PYL102 Course
Lecture-14 on 08-09-2021

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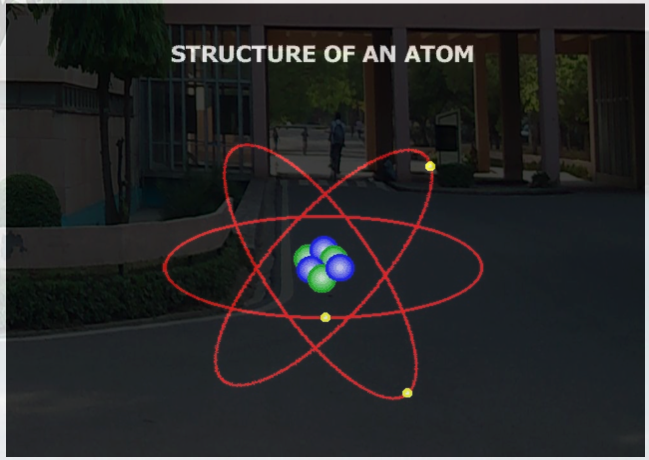
PYL102:
Principles of Electronic Materials

- Magnetism in materials:
- Types of interactions.......
- Magnetic susceptibility.......
- Curie and Neel temperatures....

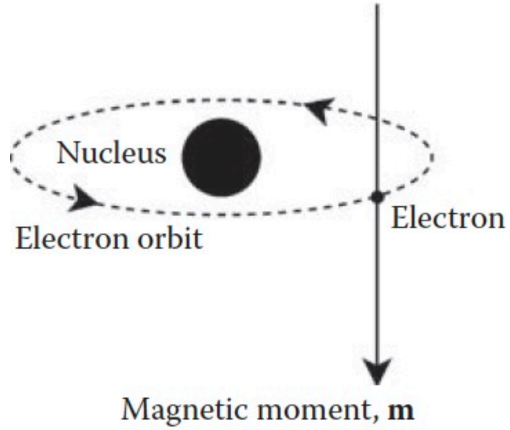


Magnetism in Materials:

All magnetic moments are produced by the angular momentum of electrons in the atoms of solids, and there are two types of angular momentum for electrons in atoms:

orbital and spin.

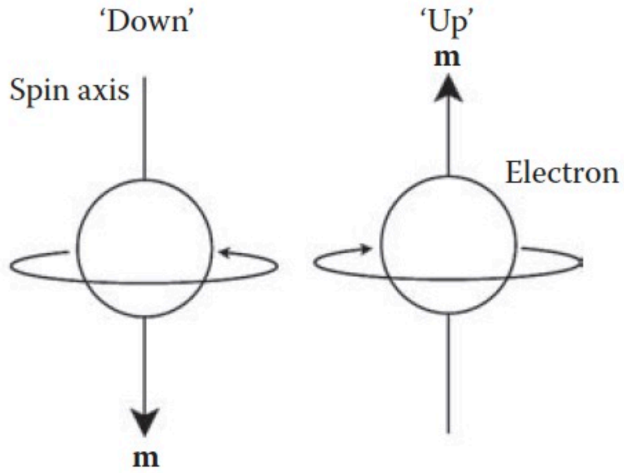
Electrons revolving around nucleus and electrons spinning about their own axis can be considered as tiny current loops.



For macroscopic purposes, these current loops are so small that we generally consider them as magnetic dipoles.

In general, these magnet dipoles cancel each other due to random orientations of the atoms.

when a magnetic field is applied, a net alignment of these magnetic dipoles occurs, and the medium becomes magnetically polarized, or magnetized

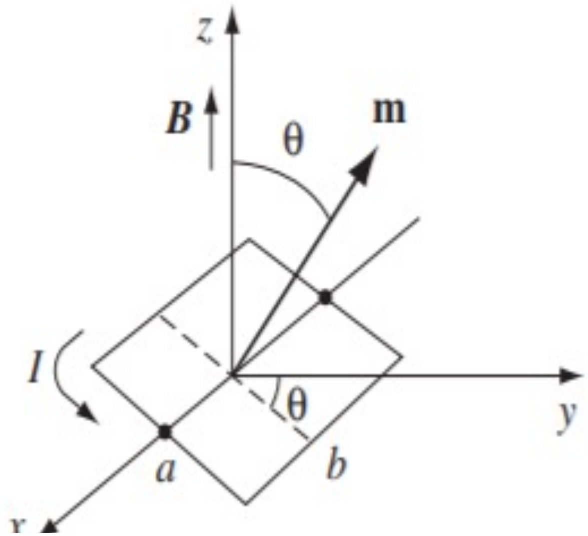


Unlike electric polarization, which is almost always in the same direction as E, some materials acquire a magnetization parallel to B (paramagnets) and some opposite to B (diamagnets)

A few substances retain their magnetization even after the external field has been removed→ Ferromagnets → The magnetization is not determined by the present field but by the whole magnetic "history" of the object.

