

## Chapter 36 & 37: Magnetism and Electromagnetic Induction

### What you will learn:

- You will relate magnetism to electric charge and electricity
- You will describe how electromagnetism is harnessed to produce mechanical work

### Why it's important:

- Using electromagnetism in electric motors, you can convert electrical energy to mechanical energy
- Every day, you apply mechanical energy produced from electrical energy

### State Standards Addressed

**Electric and Magnetic Phenomena:** *Electric and magnetic phenomena are related and have many practical applications. As a basis for understanding this concept:*

- *Students know* magnetic materials and electric currents (moving electric charges) are sources of magnetic fields and are subject to forces arising from the magnetic fields of other sources.
- *Students know* how to determine the direction of a magnetic field produced by a current flowing in a straight wire or in a coil.
- *Students know* changing magnetic fields produce electric fields, thereby inducing currents in nearby conductors.

### I. Historical Background

**A.** The term **magnetism** comes from region of Magnesia, a province in Greece, where certain stones (**lodestones**) had the unusual property of attracting pieces of iron

**B.** The **Chinese** were first to fashion magnets into **compasses** in the 12th century

**C.** **European** explorers brought back knowledge in 1500's

**D.** In 16th century, **William Gilbert** (Queen Elizabeth's physician) made **artificial magnets** by rubbing pieces of iron against lodestone and suggested that a compass always points north and south because the **Earth has magnetic properties**.

**E.** In 1750, **John Michell** in England found that magnetic poles obey the **inverse square law**, and his results were confirmed by **Charles Coulomb**.

**F.** Hans Christian **Oersted** discovered that an electric current affects a magnetic compass. He saw that **magnetism was**

related to electricity

G. Shortly thereafter, the French physicist Andre-Marie **Ampere** proposed that **electric currents** are the source of all **magnetic phenomena**.

## II. Magnetic Properties

### A. Magnetic Poles

1. A magnet is polarized (it has two ends)

a. **North-seeking pole**- points **northward**

b. **South-seeking pole**- points **southward**

c. **Poles are located at the end of the magnets**

2. **Like poles repel** and **unlike attract** (just like forces between electric charges)

### B. Magnetic Forces

1. Are similar to electric forces

a. **Can both attract and repel**

b. **Strength of magnetic interaction** depends on the **distance** between the two magnets

2. Whereas electric charges produce electric forces, regions called **magnetic poles** give rise to magnetic forces

### C. Permanent magnets

1. Caused by **motion of electrons** within the material (both **electron spin** and **revolution**)

a. Electrons spinning in **same** direction make up a **tiny magnet**.

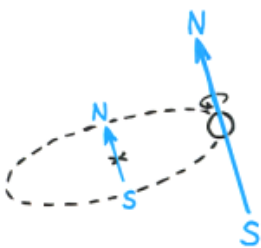
b. A pair of electrons **spinning in opposite directions** work against each other and **magnetic fields cancel**

2. In materials such as iron, each atom has four electrons whose **spin magnetism is uncanceled**.

a. Each iron atom is tiny magnet

b. The magnetic fields from groups of atoms can add together. These are called **domains** ( $10^{20}$  atoms)

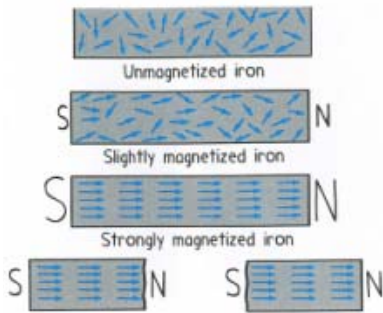
c. When piece of iron is not in a magnetic field, the domains do not all point in same direction



(magnetic fields cancel)

d. When iron placed in **magnetic field**, domains tend to **align** with the **external field** producing a **temporary magnet**. After removing from field domains return to random arrangement.

e. In **permanent magnets**, the iron has been **alloyed** with other substances (aluminum, cobalt, nickel) that keep domains aligned after external magnetic field is removed



## D. Magnetic Fields

1. **Magnetic forces** can be described by existence of **magnetic fields** around the magnets

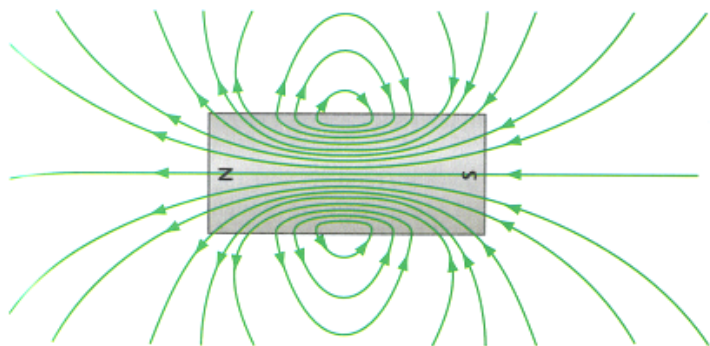
a. These lines are **imaginary**

b. Help **visualize** the field and provide **measure of strength**.

