# University Of Technology- Iraq
# Department of Materials Engineering
# General Materials Branch-Fourth Class
# Smart Materials

## Lecture 5 :Introduction into Magnetoretictve Materials

Class Code on Google Classroom :2shhens

# Magnetostrictive Materials

- Noncontact sensors and actuators have a very demand in the advanced materials market. Use of magnetostrictive materials in advanced applications has been discussed
- Magnetostrictive sensors construction and working along with the electromagnetic properties and various associated magnetostrictive effects has been discussed here.

# Magnetostrictive Materials

- Specific categories of materials such as

1. iron-based alloys
2. Ni-based alloys
3. Terfenol-D
4. Metglas
5. Ferromagnetic shape memory alloys

# Magnetostrictive Materials

- All the potential applications in

1. Mechanical industries
2. Aero-industries
3. Automotive industries,
4. Biomedical industries
5. Construction industries
6. Energy-harvesting industries

# Magnetostrictive materials

- Magnetostrictive materials are smart materials that are an essential part of applications going from dynamic vibration control, control surface deployment, and energy harvesting to stress and torque detecting
- Magnetostrictive material converts the magnetic energy  to mechanical energy and vice versa as given in Fig. Below. In another it can explain, the magnetostrictive materials can convert magnetic energy into kinetic energy, or the reverse

# Mechanism of Magnetostrictive Effect

- Internally, ferromagnetic materials have structures that are divided into domains, each of which is a region of uniform magnetic polarization. When a magnetic field is applied, the boundaries between the domains shift and the domains rotate.
- The change in the magnetic domains of material results in a change in materials dimensions.
- This phenomenon is a consequence of magneto-crystalline anisotropy, which indicates it consume more energy to magnetize a crystalline

# Mechanism of Magnetostrictive Effect

- Since different crystal directions are associated with different lengths, this effect induces a strain in the material. The change in magnetic field gives the change in strain is known as ***Joule's effect***.
- Most magnetic materials exhibit Joule magnetostrictions, only a small number of compounds containing rare earth elements provide strains in excess of $1000*10^{-6}$
- These large strains are a direct consequence of a strong magnetoelastic coupling arising from the dependency of magnetic moment orientation with interatomic spacing. Whereas, the reciprocal effect, that is, by application of stress (mechanical energy) produces magnetization of the material is known as the ***Villari effect***

# Curie Temperature

- The Curie temperature is the temperature where the stable magnetic properties of the material change due to the extra energy provided by heat.
- Ferromagnetic materials become paramagnetic when the temperature is above the Curie temperature.
- When the magnetic properties of the material change, this also changes the permeability of the material.

# Magnetic materials type and their properties

A description of various types of magnetic materials with their inherent properties has been provided in The Table below with examples of materials.

| Magnetic material | Susceptibility to induced magnetic field | Permeability | Examples |
|---|---|---|---|
| Diamagnetic | Negative and small | $< -1$ | Cu, Ag, Au |
| Paramagnetic | Positive and small | $>1$ | Mg, Li |
| Ferromagnetic | Positive and very large | $>>1$ | Fe, Ni |
| Anti-ferromagnetic | Positive and small | $<1$ | NiO |
| Ferromagnetic | Positive and large | $>>1$ | $Fe_2O_3$ |

# Magnetic Materials

- This material has ability to attract or resist an induced magnetic field is the primary method that classifies the magnetic properties of the material.
- This is referred to as the permeability ratio of the material.
- The permeability ratio of the material is attributed to the spin and orbital spin of electrons around the nucleus of the atom and incomplete inner electron shells.

# Diamagnetic Material

- *A diamagnetic material exhibits negative magnetism.*
- A diamagnetic material repels an external magnetic field by producing a smaller internal magnetic field in opposite polarity.
- The external magnetic field will conduct around the diamagnetic material, rather than through the diamagnetic material.
- The permeability of diamagnetic material is less than one and negative.

# Paramagnetic Material

- A paramagnetic material has a permeability of less than 1.
- That is the magnetic field can conduct through the paramagnetic material although the magnetic field will experience less resistance by conducting around the paramagnetic material.
- An external magnetic field may tend to polarize the random moments by creating thermal agitations causing only a very small (partial) magnetism

# Ferromagnetic Material

- Ferromagnetic materials are a refined material that has the ability to conduct higher magnetic flux compared to free space.
- Ferromagnetic materials have a permeability greater than one and therefore attract magnetic flux compared to free space.
- The three ferromagnetic elements are iron, cobalt, and nickel.

