
# ENGINEERING PHYSICS

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# ENGINEERING PHYSICS

## Unit 5 : Quantum mechanical treatment of Magnetic materials

PES UNIVERSITY ONLINE

**Class # 52**

- Giant Magneto Resistance effect
- Applications of GMR effect
    - Memory-storage device
    - Other applications

# ENGINEERING PHYSICS

## Unit 5 : Applications of Magnetic materials

➢ *Suggested Reading*

1. *The Science and Engineering of Materials by Donald R. Askeland, Pradeep P. Fulay, Wendelin J. Wrigh, 6th edition, Ch 20, 2011.*
2. *Learning material prepared by the Department of Physics, PESU*

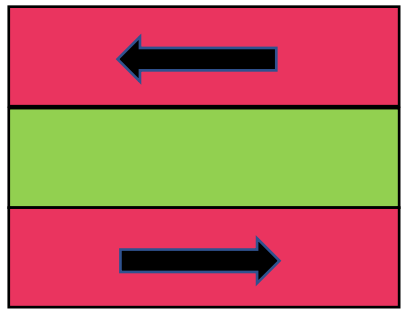
➢ *Reference Videos*

*https://nptel.ac.in/courses/115/105/115105122/*

# ENGINEERING PHYSICS

## Giant Magneto Resistance effect

- *Quantum mechanical magneto resistance effect*
- *Observed in layered magnetic materials*
- *Significant change in resistance to the current flow.*
- *Spin scattering of electrons*



Ferromagnet

Non magnet

Ferromagnet

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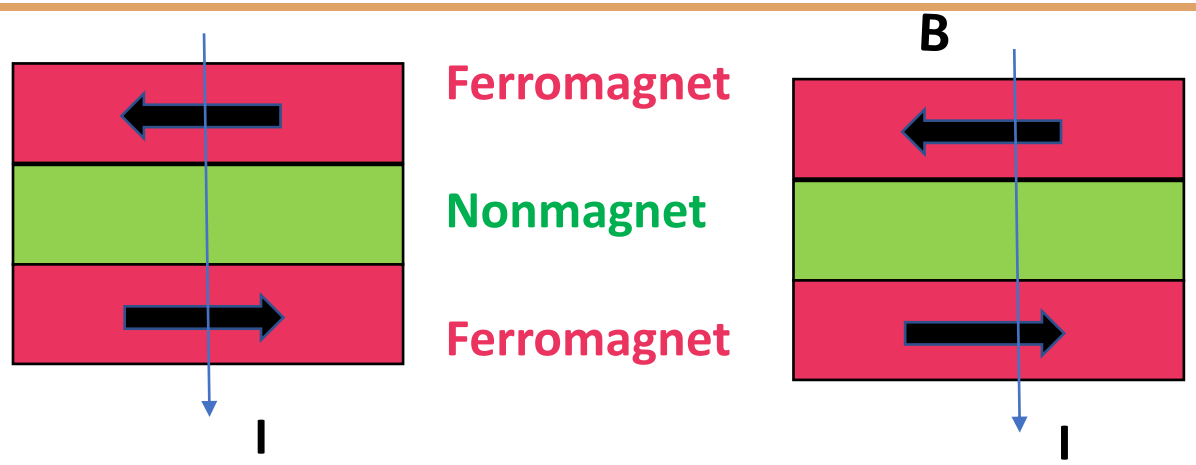
## Giant Magneto Resistance effect

- *Antiparallel magnetisation – high resistance*
- *Parallel magnetization - low resistance*
- *Magnetisation direction can be controlled by applying an external field.*




