; the mistake is all because of our sources, we again apologize for that.

1 Introduction

– In this assignment we are willing to discuss to our beloved audience about the prime history of electromagnetism and about sir Maxwell's equations, so, come along and take the journey with us.–

Next to the discovery of gravity, for years people had been trying to model electric and magnetic forces. These behave like gravity, with the important difference bring that two electric charges or two magnets of the same kind repel each other, while unlike charges or unlike magnets attract. Electricity and magnetic forces are far stronger than gravity, but we don't usually notice them in everyday life because a macroscopic body contains almost equal numbers of positive and negative electrical charges. This means that the electric and magnetic forces between two macroscopic bodies nearly cancel each other out, unlike the gravitational force, which all add up.

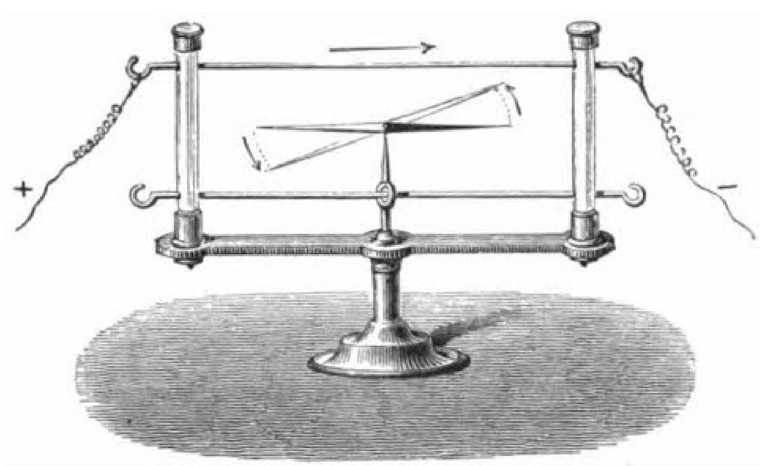
One of Our current ideas about electricity and magnetism were developed over a period of about a hundred years from the mid-eighteenth to the mid-nineteenth century, when physicists in several countries made detailed experimental studies of electric and magnetic forces. One of the most important discoveries was that electrical and magnetic forces are related: A moving electrical charge causes a force on magnets, and a moving magnet causes a force on electrical charges.

2 History Of Electromagnetism

2.1 Pre-History

A central feature of nineteenth-century science was the unification of the previously separate branches of physics. In 1820 Hans Christian Oersted made one of the earliest and most significant discoveries in this respect when he found a connection between electricity and magnetism.
Oersted's physical research was profoundly influenced by philosophical ideas. Having learned German as a boy, Oersted absorbed German philosophy and completed his doctoral dissertation on Immanuel Kant's philosophy in 1799. While visiting Germany in 1801, he met, among others, the Idealist philosopher Friedrich Wilhelm Joseph Schelling. Schelling taught that all the apparently separate powers of nature (such as electricity and magnetism) were, in reality, unified. Oersted accepted Schelling's general view of nature, but came to stress the necessity of empirically demonstrating the connections between nature's powers.

In 1806, at the age of 29, he became Professor of Physics at the University of Copenhagen. During many years of scientific research, Oersted frequently expressed his belief in the unity of nature's powers and continued searching for a connection between electricity and magnetism. In 1820 he found it. While delivering a lecture, Oersted brought a magnetic needle close to a wire carrying an electric current. The needle was deflected. Unlike other forces in nature already known, the force between the electric wire and the magnetic needle turned out to be a "non central" force. Whereas a falling rock, for example, is attracted toward the center of the Earth, Oersted's magnetic needle was not attracted toward the wire.



No matter where it was placed in the vicinity of the wire, it pointed in a direction perpendicular to the wire. This indicated the presence of a force encircling the wire. When Oersted sent word of his results throughout Europe a few months after his initial discovery, he caused a sensation and prompted a whole new line of scientific research. Attacking problems posed by Oersted's discovery, physicists found many other connections between electricity and magnetism., Although primarily known for this one discovery, Oersted did research in other areas as well - most importantly on the compressibility of water.

2.2 HISTORY-*short version*

It is sometimes hard to imagine there was a time without electricity. Although it is only relatively recently that people started enjoying the benefits in their homes. The oldest reference is an Egyptian text from 2750 BC speaking of the 'Thunders of the Nile'. However these were actually electric fish.

The earliest known discovery of electricity comes in 585 BC in a statement written by Thales of Miletus. Thales recognized the attractive powers of amber rubbed with animal fur as well as iron to lodestone. Thales attributed the objects to having some sort of soul, but what he truly discovered were the first observations of static electricity and magnetism. He became interested in how magnetic materials pull and push iron. He thought this was because these 'lodestones' were alive and contained energy. Nowadays we understand how magnetic fields move some objects. We use this knowledge to generate electric power and rotate an electric motor.

