ENGINEERING PHYSICS

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Classification of magnetic materials

Class #48

- *Diamagnetic materials*
- *Paramagnetic materials*
- *Ferromagnetic materials*

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Classification of magnetic materials

➢ ***Suggested Reading***

1. *Quantum Physics of Atoms Nuclei and Molecules, Robert Eisberg, Robert Resnick, Wiley, 2nd edition, Ch 14, 2006.*

2. *The Science and Engineering of Materials by Donald R. Askeland, Pradeep P. Fulay, Wendelin J. Wright, 6th edition, Ch 20, 2011.*

3. *Learning material prepared by the Department of Physics*

Diamagnetic materials

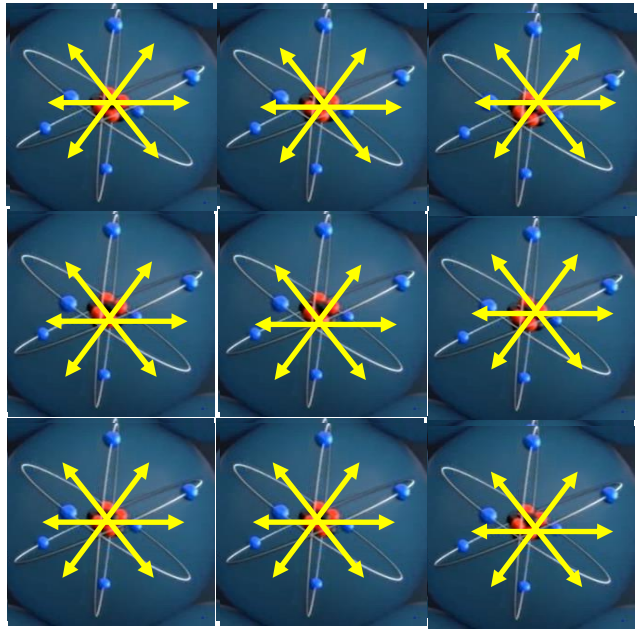
Diamagnetic materials

- *No unpaired electrons in the orbitals*
- *Atoms/molecules that have zero magnetic moment hence no permanent magnetism*

Zinc [Ar] ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ ↑↓

$3d^{10}$ $4s^2$

Diamagnetic material



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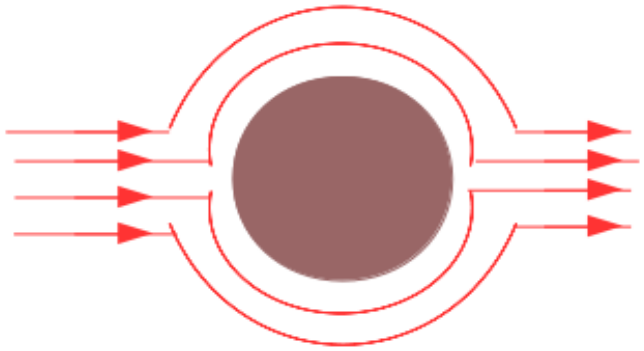
Diamagnetic materials

- *In presence of external field, interaction between field and electrons*
- *This effect is similar to that due to Lenz's law induced magnetic fields tend to oppose the change which created them.*
- *Diamagnetic materials have negative susceptibility*
- *Magnetic Susceptibility is*

$$\chi_{dia} = \frac{Ne^2\mu_0}{6m}\langle r^2 \rangle$$



- χ *is independent of temperature*

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Diamagnetic materials

- *All materials show some degree of diamagnetism at low fields*
- *If diamagnetism is the only contribution to the magnetism, the material is called diamagnetic.*

Zinc [Ar] 

$3d^{10}$ $4s^2$

Element	Susceptibility (10^{-6})	Permeability
Water	*–9.05*	*0.999992*
Copper	*–6.4*	*0.999994*
Zinc	*-15.0*	*0.999985*
Bismuth	*-166*	*0.999834*