Torques and forces on magnetic dipoles:

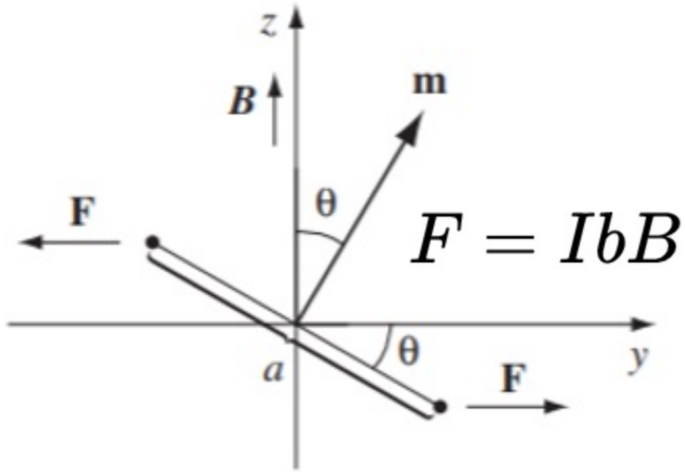
A magnetic dipole experiences a torque in a magnetic field, just as an electric dipole does in an electric field.



Let us consider the rectangular current loops in uniform magnetic field B which is directed in Z axis.

Center the loop at the origin, and tilt it an angle θ from the z axis towards the y axis

The forces on the two sloping sides cancel (they tend to stretch the loop, but they don't rotate it).



The forces on the "horizontal" sides are likewise equal and opposite (so the net force on the loop is zero), but they do generate a torque

$$\mathbf{N} = aF\sin\theta$$

Let's use the magnitude of the force on each of these segments and rewrite the above equation..

$$\mathbf{N} = IabB\sin\theta\hat{\mathbf{x}} = mB\sin\theta\hat{\mathbf{x}} = \mathbf{m}\times\mathbf{B}$$

The torque is again in such a direction as to line the dipole up parallel to the field. This is a universal phenomena since every electron constitute a magnetic dipole.

Effect of magnetic field on atomic orbits:

For simplicity, let's assume that the electrons orbit in a circle of radius R around the nucleus.

We consider the consequent current to be a steady current as the period of motion is too small, so the steady current:

$$I = \frac{-e}{T} = -\frac{ev}{2\pi R} \quad \text{------(1)} \qquad \text{where,} \quad T = 2\pi R/v$$

Accordingly, the orbital dipole moment $(I\pi R^2)$ is

$$\mathbf{m} = -\frac{1}{2} evR\hat{\mathbf{z}} \quad \text{------(2)}$$

Normally, it's a lot harder to tilt the entire orbit than it is the spin, so the orbital contribution to paramagnetism is small

There is, however, a more significant effect on the orbital motion:

The electron speeds up or slows down, depending on the orientation of B…

The centripetal acceleration is ordinarily sustained by electrical forces alone,

$$\frac{1}{4\pi\varepsilon_0}\frac{e^2}{R^2} = me\,\frac{{v_0}^2}{R} \quad \text{-----(3)}$$

Effect of magnetic field on atomic orbits:

For B perpendicular to the plane of the orbit, we can write..