4000 years ago, in northern Greece, a shepherd went out to look after his herd. The shepherd Magnes, who lived in Magnesia lost a sheep, he went to rescue it but in the way the stuff he had been holding to and his feet got stuck into a mysterious rock which pulled magnetic objects, aka metals. That had been the very first moment of the discovery of a magnet and led for - questioning and using it for good.

In the year 1600, a father of Philosophy, William Gilbert did some extensive research and experiments on electricity and magnetism. he published on "Magnet and Magnetic Bodies" dealing that static electricity and magnetism are not the same thing. he originally coined the term *electricity* from the latin word electrus to the greece word electron which means 'like amber' and 46 years leater sir Thomas Browne brought the term "electricity". Gilbert is known for his first telling that the earth is a huge magnet and how and why compasses point to the north and so.

It is Franklin's work on electricity that is most remembered by science, and his published collection of the latest theories on the subject made him world famous. In 1746 he saw a demonstration of static electricity by a Dr Spencer from Edinburgh, Scotland. He brought Spencer's equipment and experimented with it during the winter of 1746-47. He formulated the idea of positive and negative electricity by watching how static electricity jumped from one of his colleagues to another. He said that a person who had more electricity than another was positively charged, and when a spark jumped from that person to another, it was because that person was negatively charged. He described how a battery of glass panes could be charged with electricity . Franklin also invented the lightning rod, which was first used in experiments in Paris, France, in 1752. Franklin's electric terminology survives; although it is now known that electricity is a flow of negative electrons, convention holds that it flows from positive to negative terminals.

The first to realize there was some connection was Danish physicist Hans Christian Ørsted. While setting up for a lecture he was to give at the university in 1820, Ørsted noticed that the electric current from the battery he was using deflected a nearby compass needle. He soon realized that moving electricity created a magnetic force, and coined the term "electromagnetism." A few years later British scientist Michael Faraday reasoned that-expressed in modern terms-if an electric current could cause a magnetic field, a magnetic field should be able to produce an electric current. He demonstrated that effect in 1831. Fourteen years later Faraday also discovered a connection between electromagnetism and light when he showed that intense magnetism can affect the nature of **polarized light.**

Maxwell's contribution to electromagnetism allowed for more accurate methods to be used to calculate the speed of light.
In 1907, Rosa and Dorsey indirectly determined the speed of light through using the electric and magnetic permeability of air.
This positive finding verified the existence of electromagnetic waves and confirmed that light in fact does have electromagnetic properties.
The value attained from this experiment had to be later corrected because speed of electromagnetic waves was deduced to be independent of the medium they propagate in.

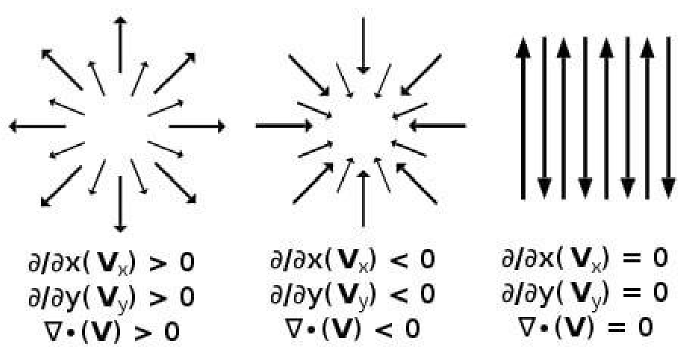
Heinrich Hertz proved the existence of radio waves,in addition to Maxwell's predictions, in the late 1880s. He used two rods to serve as a receiver and a spark gap as the receiving antennae. Where the waves were picked up, a spark would jump. Hertz showed in his experiments that these signals possessed all of the properties of electromagnetic waves.

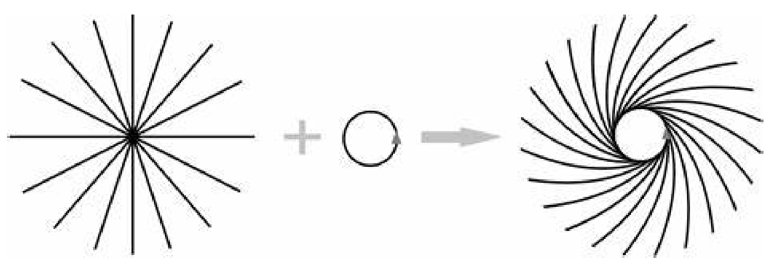
Guglielmo Marconi was 20 when he first learnt of Hertz's work and he immediately embarked on a period of intense experimentation in two attic rooms of his family's country mansion outside Bologna. He filled these with equipment including a coil and spark gap -for creating the electromagnetic waves-and a receiver for detecting them. Soon Marconi was able to show his mother (who constantly encouraged him) how a key that was pressed at one end of a room could cause a buzzer to sound 30 ft away.

