Lecture (1)

Electricity and Magnetism II

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Syllabus of Electricity and Magnetism II

Week	Topic
1	Introduction to Magnetism Magnetic field Magnetic Flux
2	Magnetic force Magnetic force on an electric current Uniform Magnetic field in a charged ring
3	Motion of a charged particle in a uniform magnetic field Application of moving particle in magnetic field Magnetic field of moving charge
4	Motion of a charged particle in a nonuniform magnetic field Magnetic field of a rectilinear current (Biot-Savart Law)
5	Magnetic field produced by a closed current Magnetic field of a circular current
6	Gauss's law for magnetism
7	**Amperes Law for the magnetic field** **Examples on Amperes Law**
8	Faraday's Law Lens's Law Faraday Henry Law
9	Magnetic Potential
10	Magnetic Flux Magnetization Vector
11	Solving Problems
12	Inductance Self Inductance Mutual Inductance
13	Transformer
14	Magnetic susceptibility Magnetization field
15	AC circuits

DR. AHMED ALMURSHEDI

References

- Fundamentals of Physics, Halliday & Resnicle, John Wiley, 2011 9th edition.
- University Physics by Francis and others.
- Physics for Scientists and Engineers with Modern Physics, Raymond Serway and John Jewett
- الفيزياء العامة (ميكانيك - كهربائية ومغناطيسية) - أ.م.د. فؤاد شاكر د. علي خلف
- الكهربائية والمغناطيسية - إبراهيم ناصر واخرون
- Website

Magnetism

- Centuries before Christ, men observed that certain iron ores, such as the lodestone, have the property of attracting small pieces of iron.
- The property is exhibited in the natural state by iron, cobalt and manganese and by many compounds of these metals. This property is unrelated to gravitation, since not only does it fail to be exhibited naturally by all bodies, but it appears to be concentrated at certain spots in the mineral ore. It is also apparently unrelated to the electric interaction, because neither cork balls nor pieces of paper are attracted to all by these minerals. Therefore a new name “magnetism” was given to this physical property. The reigns of a body where the magnetism appears to be concentrated are called magnetic poles. A magnetized body is called a magnet.

- The earth itself is a huge magnet. For example, if we suspend a magnetized rod at any point on the earth surface and allow it to rotate freely about the vertical, the rod orients itself so that the same end always points towards the north geographic pole. This result shows that the earth is exerting an additional force on the magnetized rod, which it does not exert on unmagnetized rods.
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- This experiment also suggest that there are two kinds of magnetic poles which we may designate by the signs (+) and (-) by the letters (N) and (S), corresponding to the north-seeking and south-seeking poles, respectively. If we take two magnetized bars and place them as showing in the figure below:

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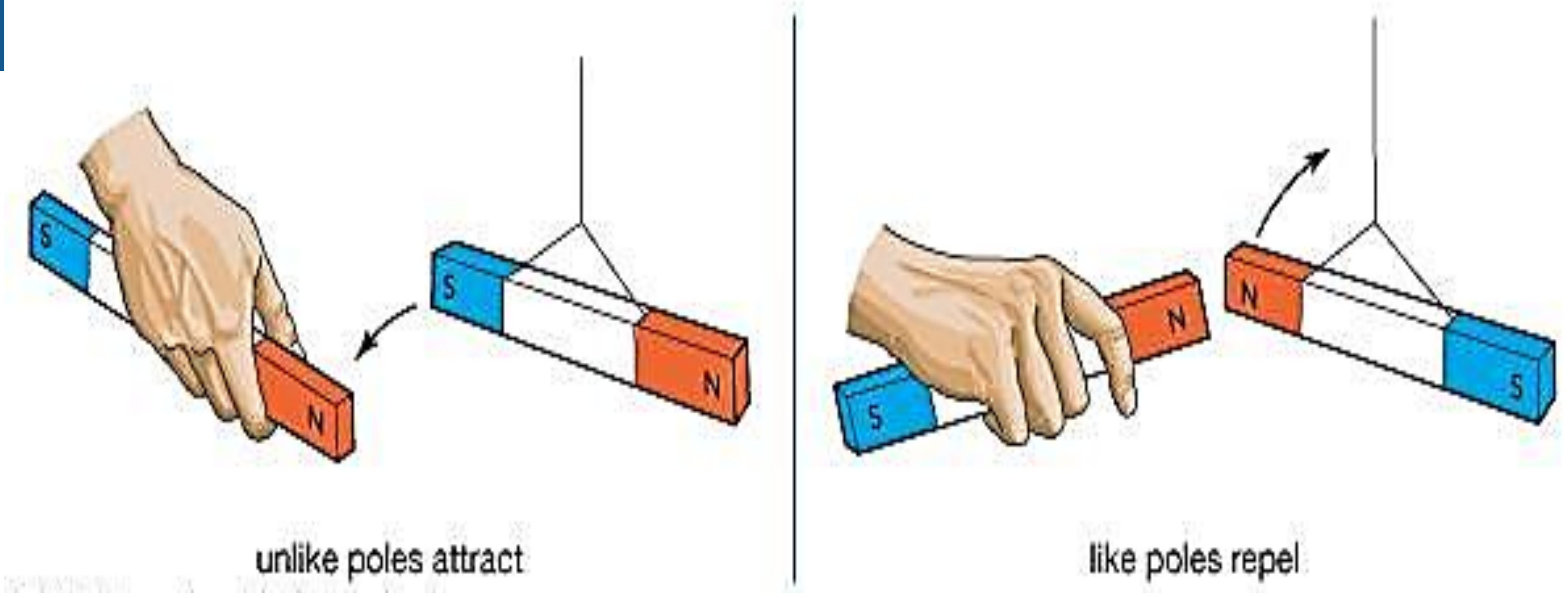