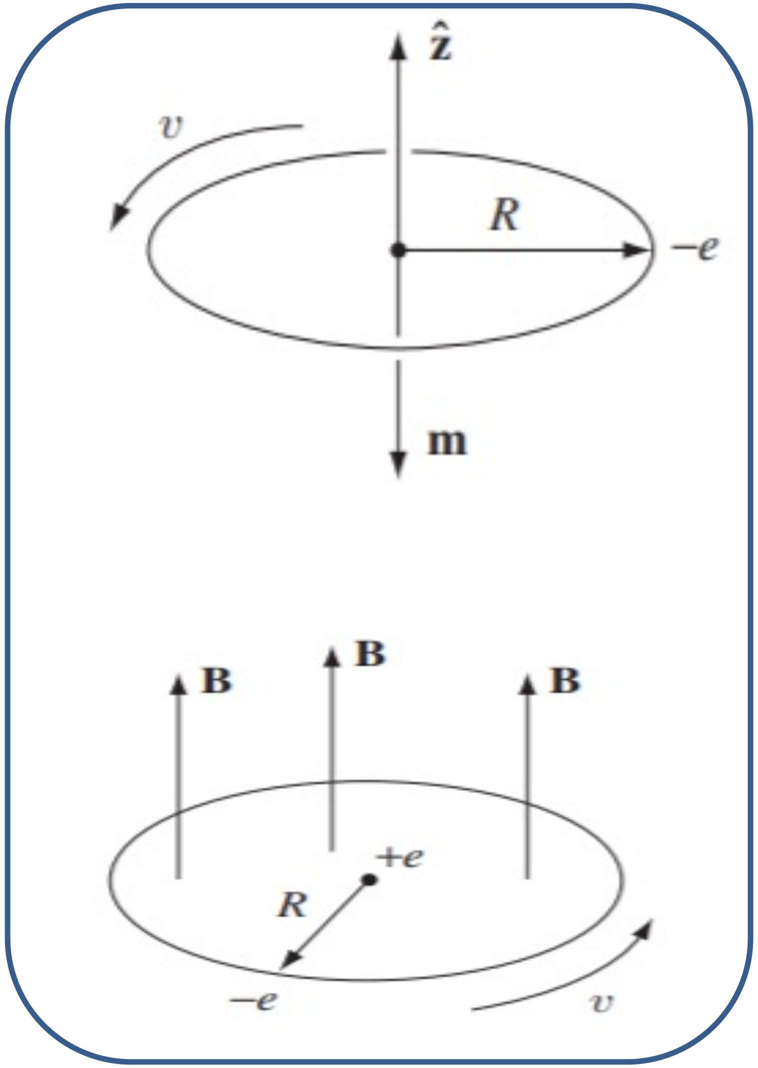
$$\frac{1}{4\pi\varepsilon_0}\frac{e^2}{R'^2} + evB = me\frac{v^2}{R'}$$

-----(4)

Special case, $\Delta R = 0,$ under this condition, the new speed v is greater than v_0: so, from eqs. (3) and (4)…

$$evB = \frac{m_e}{R}(v^2 - {v_0}^2) = \frac{m_e}{R}(v + v_0)(v - v_0)$$

----(5)



Assuming the change in velocity is small,

$$\Delta v = \frac{eRB}{2me}$$

-----(6)

When B is turned on, then, the electron speeds up

A change in orbital speed means a change in the dipole moment

$$\Delta\mathbf{m} = -\frac{1}{2}e(\Delta v)R\hat{\mathbf{z}} = -\frac{e^2R^2}{4m_e}\mathbf{B}$$

---(7)

The change in m is opposite to the direction of B…

Effect of magnetic field on atomic orbits:

Ordinarily, the electron orbits are randomly oriented, and the orbital dipole moments cancel out. But in the presence of a magnetic field, each atom picks up a little "extra" dipole moment, and these increments are all antiparallel to the field.

This is the mechanism responsible for diamagnetism..