Antiparallel Magnetisation

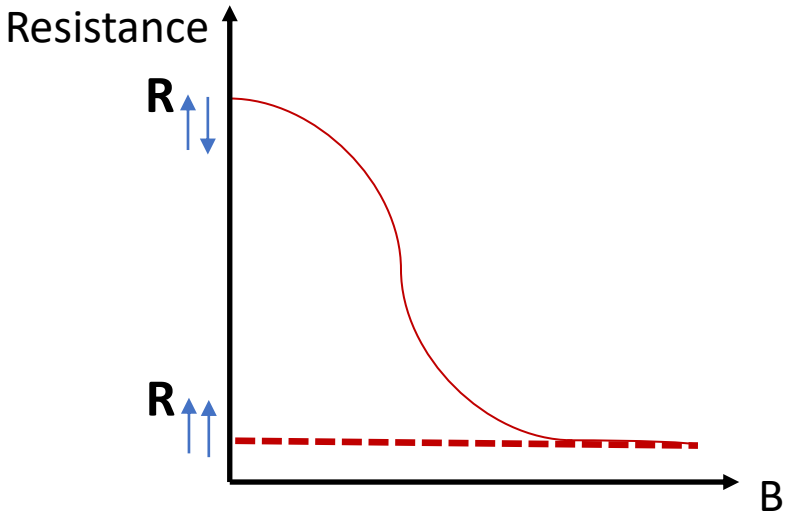
Parallel Magnetisation

# ENGINEERING PHYSICS

## Giant Magneto Resistance effect

$$GMR = \frac{R_{\uparrow\downarrow} - R_{\uparrow\uparrow}}{R_{\uparrow\uparrow}}$$

- *Depends on many parameters such as the geometry of the device, temperature and thickness of ferromagnetic and non-magnetic layers.*



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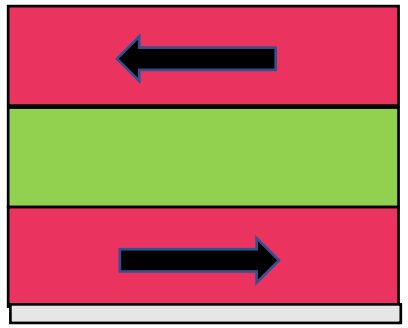
## Giant Magneto Resistance effect

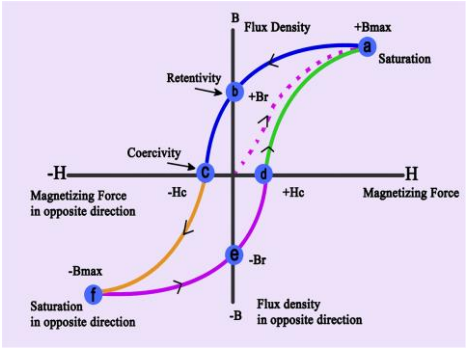
- *magnetic layers - 3-5nm and*

  *non-magnetic layer - 25nm*

  *observed change in resistance is as high as 50% of which is significant for any practical measurements and applications.*