1). **magnetic flux**- *the number of field lines in any given region*

2). The **flux per unit area** is **proportional** to the **strength** of the **magnetic field**

2. Field lines **come out N-pole** of magnet and **enter magnet at its S-pole**.



3. Field lines **continue through** the **inside** of the magnet.

4. Field lines always form **closed loops**

5. **Magnetic fields exert forces on other magnets**

a. **N-pole of one magnet pushes N-pole of another magnet.**

b. **N-pole of one magnet attracts S-pole of another magnet.**

### III. Electromagnetism

A. In 1820, Hans Christian **Oersted** discovered that **electric currents produce magnetic fields**

#### B. Magnetic field near a current-carrying wire

1. **Force** is **perpendicular** to direction of current in wire

2. Magnetic field lines form **concentric circles** around the wire (closed loops)

a. **Strength** of magnetic field is **proportional** to the **current**

b. **Strength** of field varies **inversely** with the **distance** from the wire

3. **First right-hand rule-** *allows you to find the direction of the field around a wire*

a. **Thumb** points in **direction** of **conventional current (+ flow)**

b. **Fingers** of hand **circle** the wire and point in **direction of magnetic field**

#### C. Magnetic field near a coil

1. An electric current in a single circular loop of wire forms a magnetic field all around the loop

2. When wire looped several times to form a coil and current is allowed to flow- **field** around all the loops is always in **same direction**

a. **Solenoid**-*long coil of wire with many loops*

b. Field of each loop adds to fields of other loops

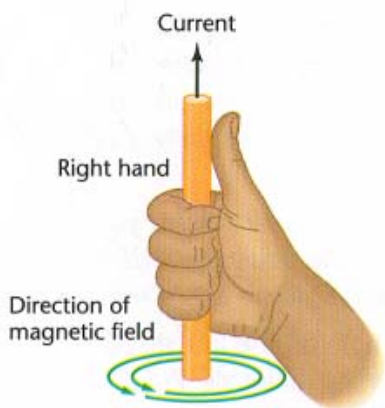
3. Electric current in a coil of wire has a **field** like that of a **permanent magnet** (has N and S poles)

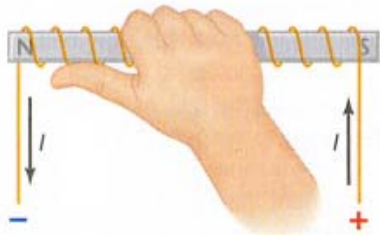
a. called an **electromagnet**

b. **Strength** of field is **proportional** to **current** in coil

c. Can increase strength by placing an iron rod inside the coil. The field inside the coil magnetizes the core. These add together

4. **Direction** of field produced by electromagnet can be found using the **second right-hand rule**





- a. Imagine holding insulated coil with you right hand
- b. **Curl fingers around loops** in the **direction** of the **conventional current** (+ flow)
- c. **Thumb points toward the N-pole** of the electromagnet

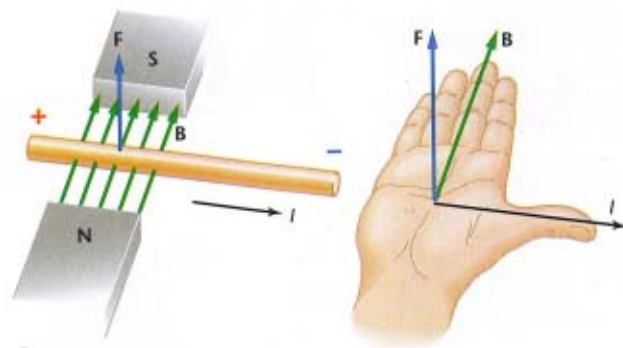
#### IV. Forces Caused by Magnetic Fields

##### A. Forces on currents in magnetic fields

1. Michael **Faraday** (mid 1800's) discovered that the **force** on a wire is at **right angles** to the **direction of the magnetic field**.
2. **Force** is also at **right angles** to the **direction** of the **current**

##### B. Use third right-hand rule to determine direction of force

1. Point **fingers** of right hand in **direction** of **magnetic field**.
2. Point **thumb** in **direction** of **conventional (+) current**
3. **Palm of hand** points in **direction** of **force** acting on the wire



##### C. Magnitude of force (F) on wire is proportional to 3 factors

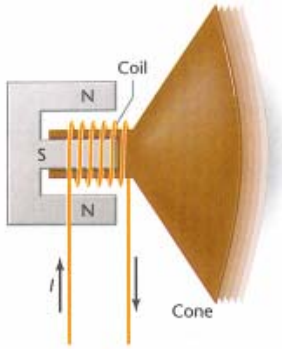
1. The **strength of field (B)**
2. The **current (I) in the wire**
3. The **length (L) of the wire** that lies in the magnetic field

