# Lecture (07) Magnetism (II)

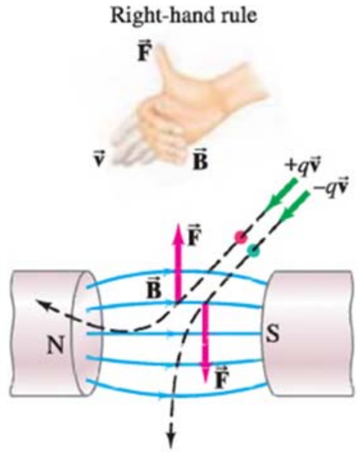
## By:

## Dr. Ahmed ElShafee



# Revision

- $\vec{F} = q\vec{v} \times \vec{B}.$






# Lorentz Equation

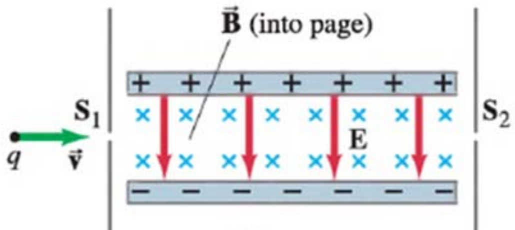
- If a particle of charge *q* moves with velocity v in the presence of both a magnetic field B and an electric field E, it will feel a force

$$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$$

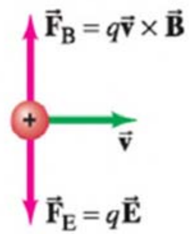


**Velocity selector, or filter: Crossed E and B fields.**

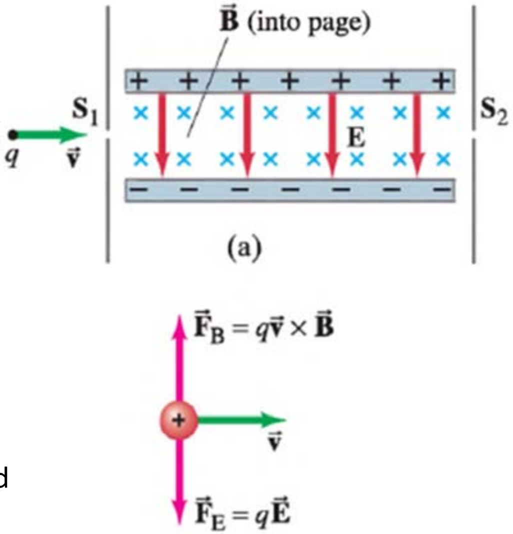
- Some electronic devices and experiments need a beam of charged particles all moving at nearly the same velocity.
- This can be achieved using both a uniform electric field and a uniform magnetic field,




(a)

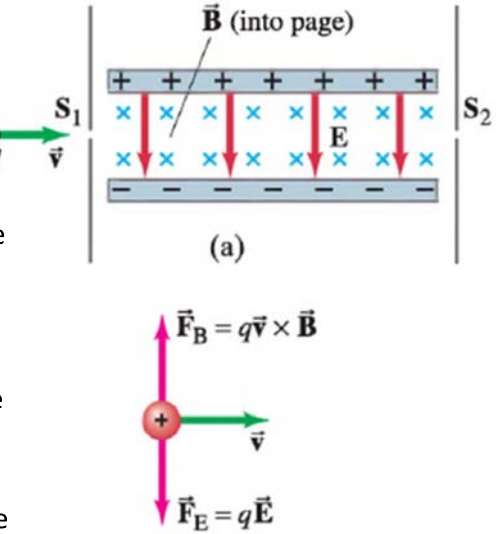


- articles of charge $q$ pass through slit $S1$ and enter the region where B points into the page and E points down from the positive plate toward the negative plate.
- If the particles enter with different velocities, show how this device “selects” a particular velocity, and determine what this velocity is
- The exit slit, S2, is assumed
- to be directly in line with Si and the particles’ velocity v.