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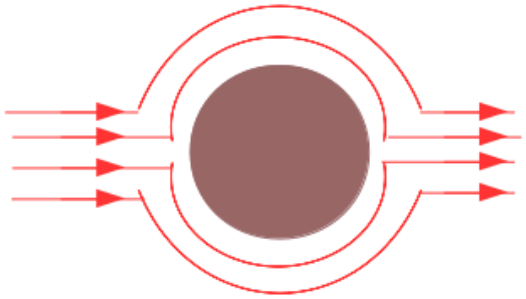
Diamagnetic materials- applications

- *Superconductors are perfect diamagnetic materials*
- *Diamagnetic levitation – maglev trains*
- *Diamagnetic levitation of objects, live animals, frictionless bearings….*

Superconductor



Maglev trains

Image courtesy Wikipedia

Magnetic levitation at fingertips

Ref: A.K. Geim et.al, Nature 400 (1999) 323e324rial

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Paramagnetic materials

- *Atoms have non-zero magnetic moment due to unpaired electrons*
- *Aluminium*

- *Paramagnetic materials have positive susceptibility*
- *Examples*

Element	Susceptibility(10^{-6})	Permeability
Aluminium	*22*	*1.0000220*
Oxygen	*0.37*	*1.0000003*
Sodium	*7.3*	*1.0000073*

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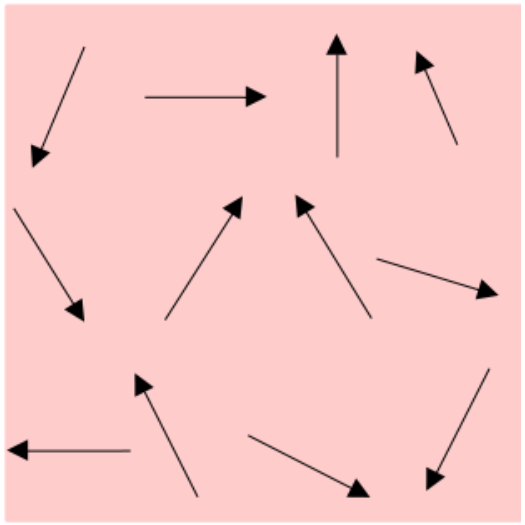
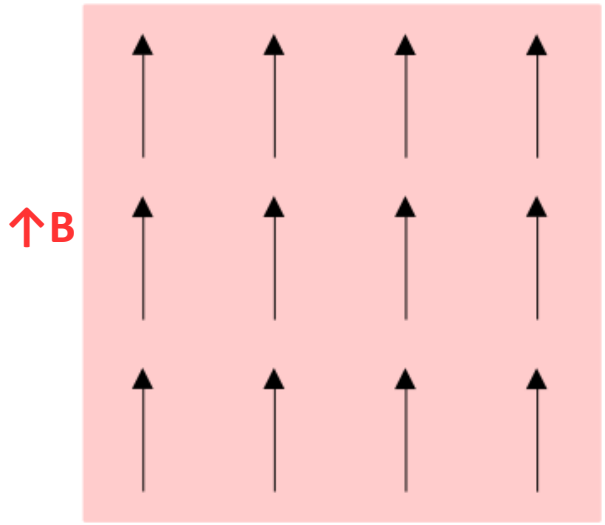
Paramagnetic materials

- *Magnetic moments of unpaired electrons are in random directions*
- *Applied field induces magnetization*
- *State of magnetization is disturbed due to thermal agitation*
- *χ depends on temperature*



B=0

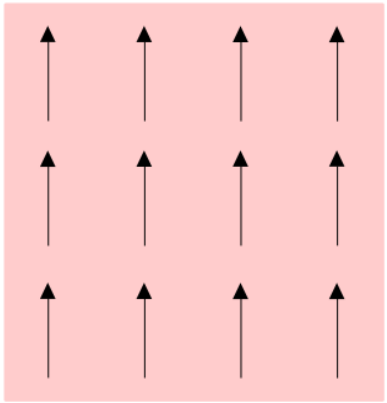


In the presence of applied field B>0

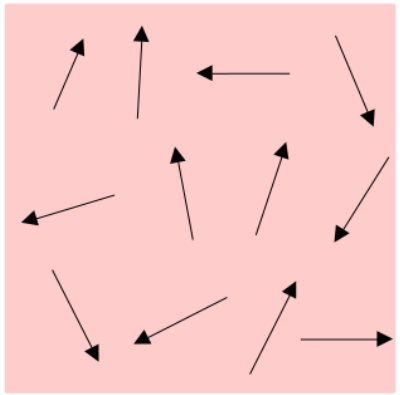
Paramagnetic materials

When the field is removed the magnetic moments go back to random orientations

↑B



In the presence of Applied field, B>0



Field removed B=0

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Paramagnetic materials- applications