# Ferromagnetic Material

- Soft ferromagnetic material has high permeability and will return to its natural state when the induced magnetic field is removed.
- Soft ferromagnetic materials are used in transformers where the magnetic flux changes direction every cycle. Nickel is classed as soft ferromagnetic material.
- Hard ferromagnetic materials have high permeability and will attempt to retain its induced magnetized state.
- Hard ferromagnetic materials are ideal permanent magnets.

# Antiferromagnetic Material and Ferrimagnetic Material

- Antiferromagnetic material relies on temperature to become permeable. The temperature that allows maximum permeability is known as the Neel Temperature.

- The permeability of antiferromagnetic material is usually less than 1. Naturally found materials, such as iron ore and nickel ore, that have an overall magnetic flux are known as ferrimagnetic.

# Permittivity

$$\varepsilon = \varepsilon_0 \varepsilon_r$$

- where $\varepsilon_0$ is the permittivity of free space $(1/(36\pi) * 10^{-9})$ F. $m^{-1}$ and $\varepsilon_r$ is the permittivity ratio of the material. Nickel is a solid conductive metal having a permittivity value of infinite.
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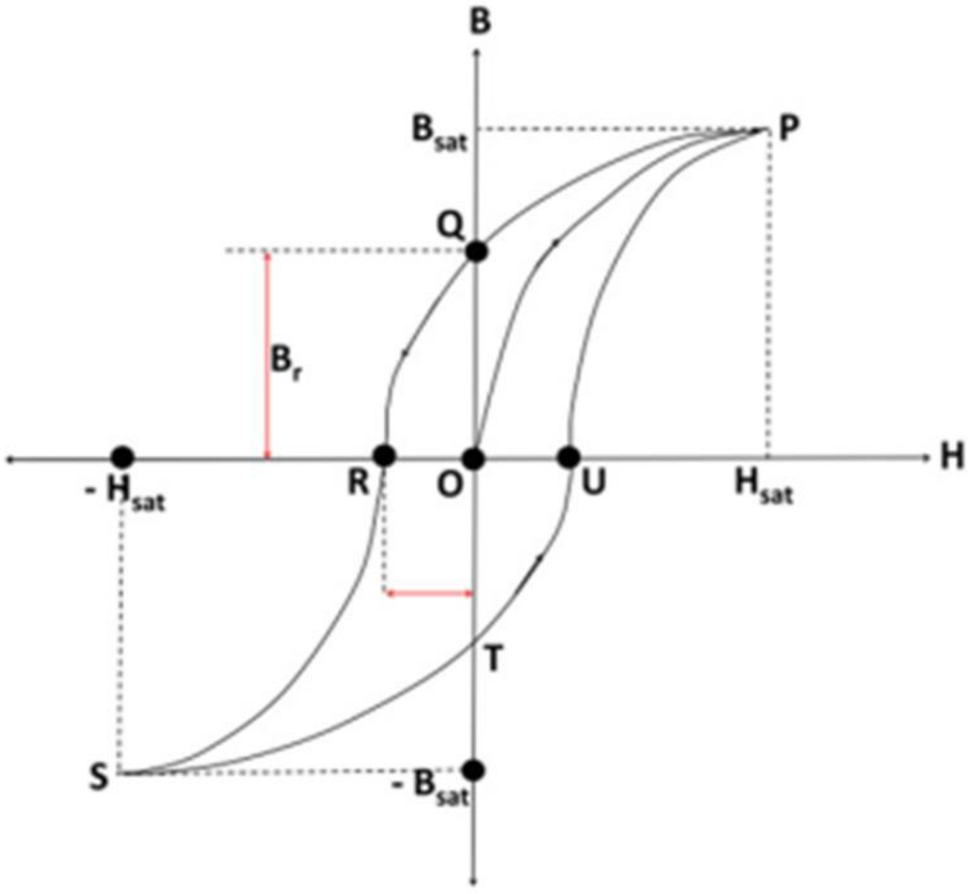
# Permeability

- Permeability is the property of the material to attract or repel magnetic fields. An example of a permeable material can be found in the core of an electrical transformer.
- A magnetic field is produced by the primary winding and is conducted through the core to the secondary windings.
- The core material can attract or repel the magnetic field. In the case of an electrical transformer, it is desired to attract the magnetic field