- After passing through slit S i, each particle is subject to two forces as shown in Fig
- If $q$ is positive, the magnetic force is upwards and the electric force downwards. (Vice versa if $q$ is negative.)
- Depending on the
- magnitude of v, some particles will be bent upwards and some downwards.
- The only ones to make it through the slit S2 will be those for which the net force is zero:

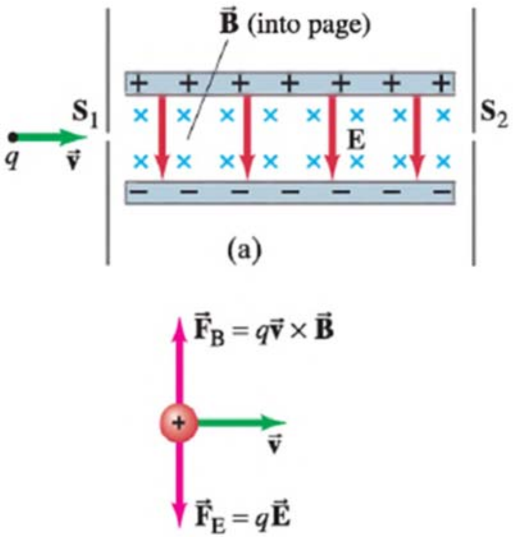





$$\Sigma F = qvB - qE = 0.$$

- **device selects particles whose velocity is**

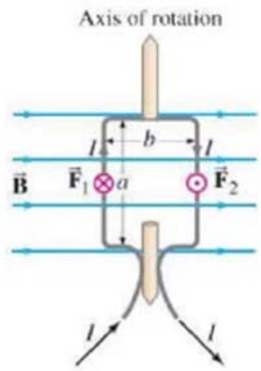
$$v = \frac{E}{B}.$$

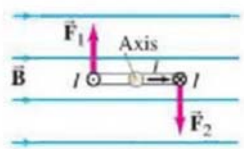





# Torque on a Current Loop; Magnetic Dipole Moment

- When an electric current flows in a closed loop of wire placed in an external magnetic field.
- the magnetic force on the current can produce a torque.
- This is the principle behind motors and analog voltmeters and ammeters
- Horizontal wires that  in parallel to B. .
- B exerts no force and no torque on the horizontal sin$\theta$ = 0
- *F = IaB,* where *a* is the length of the vertical arm of the coil.



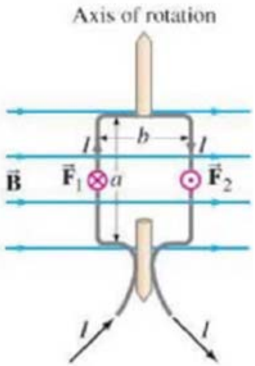



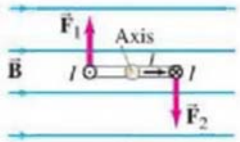
- The lever arm for each force is b/2, where b is the width of the coil and the "axis" is at the midpoint.
- The torques produced by F1 and F2 act in the opposite direction
- the total torque is the sum of the two torques:

$$\tau = IaB\frac{b}{2} + IaB\frac{b}{2} = IabB = IAB,$$

- where $A = ab$ is the area of the coil
- if the coil consists of $N$ loops of wire, the current is then $NI$,

$$\tau = NIAB.$$






- If the coil makes an angle $\theta$ with the magnetic field

$$\tau = NIAB\sin\theta.$$

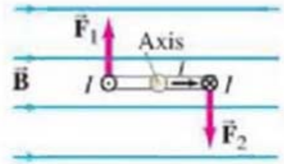
- Equation is valid for any shape of flat coil
- magnetic dipole moment