Using his capacity for improving and inventing. Marconi gradually developed his apparatus so that he could transmit over greater and greater distances. And he soon discovered that a hill between transmitter and receiver was no obstacle. At that stage he emigrated to England in search of support, which he got, from both the Post Office and the War Office. By 1897, when he was 23, Marconi was sending radio signals over nine miles (14 km).

3 MAXWELL’S EQUATIONS

3.1 INTRODUCTION





The above diagrams simply demonstrate "Divergence" and "Convergence" respectively, which is later to be discussed on.

3.2 Story line

Maxwell’s first paper on electromagnetism, published while he was at Aberdeen and twenty-four years old, had the title On Faraday’s Lines of Force. It was aimed at giving mathematical form to Faraday’s field concept. Maxwell was following Thomson, who had earlier composed a mathematical theory of Faraday’s concept of electric lines of force. Thomson cheerfully opened the gates to his electrical preserves wishing Maxwell good hunting on his quest.

And Maxwell found it. His theory delved deeper than Thomson’s; it concerned magnetic fields as well as electric fields, and showed mathematically how they were interconnected. He found his mathematical ideas in an analogy between Faraday’s lines of force and the lines of flow in a fictitious, weightless, in-compressible fluid.

Like all of the analogies evoked by Maxwell, this one did not constitute a complete physical theory. The gift of the analogy was a short list of equations that accounted for many of the observed phenomena of electricity, magnetism, and electromagnetism. The ingredients of the equations were five vectors, which we now write **A, B, E, H**, and **J**. The electric field was represented by the **E** vector, and **J** described electric current. For the magnetic field two vectors were required, **B** and **H**. **H** was generated by the currents **J**, as observed in Oersted's experiment. The second magnetic vector, **B**, was equal to **H** in a vacuum but differed from it in a material medium.

Without any further a do, let's look at these 4 magnificent equations.

1. $\nabla \cdot D = \rho$
2. $\nabla \cdot B = 0$
3. $\nabla \times E = -\frac{\partial B}{\partial t}$
4. $\nabla \times H = J + \frac{\partial}{\partial t} D$

FIRST EQUATION

Let us consider a surface S bounding a volume V with a dielectric. Originally the volume contains no net charge but, we allow the dielectric to be polarized, say by placing it to an electric field E. We also deliberately place some charge on the dielectric body. Thus, we have two types of charge:
I. Real charge ρ
II. Bound charge ρ'
Therefore, from Gauss' law, we have: $\int_s E \cdot ds = \frac{1}{E_0} \int_v (\rho + \rho') \cdot dv$

$\rightarrow \int_s E \cdot ds = \frac{1}{E_0} \int_v \rho dv + \int_v \rho' dv$ ....(*)

But, $\rho' = -\nabla \cdot P$ where, P is the polarization and $\nabla \cdot P$ is the amount of polarized charge in unit volume.

Also, $\int_s E \cdot ds = \int_v (\nabla \cdot E) \cdot dv$

Therefore, (*) becomes:

$$E_0 \int_v \nabla \cdot E dv = \int_v \rho dv - \int_v \nabla \cdot P dv \text{............(1)}$$

$$E_0 \int_v \nabla \cdot E dv + \int_v \nabla \cdot P dv = \int_v \rho dv \text{............(2)}$$

$$\int_v \nabla \cdot (E_0 E + P) dv = \int_v \rho dv \text{......................(3)}$$

$$\int_v \nabla \cdot D dv = \int_v \rho dv \text{.................................(4)}$$

where $E_0 E = D$, which is electric displacement

$\therefore \nabla \cdot D = \rho$ – proved

SECOND EQUATION

according to Gauss' law, the total normal magnetic induction over a closed surface S is always equal to zero because no free magnetic pole exists. If B is the magnetic induction vector, then:

$$\int_s Bds = 0$$

But by Gauss' divergence theorem:

$$\int_s Bds = \int_v \nabla \cdot Bdv$$

where v is the volume enclosed by surface S.