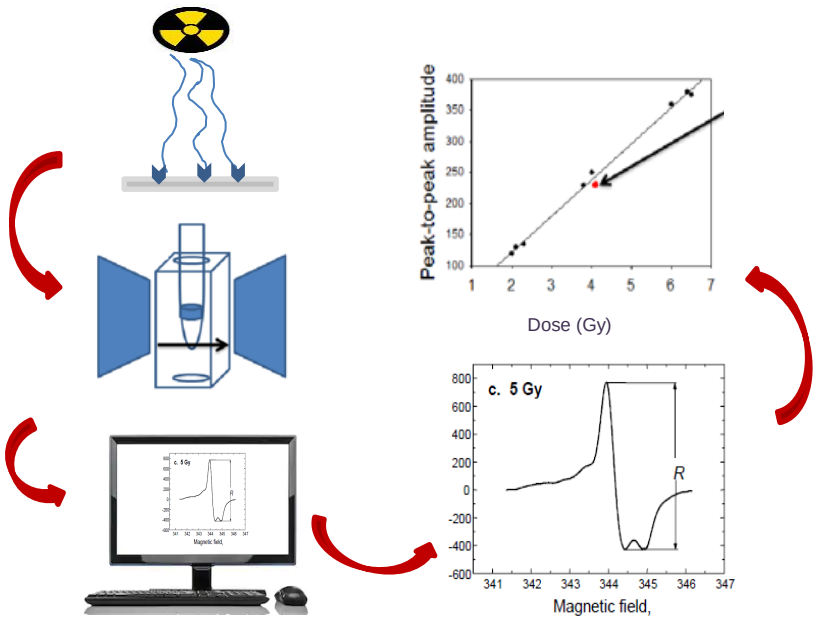
EPR Dosimetry – Electron paramagnetic resonance

- ***Retrospective determination - quantify the absorbed dose***

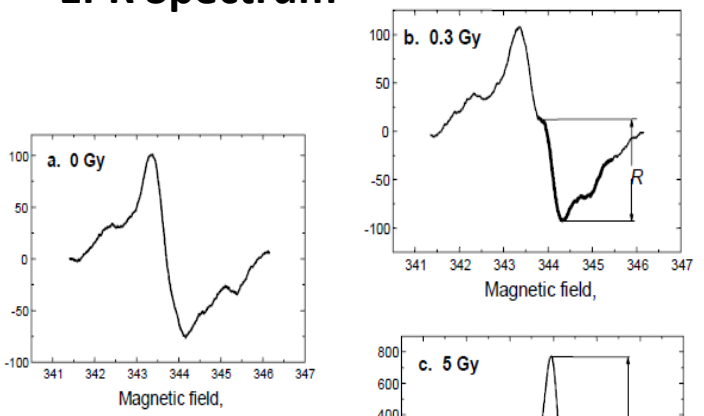
$$h\gamma = g\mu_B B$$

- ***Intensity of EPR signal increases proportionally with increase in the absorbed dose rate***

Dose estimation



EPR Spectrum



Report of a CRP, IAEA, 2002

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Paramagnetic materials- applications

- ***Study the changes in calcified human tissues***
- ***Alanine, Tooth enamel etc.***
- ***Identify irradiated foods***

tooth enamel

CO_2^- radicals in hydroxyapatite matrix

Ref: Tomasz Kubiak, Current Topics in Biophysics 2018, 41, 11-21

Irradiated food

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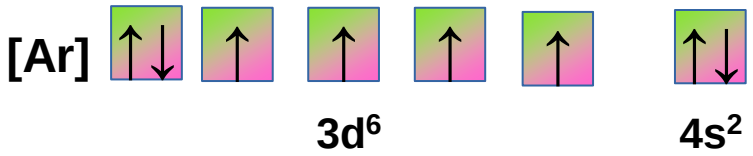
Ferromagnetic materials