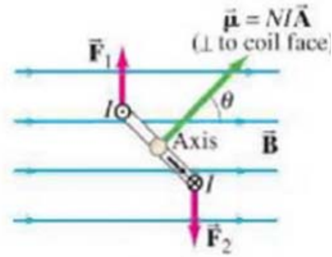
$$\vec{\mu} = NI\vec{A},$$

- Torque

$$\vec{\tau} = NI\vec{A} \times \vec{B}$$

$$\vec{\tau} = \vec{\mu} \times \vec{B},$$



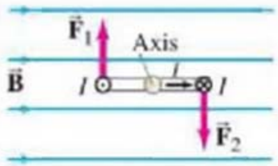


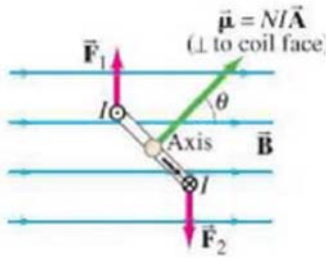

- **potential energy given by**

$$U = \int \tau\, d\theta = \int NIAB\sin\theta\, d\theta = -\mu B\cos\theta + C.$$

- $U$ **= 0 at** $\theta = \pi/2$, **then the arbitrary constant C is zero**

$$U = -\mu B\cos\theta = -\vec{\mu}\cdot\vec{B},$$






# Example 01

- A circular coil of wire has a diameter of 20.0 cm and contains 10 loops.
- The current in each loop is 3.00 A, and the coil is placed in a 2.00-T external magnetic field.
- Determine the maximum and minimum torque exerted on the coil by the field.

The area of one loop of the coil is

$$A = \pi r^2 = \pi(0.100\,\mathrm{m})^2 = 3.14 \times 10^{-2}\,\mathrm{m}^2.$$

- The maximum torque occurs $\theta = 90°$

$$\tau = NIAB\sin\theta$$
$$= (10)(3.00\,\mathrm{A})(3.14 \times 10^{-2}\,\mathrm{m}^2)(2.00\,\mathrm{T})(1)$$
$$= 1.88\,\mathrm{N \cdot m}.$$

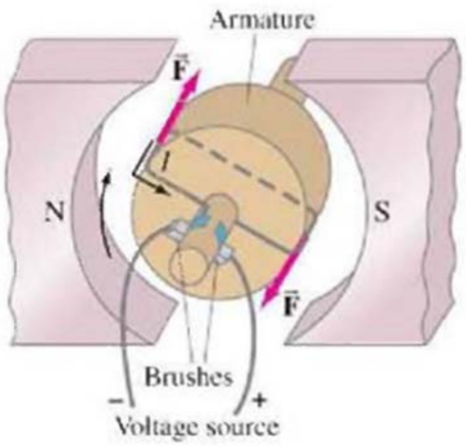
- minimum torque occurs if sin $\theta$ = 0,

$\theta = 0°$, and then $\tau = 0$



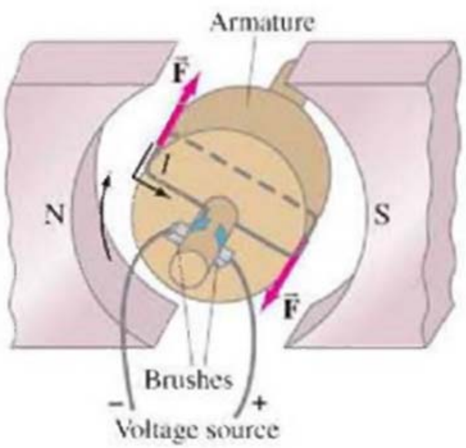
# Applications: Motors, Loudspeakers, Galvanometers

- Electric Motors electric motor changes electric energy into (rotational) mechanical energy
- A motor works on the principle that a torque is exerted on a coil of current-carrying wire suspended in the magnetic field of a magnetic.
- The coil is mounted on a large cylinder called the rotor or armature