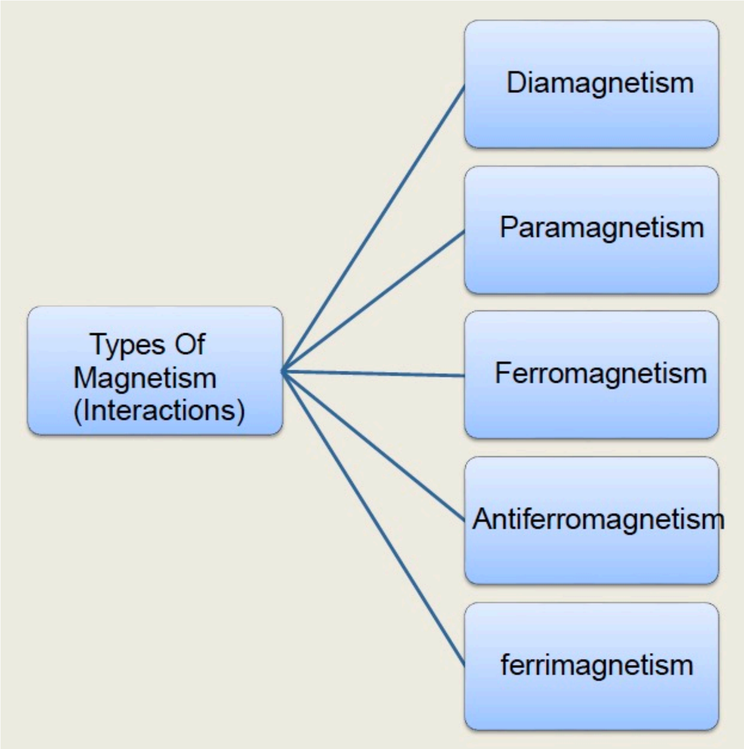
With the application of a magnetic field, magnetic moments in a material tend to align and thus increase the magnitude of the field strength.

Depending on the existence and alignment of magnetic moments with or without application of magnetic field, broadly speaking, five types of magnetism can be defined.

Being a moving charge, electrons produce a small magnetic field having a magnetic moment along the axis of rotation.

The spin of electrons also produces a magnetic moment along the spin axis.

Magnetism in a material arises due to alignment of magnetic moments.



PYL102 Course
Lecture-15 on 09-09-2021

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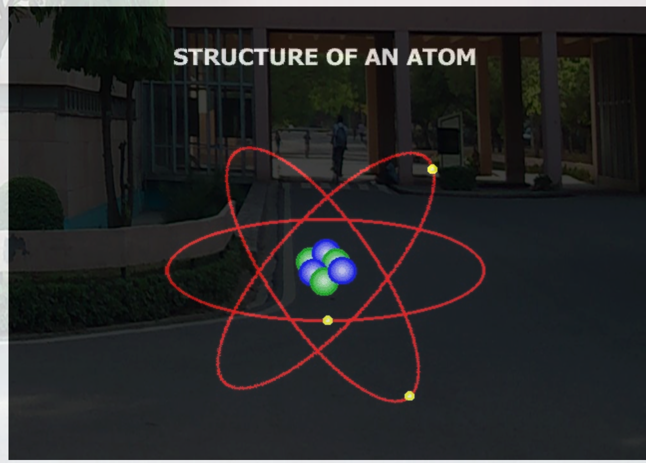
PYL102:
Principles of Electronic Materials

- Types of magnetic interactions…
- Magnetic susceptibility….
- Dia/para-magnetism….
- Curie and Neel temperatures….



Materials in magnetic field:

When a material is placed in an external magnetic field H, The magnetic flux density inside the material (B) is given by

$$B = \mu_0(H + M)$$

where: μ_0 is vacuum permeability and

M is the magnetization and is given by

$$M=\chi H \quad \text{or} \quad \chi=M/H$$

where χ is susceptibility and can be expressed interns of volume, atomic or molar susceptibility.

Therefore, we can write

$$B = \mu_0(H + M)= \mu_0(1+ \chi)H$$

……..based on the susceptibility, we classify the materials into different category…..

The magnetic flux density B seen within the magnet is the result of the driving force of the externally applied magnetic force H and that resulting from the internal magnetization M….

Materials in magnetic field:

- The magnetic properties of a material are characterized not only by the magnitude and sign of M but also the way in which M varies with H……..
- The ratio of these two quantities is called the susceptibility:

$$\chi_v = \frac{M}{H} \quad \frac{\text{emu}}{\text{Oe} \cdot \text{cm}^3}$$

$\chi_m = \chi_v/\rho =$ mass susceptibility (emu/Oe g), where $\rho =$ density,

$\chi_A = \chi_v A =$ atomic susceptibility (emu/Oe g atom), where $A =$ atomic weight,

$\chi_M = \chi_v M' =$ molar susceptibility (emu/Oe mol), where $M' =$ molecular weight.

