Classification of magnetic materials :

In general the magnetic susceptibility ψm or the relative permeability μ_r is used to classify materials in terms of their magnetic property. A material is said to be *nonmagnetic* if $\psi m = 0$ (or $\mu_r = 1$); it is magnetic otherwise^,Free space, air, and materials with $\psi m = 0$ (or $\mu_r = 1$) are regarded as non imagnetic. Magnetic materials may be grouped into three major classes: diamagnetic, paramagnetic, and ferromagnetic.

A material is said to be *diamagnetic* if it has $\mu_r \leq 1$ (i.e., very small negative ψm)- It is *paramagnetic* if $\mu_r \geq 1$ (i.e., very small positive ψm)- If $\mu_r \gg 1$ (i-e->very large positive ψm) the material is *ferromagnetic.*

assume that $\mu_r \approx 1$for diamagnetic and paramagnetic materials. Thus, we may regard diamagnetic and paramagnetic materials as linear and nonmagnetic. Ferromagnetic materials are always nonlinear and magnetic except when their temperatures are above curie temperature.

Diamagnetism occurs in materials where the magnetic fields due to electronic motions of orbiting and spinning completely cancel each other. Thus, the permanent (or intrinsic) magnetic moment of each atom is zero and the materials are weakly affected by a magnetic field. For most diamagnetic materials (e.g., bismuth, lead, copper, silicon, diamond, sodium chloride), ψm is of the order of -10^{-5}. In certain types of materials called *superconductors* at temperatures near absolute zero, "perfect diamagnetism" occurs: $\psi m = -1$ or $\mu_r = 0$ and $B = 0$. Thus superconductors cannot contain magnetic fields. Except for superconductors, diamagnetic materials are seldom used in practice. Although the diamagnetic effect is overshadowed by other stronger effects in some materials, all materials exhibit diamagnetism.

Materials whose atoms have nonzero permanent magnetic moment may be paramagnetic or ferromagnetic. *Paramagnetism* occurs in materials where the magnetic fields pro-duced by orbital and spinning electrons do not cancel completely. Unlike diamagnetism, paramagnetism is temperature dependent. For most paramagnetic materials (e.g., air, platinum, tungsten, potassium), ᴪm is of the order $+10^{-5}$ to $+10^{-3}$ and is temperature dependent. Such materials find application in masers. *Ferromagnetism* occurs in materials whose atoms have relatively large permanent magnetic moment. They are called ferromagnetic materials because the best known member is iron. Other members are cobalt, nickel, and their alloys. Ferromagnetic materials are very useful in practice. As distinct from diamagnetic and paramagnetic materials,

ferromagnetic materials have the following properties:

1.They are capable of being magnetized very strongly by a magnetic field.

2. They retain a considerable amount of their magnetization when removed from the field.

3. They lose their ferromagnetic properties and become linear paramagnetic materials when the temperature is raised above a certain temperature known as the *curie temperature.* Thus if a permanent magnet is heated above its curie temperature (770°C for iron), it loses its magnetization completely.

4. They are nonlinear; that is, the constitutive relation $B = \mu_0\mu_r H$ does not hold for ferromagnetic materials because μ_r depends on B and cannot be represented by a single value.

Even though $B = \mu_0 (H + M)$ holds for all materials including ferromagnetics, the relationship between B and H depends on previous magnetization of a ferromagnetic material.

linear relationship between B and H (i.e., B = *fiH),* it is only possible to represent the relationship by a *magnetization curve* or *B-H* curve.

A typical *B-H* curve is shown in Figure, First of all, note the nonlinear relationship between *B* and *H.* Second, at any point on the curve, μ is given by the ratio *B/H* and not by *dB/dH,* the slope of the curve.