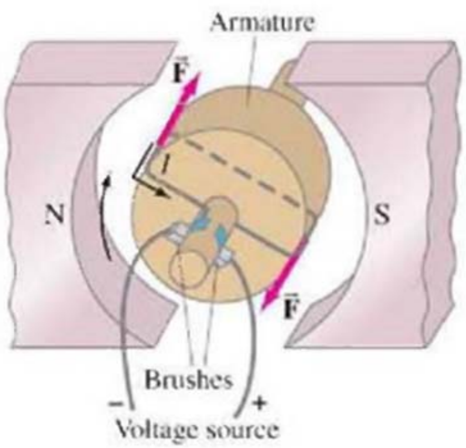



- there may be several coils,
- The armature is mounted on a shaft or axle.
- the magnetic field exerts forces on the current in the loop.
- when the coil, which is rotating clockwise, passes beyond the vertical position, the forces would then act to return the coil back to vertical, if the current remained the same

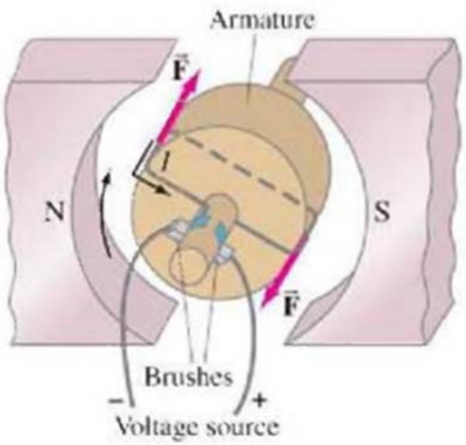





- But if the current could somehow be reversed at that critical moment, the forces would reverse, and the coil would continue rotating in the same direction.
- Thus, alternation of the current is necessary if a motor is to turn continuously in one direction.

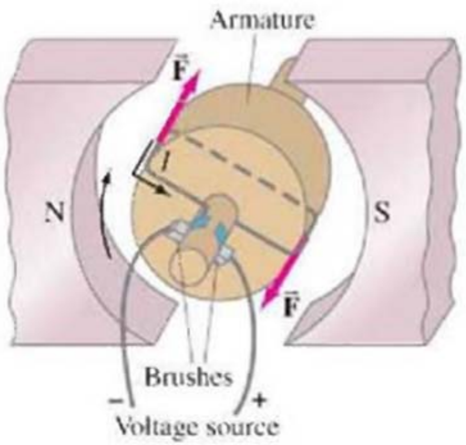


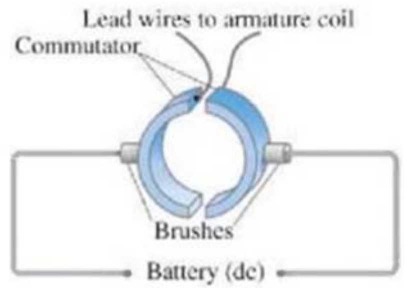
- This can be achieved in a dc motor with the use of commutators and brushes: as shown in Fig.
- input current passes through stationary brushes that rub against the conducting commutators mounted on the motor shaft.
- At every half revolution, each commutator changes its connection over to the other brush.





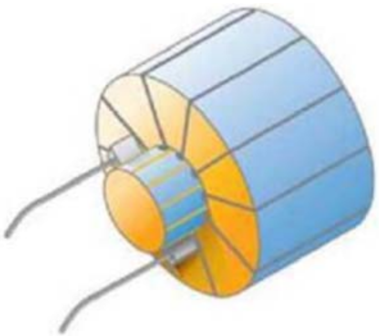

- Thus the current in the coil reverses every half revolution as required for continuous rotation.






- Most motors contain several coils, called *windings,* each located in a different place on the armature,
- Current flows through each coil only during a small part of a revolution, at the time when its orientation results in the maximum torque.
- In this way, a motor produces a much steadier torque than can be obtained from a single coil.



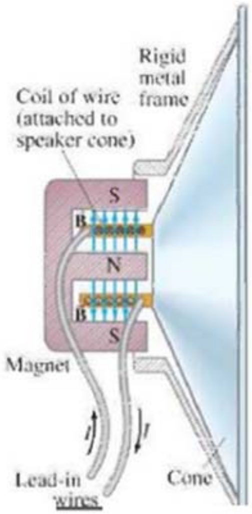
Motor with many windings.