Interaction between two magnetized bars: unlike poles attract each other and like poles repel each other

Magnetized bodies always exhibit poles in pairs, equal and opposite.

The Magnetic Field

- Since there is an interactions between magnetized bodies, we may say in analogy with the electrical case. That a magnetized body produces a magnetic field in the space around it. when we place an electric charge at rest in a magnetic field, no special force is observed on the charge. But when an electric charge moves in a region where there is a magnetic field, a force is observed on the charge in addition to this force, due to its electric interaction.
- By measuring the force at the same point in a magnetic field, the force experienced by different charges moving in different ways, we may obtain a relation between the force, the charge, and its velocity. In this we conclude that "the force exerted by a magnetic field on a moving charge is proportional to the electric charge and to its velocity, and the direction of the force is perpendicular to the velocity of the charge".
- We may write the force ($\vec{F}$) on a charge (q) moving with velocity ($\vec{\boldsymbol{v}}$) in a magnetic field ($\vec{\boldsymbol{B}}$) as the vector product.

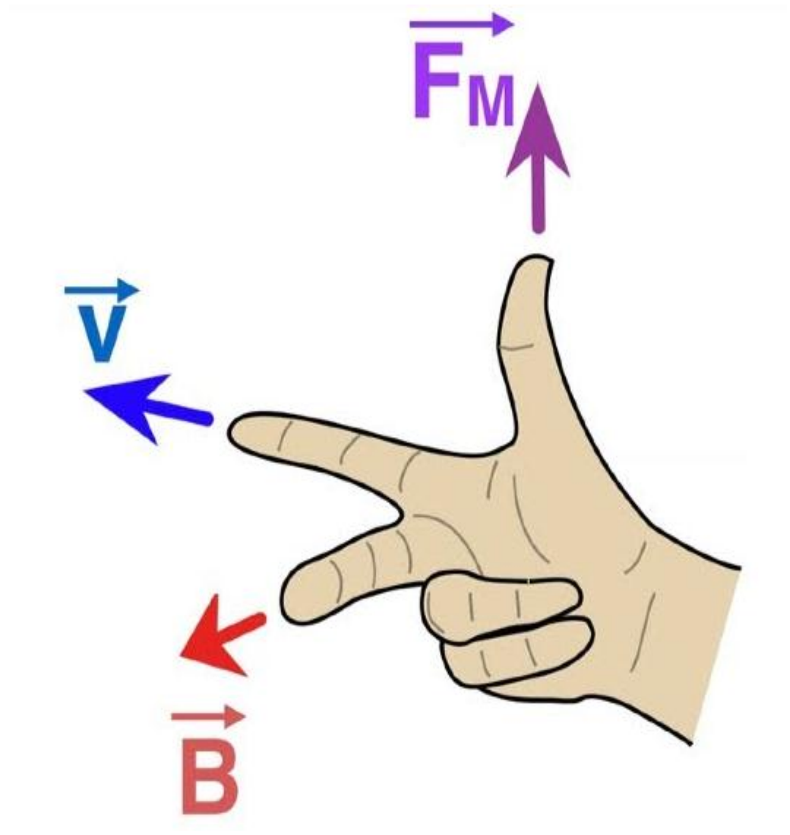
$$\vec{\boldsymbol{F}} = \boldsymbol{q}\,\vec{\boldsymbol{v}} \times \vec{\boldsymbol{B}} \qquad \textit{Magnetic force}$$