Equation: 
$$F = BIL$$

Measured in **teslas (T)**      $1 T = 1 N/A \cdot m$

## V. Applications of Magnetic Force

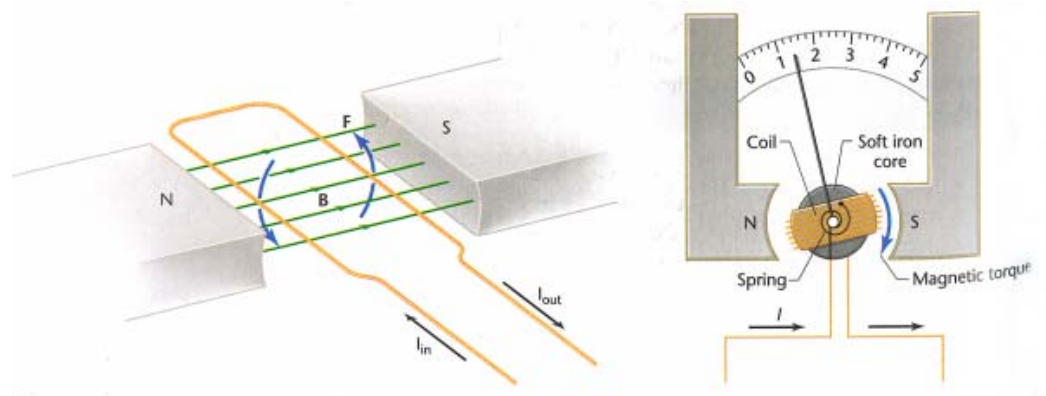
### A. Loudspeakers



1. Changes **electrical** energy into **sound** energy
2. Uses a coil of fine wire mounted on a paper cone and placed in a magnetic field
3. Amplifier driving loudspeaker sends **current** through the **coil**
4. The **current changes direction** between 20 and 20,000 times each second, depending on the pitch of the tone it represents.
5. A **force**, exerted on the coil because it is in a magnetic field, **pushes** the coil either **into or out of the field**, depending on the **direction of the current**
6. The **motion** of the **coil** causes the **cone to vibrate, creating sound waves in the air**

### B. Galvanometer

1. **Device** used to **measure very small currents**
2. Used in **voltmeters and ammeters.**
3. A small loop of current carrying wire is placed in a strong magnetic field
4. One side of loop forced down and the other side is forced up (third right-hand rule)
5. Magnitude of **torque** acting on the loop is proportional to the magnitude of the **current**
6. A small spring in the galvanometer exerts a torque that opposes the torque resulting from the current; thus, the **amount of rotation is proportional to the current**



## C. Electric Motor

1. **Apparatus** to convert **electrical** energy to **kinetic** energy

2. Must rotate **360°**, therefore the **current** must **reverse** direction just as the loop reaches its vertical position- allowing it to continue rotating.

a. To reverse direction, a **split-ring commutator** is used.

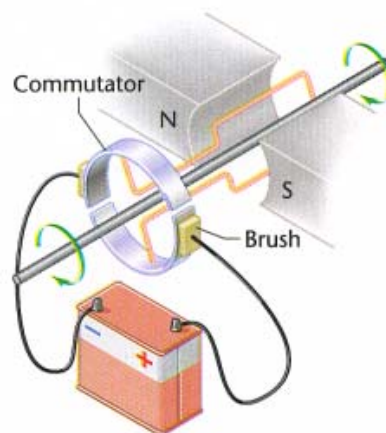
b. **Brushes** (pieces of graphite) make **contact** with the **commutator**, allowing current to flow into the loop

c. The split ring is arranged so that each half of the commutator changes brushes just as loop reaches vertical position.

d. Changing brushes **reverses** current in the loop- resulting in changing of forces acting on the loop- allowing loop to continue to rotate

e. **armature**- *many loops of wire mounted on a shaft in electric motor.* Total force proportional to  **$nBIL$**

( *$n$  = total turns on armature,  $B$  is strength of magnetic field,  $I$  is the current, and  $L$  is length of wire in each turn that moves through the magnetic field*)



## D. The Force on a Single Charged Particle

1. Charged particles do not have to be confined to a wire, but can move in any region as long as the air has been removed to prevent collisions with air molecules

2. The picture tube (or cathode ray tube) in a TV uses

electrons deflected by magnetic fields to form the pictures to be viewed.

**a.** In the tube, electrons are pulled off of atoms by electric fields at the negative electrode, or cathode.

**b.** Other electric fields gather, accelerate, and focus the electrons into a narrow beam.

**c.** Magnetic fields are used to deflect the beam back and forth and up and down across the screen of the tube.

**d.** The screen is coated with a phosphor and glows when struck by the electrons, producing the picture