- An ac motor, with ac current as input, can work without commutators since the current itself alternates.
- Many motors use wire coils to produce the magnetic field (electromagnets) instead of a permanent magnet.
- Indeed the design of most motors is more complex than described here, but the general principles remain the same.

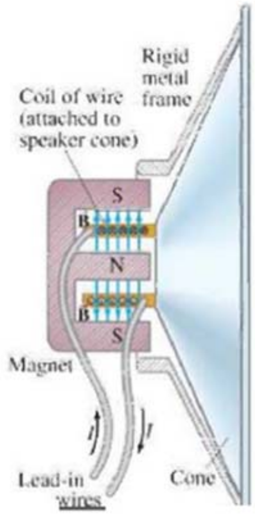
## Loudspeakers

- The electrical output of a stereo or TV set is connected to the wire leads of the speaker .
- speaker leads are connected internally to a coil of wire, which is itself attached to the speaker cone.
- The speaker cone is usually made of stiffened cardboard and is mounted so that it can move back freelv.






- A permanent magnet is mounted directly in line with the coil of wire.
- When the alternating current of an audio signal flows through the wire coil, which is free to move within the magnet, the coil experiences a force due to the magnetic
- As the current alternates at the frequency of the audio signal, the coil and attached speaker cone move back and forth at the same frequency, causing alternate compressions and rarefactions of the adjacent air, and sound waves are produced.

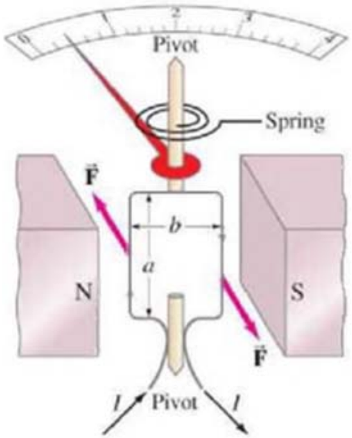





## Galvanometer

- galvanometer is the basic component of analog meters analog ammeters, voltmeters, and ohmmeters,.
- consists of a coil of wire (with attached pointer) suspended in the magnetic field of a permanent magnet.
- When current flows through the loop of wire, the magnetic field exerts a torque on the loop

$$\tau = NIAB \sin\theta.$$



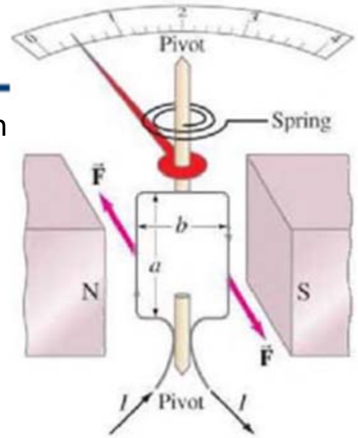


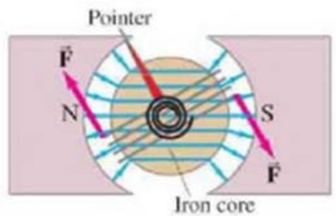

- This torque is opposed by a spring which exerts a torque t s approximately proportional to the angle <φ> through which it is turned (Hooke's law). That is,

$$\tau_s = k\phi,$$

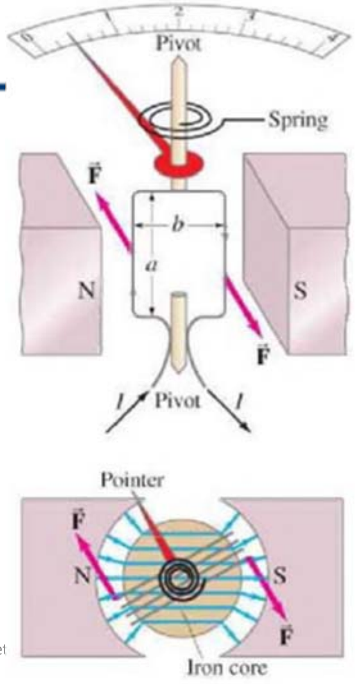
- $k$ is the stiffness constant of the spring.
- The coil and attached pointer rotate to the angle where the torques balance.
- When the needle is in equilibrium at rest,