- Here ($\vec{\boldsymbol{B}}$) is a vector found at each point by comparing the observed value of $\vec{\boldsymbol{F}}$ at the point with those of (q) and ($\vec{\boldsymbol{v}}$). The vector ($\vec{\boldsymbol{B}}$) may vary from point to point in a magnetic field, but at each point it is found experimentally to be the same for all charges and velocities. Therefore ($\vec{\boldsymbol{B}}$), as defined by above equation, describes a property that is characteristic of the magnetic field, and we shall call it the magnetic field strength.
- When the particle moves in a region where there are an electric and magnetic field, the total force is the sum of the electric force ($q\,\vec{E}$) and the magnetic force ($q\,\vec{v} \times \vec{B}$) that is:

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

- **This expiration is called “Lorentz Force”**

- Because of the vector property of the vector product, the magnetic force equation gives a force perpendicular to the velocity ($\vec{\boldsymbol{v}}$) but also perpendicular to the magnetic field ($\vec{\boldsymbol{B}}$). The magnetic force equation also implies that when ($\vec{\boldsymbol{v}}$) is parallel to ($\vec{\boldsymbol{B}}$), the force ($\vec{\boldsymbol{F}}$) is zero. In Lorentz force equation the relation between the three vectors ($\vec{\boldsymbol{v}}$), ($\vec{\boldsymbol{B}}$) and ($\vec{\boldsymbol{F}}$) is illustrated for both a positive and a negative force. Figure below shows the right hand rule for determining the direction of the force.



If ($\boldsymbol{\alpha}$) is the angle between ($\vec{\boldsymbol{v}}$) and ($\vec{\boldsymbol{B}}$), the magnitude of ($\vec{\boldsymbol{F}}$) is:

$$\boldsymbol{F = q\, v\, B \sin\alpha}$$

The maximum force occurs when $\alpha = \frac{\pi}{2}$ or when ($\vec{\boldsymbol{v}}$) is perpendicular to ($\vec{\boldsymbol{B}}$), resulting in:

$$\boldsymbol{F = q\, v\, B}$$

The force is zero when $\alpha = 0$ or when ($\vec{\boldsymbol{v}}$) is parallel to ($\vec{\boldsymbol{B}}$).

From magnetic force equation the unit of magnetic field is (**N/C m** $\boldsymbol{s^{-1}}$) or ($\boldsymbol{kg\, C^{-1} s^{-1}}$). This unit is called **Tesla (T)**.

"One tesla correspond to magnetic field that produces a force of one Newton on a charge of one coulomb moving perpendicular to the field at one meter per second".

Because the magnetic force $\boldsymbol{\vec{F} = q\vec{v} \times \vec{B}}$ is perpendicular to the velocity, its work is zero, and therefore it does not produce any change in the kinetic energy of the particle.

The magnetic force $\boldsymbol{\vec{F}_B}$ can do no work on the particle:

$$\boldsymbol{dW = \vec{F}_B\,.\,d\vec{S} = q\,\vec{v} \times \vec{B}.\vec{v}\,dt = q(\,\vec{v} \times \vec{v}).\vec{B}\,dt = 0}$$

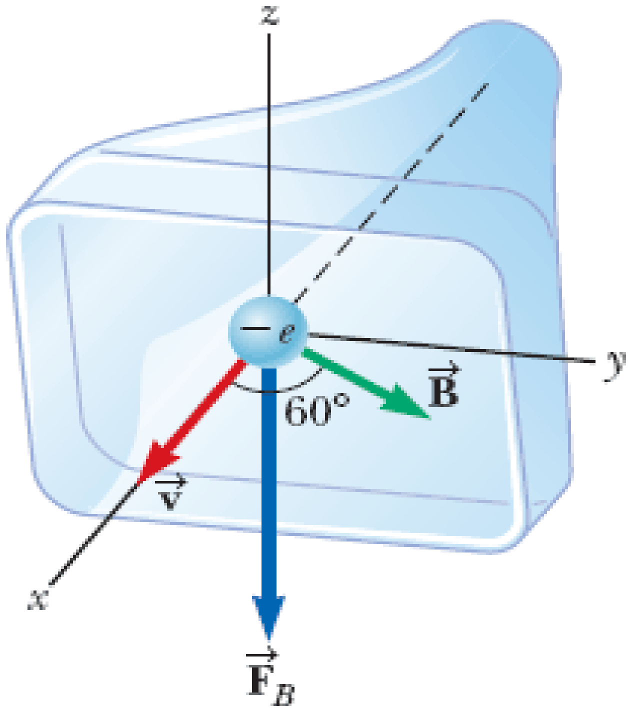
Example 1: force exerted on a cosmic ray proton which enters the magnetic field of the earth. Suppose the proton moves in the direction perpendicular to the field with a velocity equal to $10^7\ m\ s^{-1}$. The intensity of the magnetic field near the earth surface at the equator is about $1.3 \times 10^{-5}\ T$. Compare between force and acceleration of gravity and magnetic field.