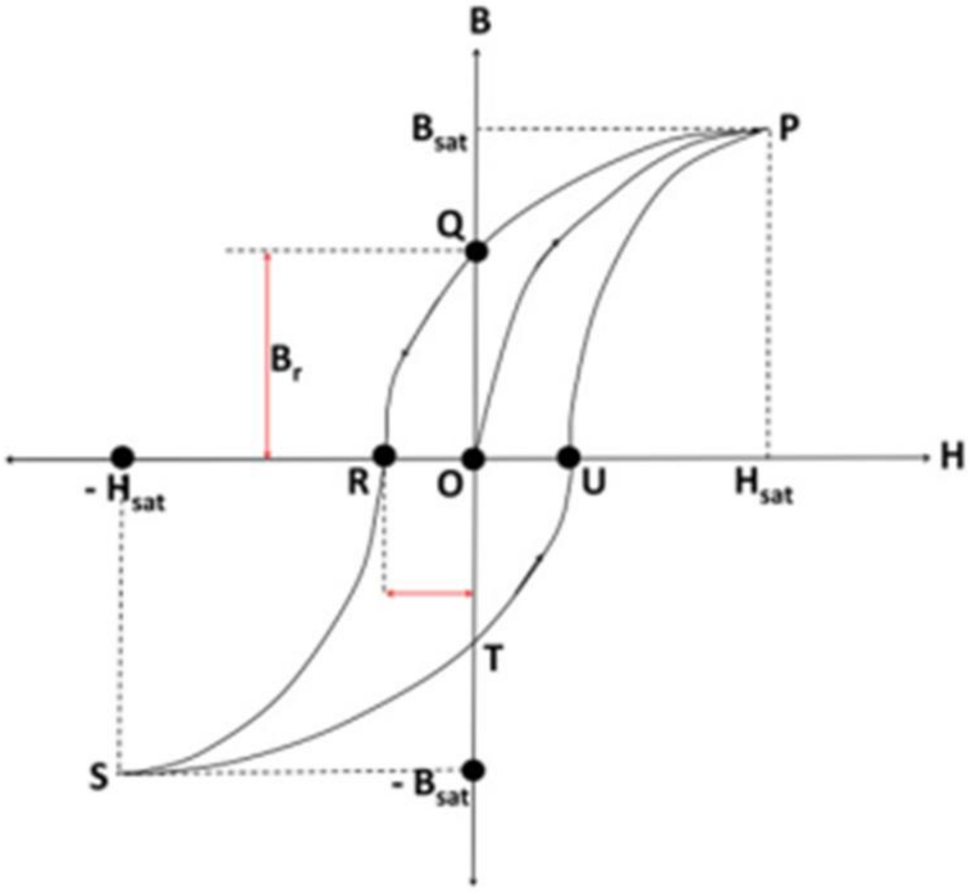
# Hysteresis

- There are limits to the amount of magnetic flux density (B) that the material can withstand.
- If the magnetic field intensity (H) is increased beyond the saturation level (Hsat) the magnetic flux density will not increase beyond the saturation level for magnetic flux density.