- *GMR effect can be enhanced by using spin filters - certain spin orientation.*






***Applications***

*read head of magnetic memories, biosensors, etc.*

Image courtesy Hyperphysics, Wikipedia

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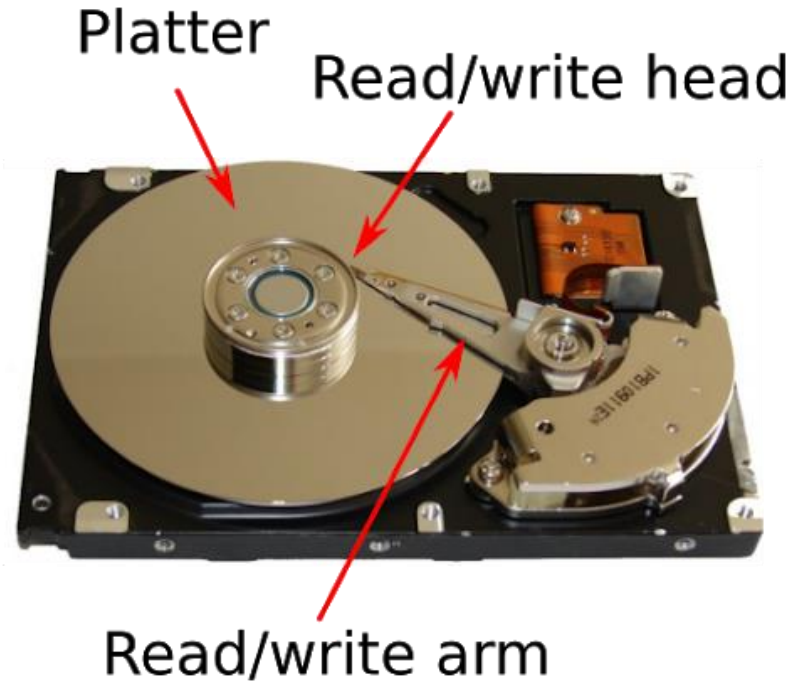
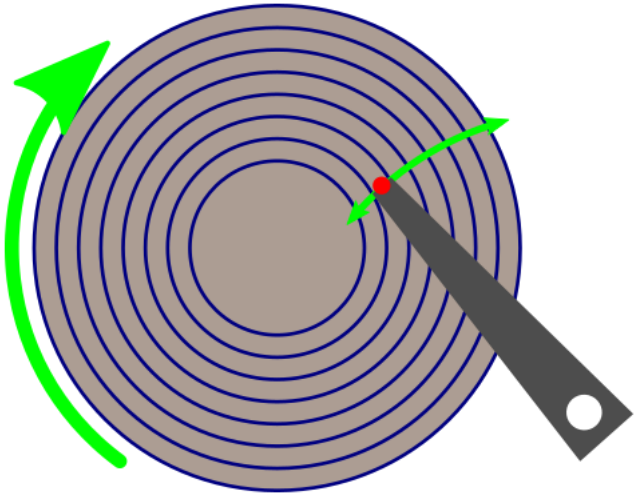
## GMR effect - Applications



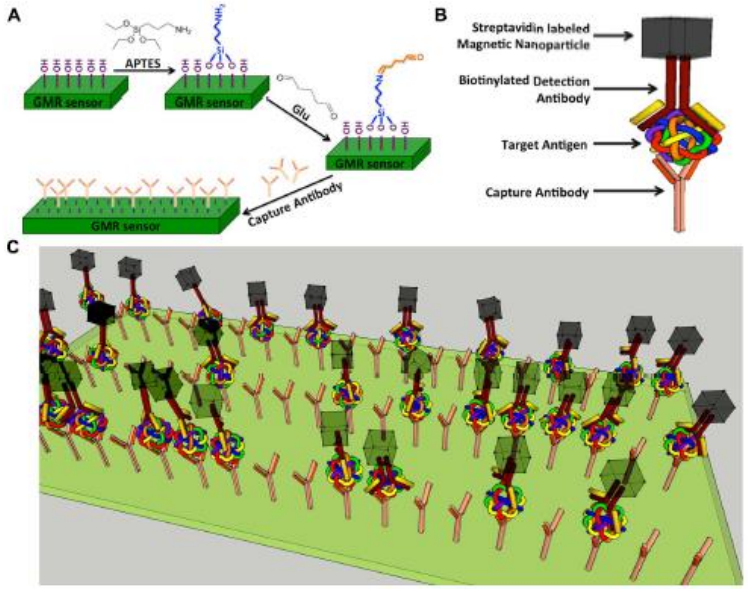
***Hard disk drive***

http://www.schoolcoders.com/memory-storage/secondary-storage/hdd/

# ENGINEERING PHYSICS

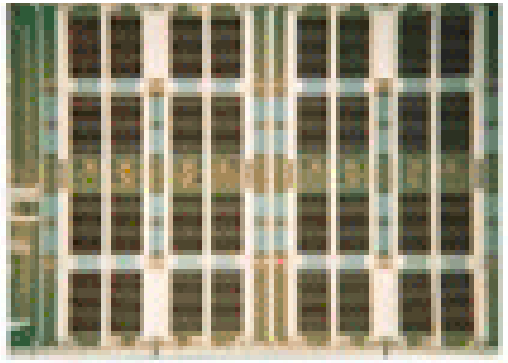
## GMR effect - Applications

### *Biosensor*



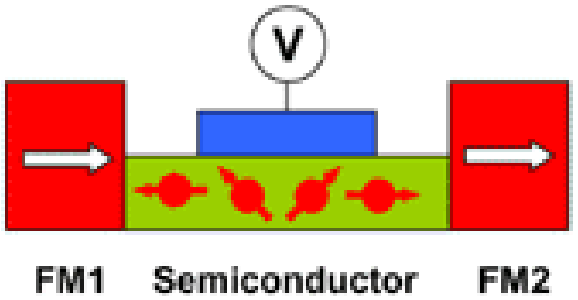

*Venkatramana D. Krishna et al., Frontiers in Microbiology,* doi: 10.3389/fmicb.2016.00400