diamagnetism and paramagnetism…..usually referred to as non-magnetic,

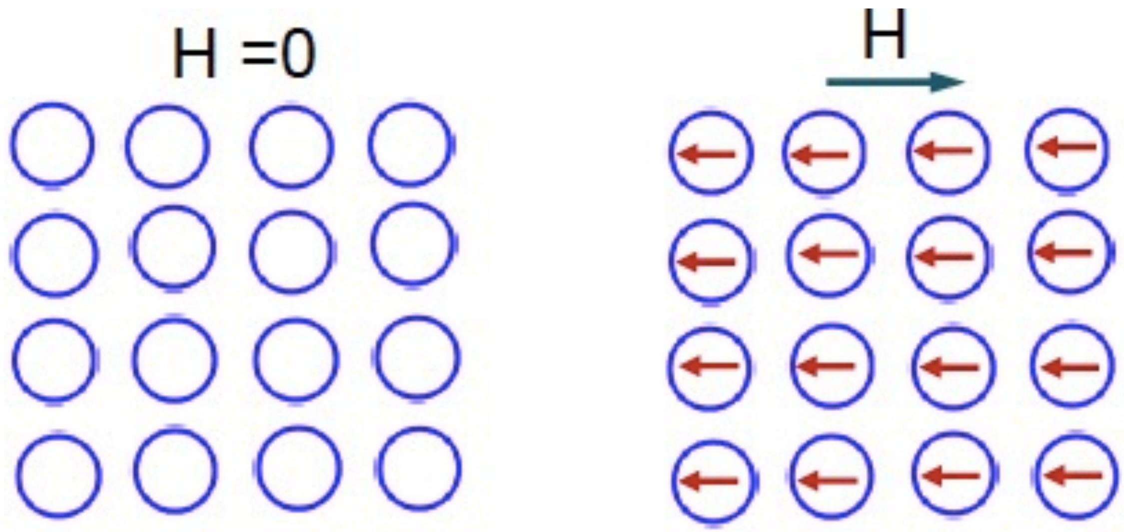
Whereas those which are referred to as magnetic are actually ferromagnetic

Anti-ferromagnetism, observed in pure elements at RT

Finally, ferri-magnetic, not observed in pure element, but can only be found in compounds, such as the mixed oxides, known as ferrites….

Classification: diamagnetism...

Diamagnetic effect is weaker compared to other phenomena. In a diamagnetic material the atoms have no net magnetic moment when there is no applied field.



Diamagnetism is a weak form of magnetism which arises only when an external field is applied.

It arises due to change in the orbital motion of electrons on application of a magnetic field.

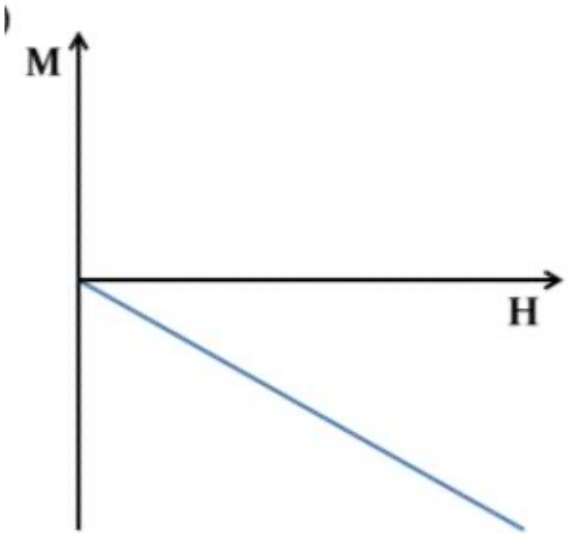
There are no magnetic dipoles in the absence of a magnetic field and when a magnetic field is applied the dipole moments are aligned opposite to the field direction.

Classification: diamagnetism…

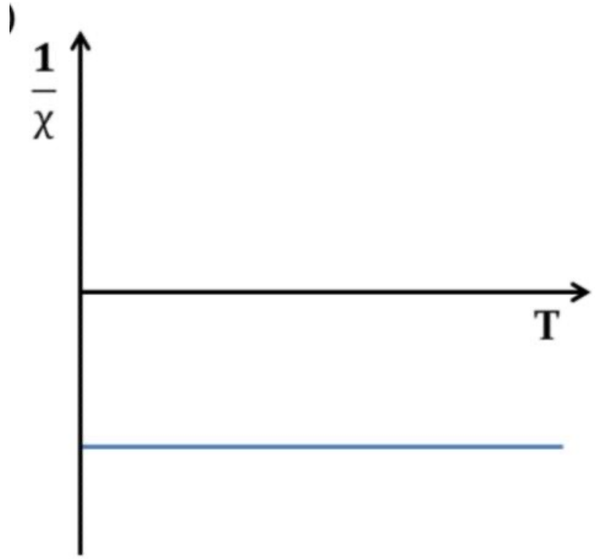
The susceptibility is negative and is independent of temperature

When an atom is placed in a magnetic field, due to the presence of Lorentz force, the speed of the electron changes. This change in orbital speed of the electrons, leads to change in the magnetic moment.