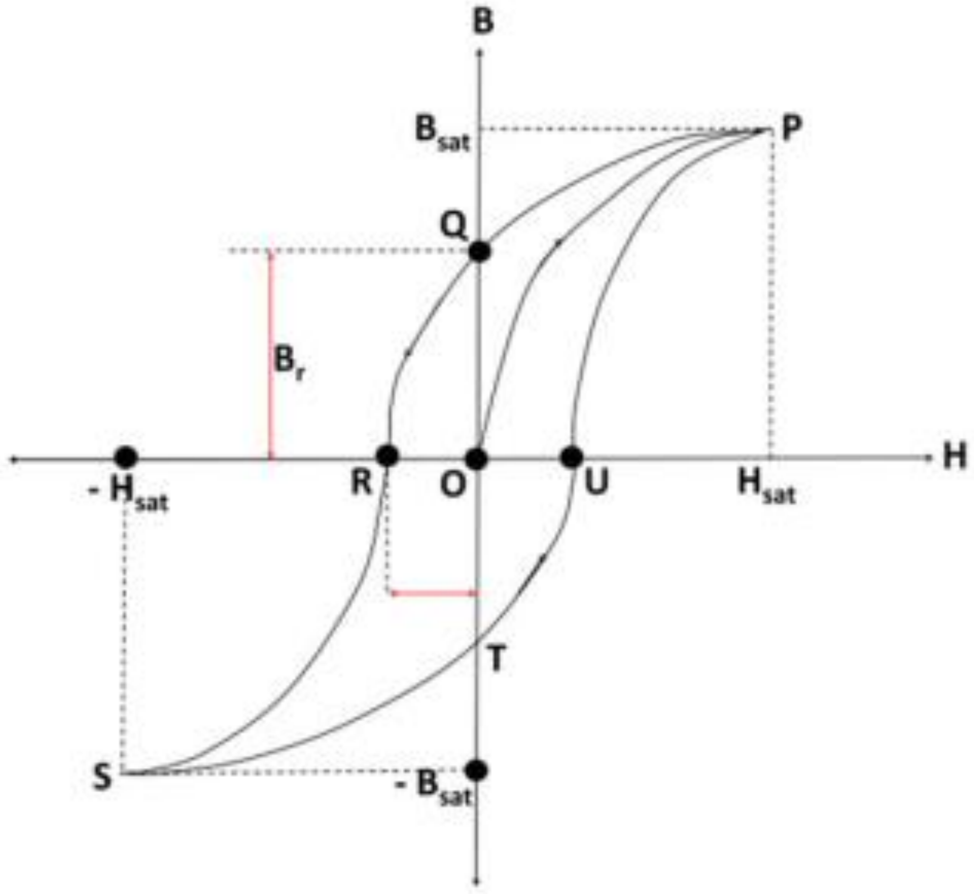
# Hysteresis

- As the magnetic field intensity is determined by the current and the number of turns, there is a maximum current and a maximum number of turns in achieving the saturation level of magnetic flux density



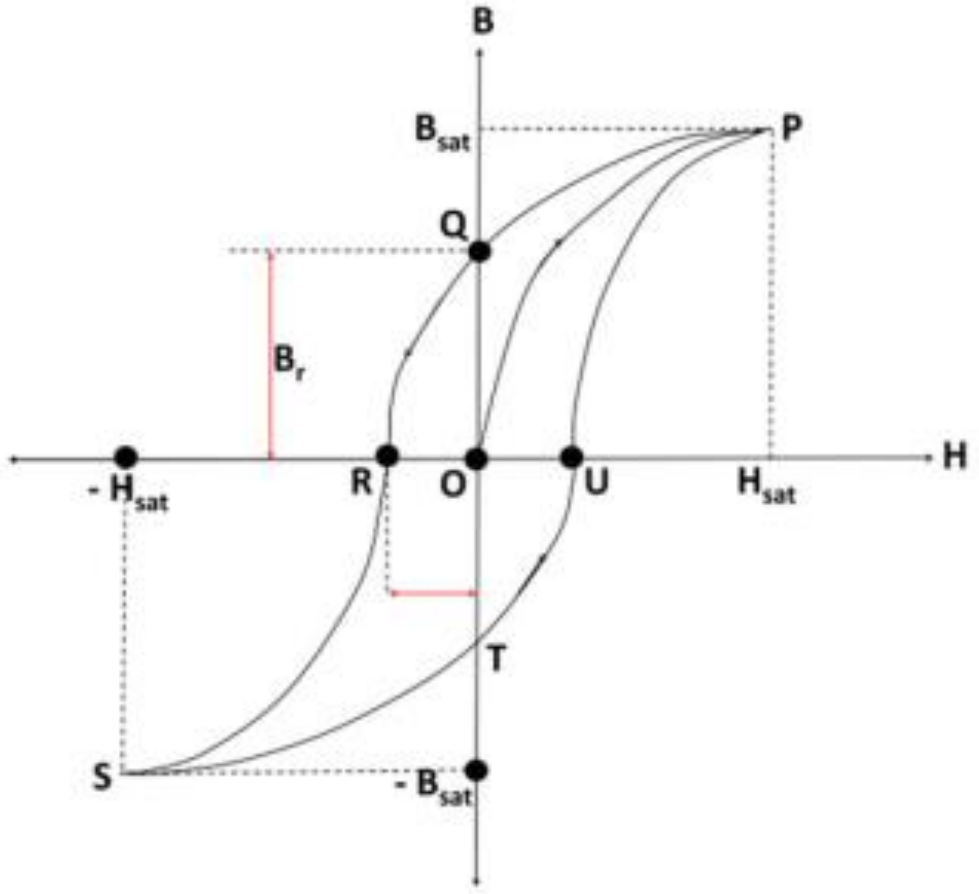
# Hysteresis

- Hysteresis also shows the different generation and degeneration of the magnetic flux as experienced in an alternating current source.
- Nickel has a saturation magnetic flux density (Bsat) of 0.617 T and a permeability of 7.547.54 $*10^{-7}$H. $M^{-1}$ leading to a saturation magnetic field intensity (Hsat) of 818.3 A. $M^{-1}$



# Hysteresis

- The magnetostrictive phenomenon has great technical importance. It can be used in the development of specialized position and level sensors, MEMS sensors, as well as ultrasonic transducers, and high accuracy actuators .
- When a magnetic material is placed in an external magnetic field, its grains get oriented in the direction of the magnetic field. Now, even after the removal of an external magnetic field, some magnetization exists, which is called residual magnetism.



# Hysteresis

- This property of the material is called magnetic retentively of material. A hysteresis loop or B-H curve of a typical magnetic material is shown in The Figure.
- Magnetization Br in the below hysteresis loop represents the residual magnetism of material