### *MRAM*



*M Johnson et al., IEEE Spectrum, 37,33, 2000*

### *Spin-FET*




*S Datta et al., Applied Physics Letters, 56, 665, 1990*

# ENGINEERING PHYSICS

## Unit 5 : Quantum mechanical treatment of Magnetic materials

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- Magnetic permeability & susceptibility
- Origin of magnetism
  - Orbital and spin angular momenta
  - Larmor precession
- Classification of magnetic materials
- Diamagnetic materials

# ENGINEERING PHYSICS

## Unit 5 : Quantum mechanical treatment of Magnetic materials

### Paramagnetic materials

- Quantum theory of paramagnetism
- Classical theory of paramagnetism
- Curie's law
- Weis molecular field theory

### Ferromagnetic materials

- Ferromagnetism
- Anti-ferromagnetism
- Ferrimagnetism

### Giant Magneto Resistance – (GMR effect)

# ENGINEERING PHYSICS

## List of Formulae

$$B = \frac{\emptyset}{A}$$

$$E_m = \mu \, . B$$

$$M = \chi_m H$$

$$B = \mu H$$

$$\mu = \mu_o \, \mu_r$$

$$H = \frac{nI}{l}$$

$$\mu_r = (1 + \chi_m)$$

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

$$\mu = IA$$

$$\omega_L = \frac{e}{2m_e} B$$

$$\chi \, \alpha \frac{1}{T}$$

$$\chi = \frac{C}{T - T_c}$$

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## Numericals

1. An iron rod of length 0.5m has a cross sectional area of $4 \times 10^{-4}$ $m^2$. If the flux of magnetic induction through the bar is $2 \times 10^{-4}$ Weber and relative permeability of iron is 1000, calculate
    a. Magnetic susceptibility
    b. Intensity of magnetising field
    c. Magnetisation

Solution: Given: $\phi = 2 \times 10^{-4}$ Weber
$A = 4 \times 10^{-4}$ $m^2$
$L = 0.5m$
$\mu_r = 1000$

To find: $\chi_m$ = ?
H = ?
M = ?

a. Magnetic susceptibility $\chi_m = (\mu_r - 1)$
$= 1000 - 1 = 999$

# ENGINEERING PHYSICS

## Numericals

b. Intensity of magnetising field $H = \frac{B}{\mu} = \frac{B}{\mu_o \mu_r}$

Since, $B = \frac{\emptyset}{A}$ $\mu = \mu_o \mu_r$ $H = \frac{\phi/A}{\mu_o \mu_r}$

Substituting the values and simplifying, we get, *H = 398.09 A/m*

c. Magnetisation $M = \chi_m H$ = *999 x 398.09*

*M = 397.7 A/m*

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## Numericals

**2. A magnetic field of 1T is applied to an electron undergoing orbital motion. Calculate the precessional frequency.**

**Solution: Given:** B = 1 T  **To find:** $\omega_L$ = ?

$$\omega_L = \frac{e}{2m_e} B = \frac{1.6\ X\ 10^{-19}}{2\ X\ 9.1\ X\ 10^{-31}}\ X\ 1$$

$$\omega_L = 87.8\ X\ 10^{9}\ rad/s$$

# ENGINEERING PHYSICS

## Class 51 . Quiz …

**The concepts which are correct are….**

1. **GMR effect is observed only in 3 layered magnetic materials.**
2. **Change in resistance due to magnetization is temperature dependent**
3. **Scattering of electrons is less in the case of parallel magnetization.**
4. **Electron spin orientation is fixed in the free layer of magnetic material**
5. **Resistance increases when spin state of the two layers are antiparallel.**

# THANK YOU

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