Lenz's law tells us that the currents are induced in the direction which opposes the applied field, so the induced magnetic moments are directed opposite to the applied field



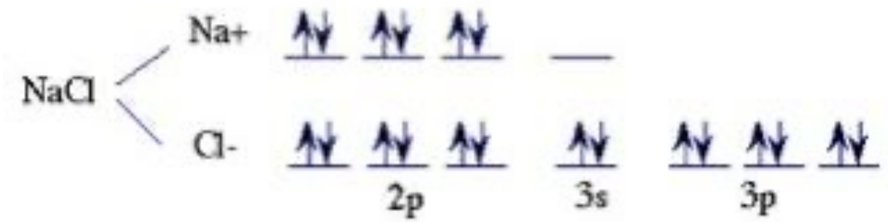
The magnetic susceptibility, χ_m (=μ_r – 1) is negative i.e., B in a diamagnetic material is less than that of vacuum….



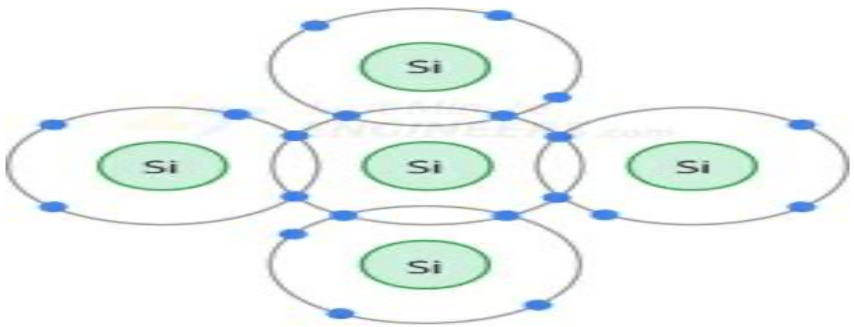
Diamagnetic substances:

Examples: metals Au, Cu, Hg; non-metallic elements B, Si, P, S; many ions Na+, Cl- & their salts; diatomic molecules H2, N2; H2O; most organic compounds….

Monoatomic rare gases He, Ne, etc., which have closed-shell electronic structures and gases such as H_2, N_2, etc., as the molecule formation usually leads to filled electron shells and no net magnetic moment per molecule, same argument explains the diamagnetism of ionic solids like NaCl, and covalent elements like C (diamond), Si, and Ge...



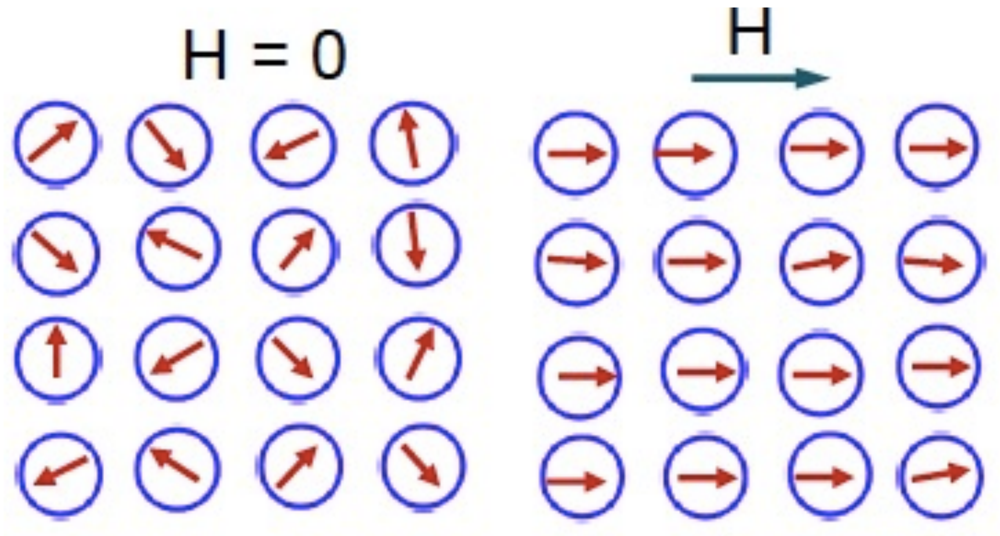
Ions like Na^+ and Cl^- have closed shells and are both diamagnetic, as it leads to closed shells



Element like Si have Covalent bonding by the sharing of electrons, also leads to closed shells hence are diamagnetic.