- *Ferromagnetic materials have large positive susceptibility values*
- *Internal dipole moments*
- *Magnetic dipole moments of atoms arising from the spin of electrons*

- *Iron*



Examples

Element	Susceptibility
Iron	*200000*
Nickel	*600*
Cobalt	*250*

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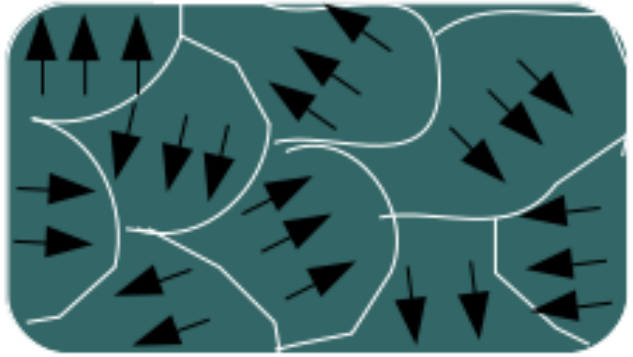
Ferromagnetic materials

- ***Exchange interaction***
- ***Magnetic domains - regions where the dipoles are aligned***

Domain size will be determined by energies such as magnetostatic energy and domain wall energy



B=0

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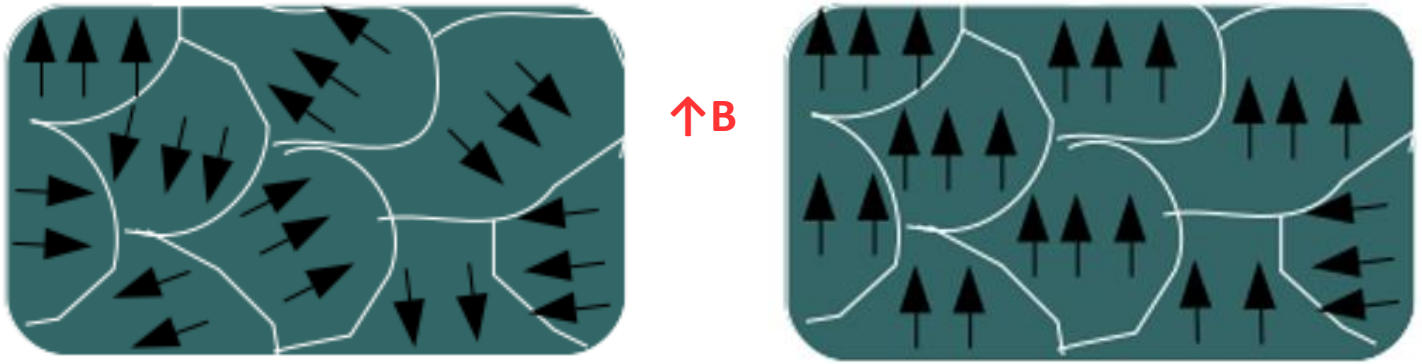
Ferromagnetic materials

- *When B is applied - alignment of all the domains along B*
- *long range alignment of spins due to strong exchange interaction*



B=0 B>0

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Ferromagnetic materials

- *Even after **B** is removed -remnant magnetization*
- *Magnetization of these materials decreases with increase in temperature*
- *χ depends on temperature*

B=0 **B>0** **Field removed B=0**

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Class #48 …….. Quiz….

The concepts related to different magnetic materials which are true are……

1. **Magnetic susceptibility is different for different materials**
2. **Diamagnetic susceptibility varies with temperature**
3. **Paramagnetic materials have spontaneous magnetization even in the absence of applied field**
4. **Magnetic moments within a domain are always aligned**
5. **Magnetization of ferromagnetic materials increases with increase in temperature**

PES UNIVERSITY ONLINE

THANK YOU

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