$\therefore \int_v \nabla \cdot Bdv = 0 - - proved$

but in a case, the above equation will be rue if the integral sign is removed. i.e –

$$\nabla \cdot B = 0$$

THIRD EQUATION

according to Faraday's law of electromagnetic induction, the electromotive force induced in a closed circuit is given by:

$$E = -\int \frac{\partial}{\partial t}(B \cdot ds) ....(**)$$

Where, $\phi = \int B \cdot dt$ is the total magnetic flux passing through a closed surfaces since, the surface S always terminates over a loop periphery. The value of electromotive force is also given by the cyclic line integral.

$$E = \int E \cdot dt ....(***)$$

This is in accordance with the fact that the work done by a unit positive charge in going round a loop enclosing the surface S is the electromotive force produced in the circuit. However, applying Stoke's theorem in order to change line integral to surface integral, we get:

$$\int E \cdot dl = \int_s (\nabla \times E) \cdot ds ....(****)$$

Equating equation ** and ****, we get:

$$\int_s (D \times E) \cdot ds = -\int_s \frac{\partial B}{\partial t} \cdot ds$$

$\rightarrow \nabla \times E = -\frac{\partial B}{\partial t}$

FOURTH EQUATION

from Ampere's circuital law, the work done in carrying unit magnetic field pole once a closed arbitrary path linked with the current I is expressed by: $\int_c H \cdot dl = l$

$$\int_c H \cdot dl = \int_s T \cdot s$$

$\therefore \int_s T \cdot s = l$

Where, S is the surface bounded by the closed path C. Now changing the line integral by Stoke's theorem: $\int_s (\nabla \times H) \cdot ds = \int_s J \cdot ds$

$\rightarrow \nabla \times H = J$

But Maxwell assumed that J itself is not complete, but it should be added with the displacement current J_d

where, $J_d = \frac{\partial D}{\partial t}$

$\therefore \nabla H = J + J_b$

$\nabla \times H = J + \frac{\partial D}{\partial t}$

So, what does these equations tell us?

1^{st} Equation :- describes the electrostatic field

2^{nd} Equation :- Magnets always found as N and S poles together, not separately.

3^{rd} Equation :- an electric field is produced by a varying magnetic field.

4^{th} Equation :- the change of electric field will produce a magnetic field.

3.3 Applications:

What are applications of Maxwell's equations anyways?

There are plenty, such as electric appliances, radio communication, optical technology and theoretical applications too - Maxwell's equations play a central role in special relativity, as they're covariant and yet, it was found that Galilean transformations don't keep the equations covariant, which means we need a new formulation of dynamics, a.k.a special relativity. A major motivation, and a direct link to the Lorentz transformations and how space and time behave. but there's another half, about modelling spacetime itself, and it's a thing of its own and after that latter exercise (done using the machinery of hyperbolic geometry, tensors, spinors, etc.), Maxwell's equations can be restated manifestly covariant. Every electrical engineer should remember these equations along with their derivation and meaning.

4 Conclusion

When Maxwell died in 1879, his theory of the electromagnetic field and its amazing progeny, electromagnetic waves, had little experimental support, just the indirect evidence that Maxwell's calculated speed of the electromagnetic waves matched the speed of light.

Key points to grasp:

E=electric field
J=electric current
B and **H**=magnetic fields
H= generated by **J**
B=**H**: at the vacuum of space

Maxwell's first equation, which describes the electrostatic field, is derived immediately from Gauss's theorem, which in turn is a consequence of Coulomb's inverse square law. Gauss's theorem states that the surface integral of the electrostatic fiel d D over a closed surface is equal to the charge enclosed by that surface.
Maxwell's Second Equation is based on Gauss's Law of Magnetism states that: "The net flux out of a magnetic flux which is passing through a closed surface is always zero." The dipole nature of the magnet generates a magnetic field.
Maxwell's third equation is Faraday's Law. In effect, it says that an electric field is produced by a varying magnetic field. The right side of the equation indicates a changing magnetic field.
The fourth law is Ampere Maxwell's law that tells the change of electric field will produce a magnetic field. The two equations of 3 and 4 can describe an electromagnetic wave that can spread on its own.

5 *Appendix*

Electromagnetic force is the second strongest of the four forces of nature. It acts between particles with electric charges.
Electron an elementary particle of matter that ha a negative charge and its responsible for the chemical properties of elements.
Proton a type of positively charged *Baryon* that with a neutron forms h nucleus of an atom.
Gravity the weakest of the four forces of nature. It is the means by which objects that has mass attract each other.
Polarization of *EMW* is the direction of the electromagnetic wave in which its electric field vector, $\vec{E}$
Gauss's law: the divergence of the electric field is proportional to the charge density at the concerned point. To understand what this physically means, consider what divergence physically means - it's a measure of the tendency of a vector field to diverge, flow out, from a point.
Lorentz transformation is the process of converting one coordinate frame to another
Torsion balance is a device used to measure the electric forces between charges and the magnetic force between poles.
Vector field a vector field is just a collection of vectors. One vector for each point in space.
Electromagnetic Induction is a current produced because of voltage production (electromotive force) due to a changing magnetic field.
Magnetic Flux is the Magnetic field times the area perpendicular to the magnetic field $\vec{B}$

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