Not all gases are diamagnetic, nor are all ionic or covalent solids.

Paramagnetism:



In a paramagnetic material the cancellation of magnetic moments between electron pairs is incomplete and hence magnetic moments exist without any external magnetic field.

❖ However, the magnetic moments are randomly aligned and hence no net magnetization without any external field.

❖ When a magnetic field is applied all the dipole moments are aligned in the direction of the field.

Al, Cr, Mo, Ti, Zr

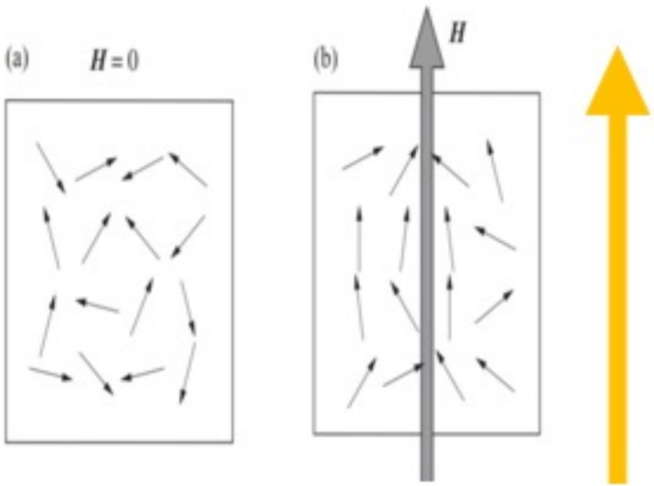
❖ Paramagnetism is a magnetic property present in materials with a non-zero magnetic moment, due to unpaired electrons.

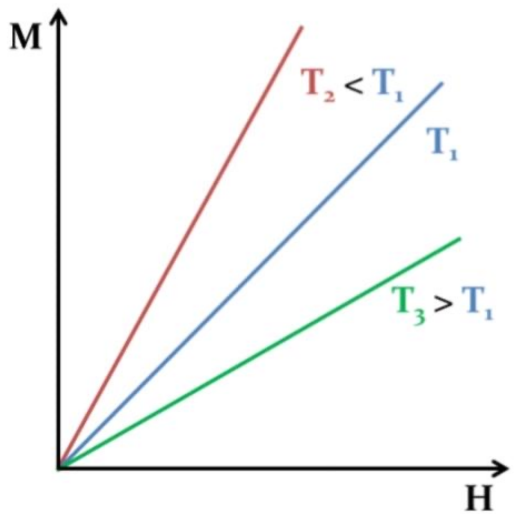
Paramagnetism:

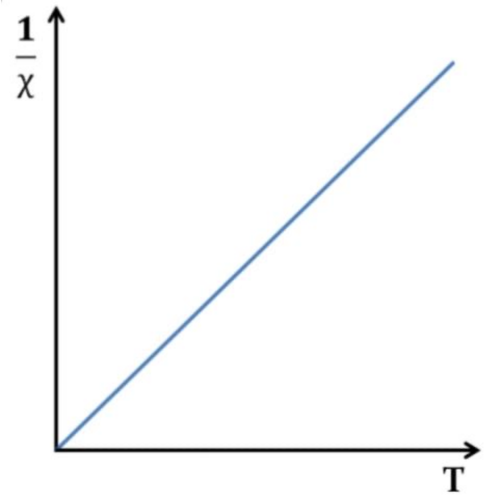
Only extremely weak interactions exist between neighboring atoms in paramagnetic materials, and they assumed to act independently of one another.

Net zero magnetization of the material in absence of external field due to random orientation of magnetic moments.

The magnetic susceptibility is small but positive, i.e., B in a paramagnetic material is slightly greater than that of vacuum.







Ex: metals Al; diatomic gases, O_2, NO; ions of transition metals and rare earth metals, and their salts; rare earth oxides.