If we assume that the ferromagnetic material whose *B-H* curve.in Figure is initially unmagnetized, as *H* increases (due to increase in current) from *O* to maximum applied field intensity H_{max}, curve *OP* is produced. This curve is referred to as the *virgin* or *initial magnetization curve.* After reaching saturation at *P,* if *H* is decreased, *B* does not follow the initial curve but lags behind *H.* This phenomenon of *B* lagging behind *H* is called *hysteresis* (which means "to lag" in Greek).

If *H* is reduced to zero, *B* is not reduced to zero but to $B_r$which is referred to as the *permanent flux density.* The value of B_r depends on H_{max}, the maximum applied field intensity. The existence of B_r is the cause of having permanent magnets. If *H* increases negatively (by reversing the direction of current), *B* becomes zero when *H* becomes H_c, which is known as the *coercive field intensity.* Materials for which H_c is small are said to be magnetically hard. The value of H_c also depends on H_{max}.
Further increase in *H* in the negative direction to reach *Q* and a reverse in its direction to reach *P* gives a closed curve called a *hysteresis loop.* The shape of hysteresis loops varies from one material to another. Some ferrites, for example, have an almost rectangular hysteresis loop and are used in digital computers as magnetic information storage devices. The area of a hysteresis loop gives the energy loss (hysteresis loss) per unit volume during one cycle of the periodic magnetization of the ferromagnetic material. This energy loss is in the form of heat. It is therefore desirable that materials used in electric generators, motors, and transformers should have tall but narrow hysteresis loops so that hysteresis losses are minimal.

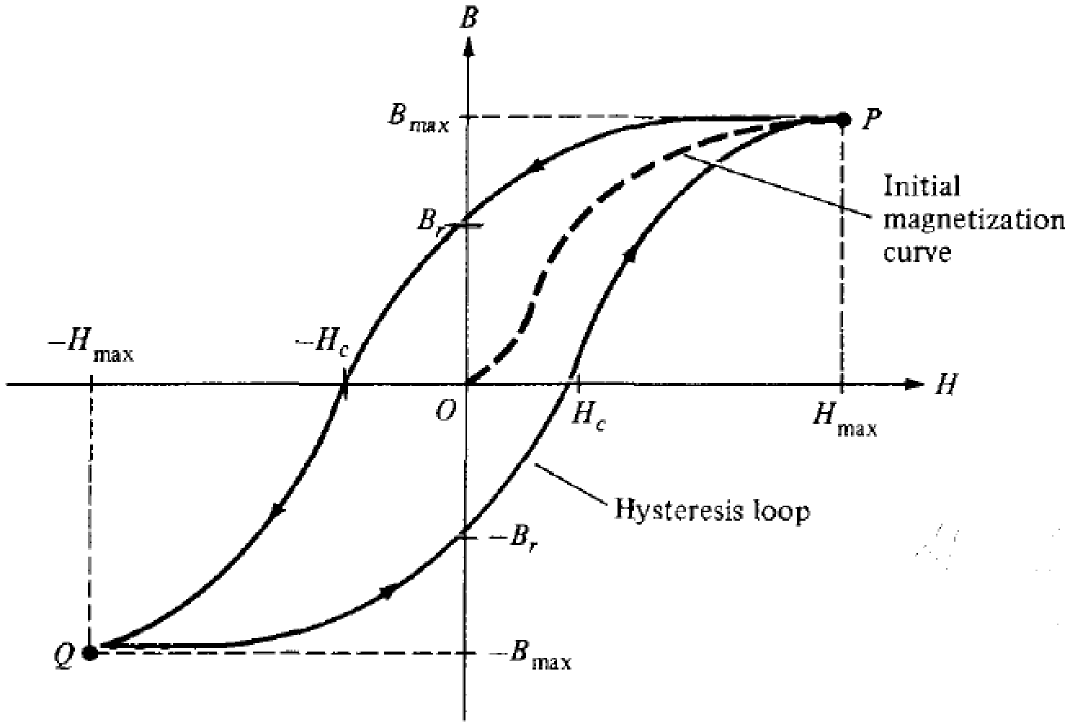

Fig: Typical magnetization B-H curve.