- **Sol.**

Example 2: an electron in a television picture tube moves toward the front of the tube with a speed of $8 \times 10^6\ m/s$ along the x-axis. Surrounding the neck of the tube are coils of wire that create a magnetic field of magnitude 0.025 T, directed at an angle of 60^o to the x-axis and lying in the x-y plane.

a) Calculate the magnetic force on the electron

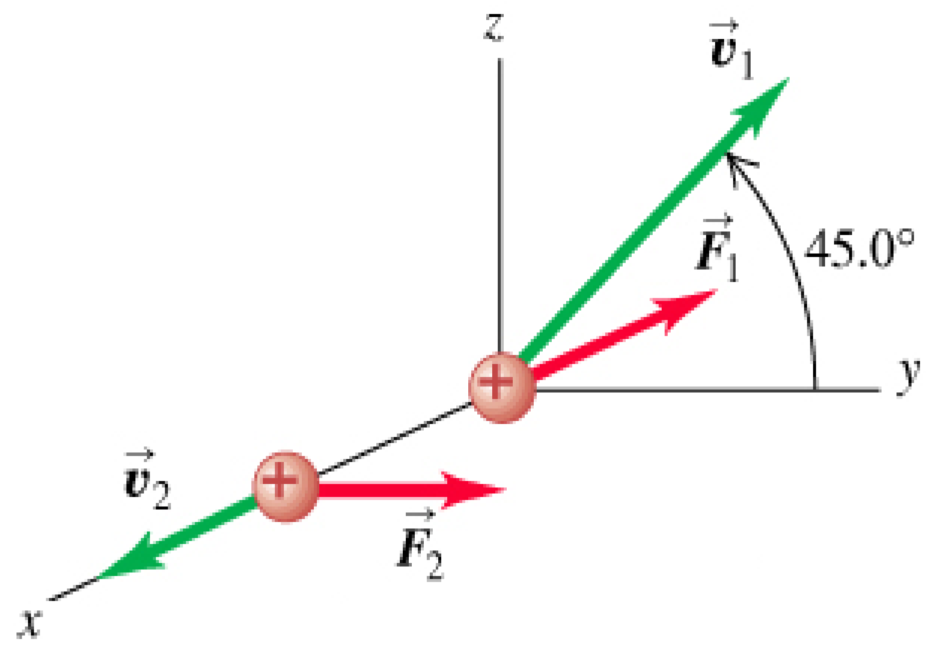
b) Find the vector expression for this magnetic force on the electron



DR. AHMED ALMURSHEDI

Example 3: A particle carries a charge of $4 \times 10^{-9}\,C$. When it moves with a velocity $\vec{v}_1 = 3 \times 10^4 \frac{m}{s} at 45^o$ above the y-axis in the y-z plane, a uniform magnetic field exerts a force $\vec{F}_1$ along x-axis when the particle moves with a velocity $\vec{v}_2 = 2 \times 10^4 \frac{m}{s}$ along the x-axis, there is a force $\vec{F}_2 = 4 \times 10^{-5} N$ exerted on it along the y-axis. What is the magnitude and the direction of the magnetic field?

Sol. The vector expression for the velocities $\vec{v}_1 and\ \vec{v}_2$ as in the figure below



Example 4: A proton moves in the $+z$ direction after being accelerated from rest through a potential difference V. The proton then passes through a region with a uniform electric field E in the $+x$ direction and a uniform magnetic field B in the $+y$ direction, but the proton's trajectory is not affected. If the experiment were repeated using a potential difference of $2V$, in which direction the proton would be deflected?

H.W:

A positively charged particle with a velocity $\vec{v} = 3 \times 10^{6}\, \acute{\imath}\, m/s$ enters a velocity selector consists of electric and magnetic fields described by the expressions $\vec{E} = E(-\acute{k})$, with E=300 N/C and $\vec{B} = B\acute{\jmath}$. Determine the magnitude and the direction of B, which produces no deflection to the charged particle.