$$\phi = \frac{NIAB \sin\theta}{k}.$$



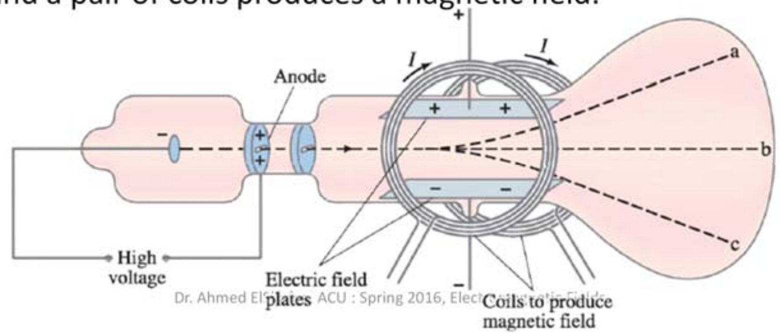
- The deflection of the pointer, $\theta$, is directly proportional to the current *I* flowing in the coil, but also depends on the angle $\theta$ the coil makes with B.





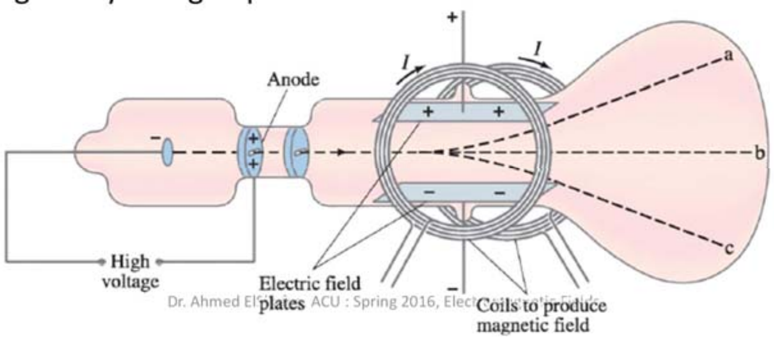

**cathode-ray tube:**

- Electrons of Cathode rays are accelerated by a high voltage and then pass between a pair of parallel plates built into the tube.
- The voltage applied to the plates produces an electric field, and a pair of coils produces a magnetic field.






- When only the electric field is present, with the upper plate positive, the cathode rays are deflected upward as in path a in Fig.
- If only a magnetic field exists, say inward, the rays are deflected downward along path c, which is expected for a negatively charged particle.






- The force on the rays due to the magnetic field is *F = evB,*
- In the absence of an electric field, the rays are bent into a curved path, so we have, from *F = ma,* $a=v^2/r$

$$evB = m\frac{v^2}{r},$$

$$\frac{e}{m} = \frac{v}{Br}.$$

- the force due to the electric field, *F = eE,* is balanced by the force due to the magnetic field, *F = evB.*
- *eE = evB* and *v = E/B .*

$$\frac{e}{m} = \frac{E}{B^2 r}$$

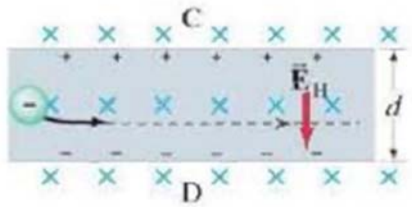
- The cathode ray tube (CRT), which can serve as the picture tube of TV sets, oscilloscopes, and computer monitors,



# The Hall Effect

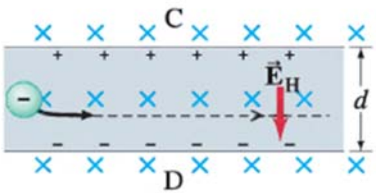
- When a current-carrying conductor is held fixed in a magnetic field, the field exerts a sideways force on the charges moving in the conductor.
- if electrons move to the right in the rectangular conductor shown in Fig

$$\vec{F}_B = -e\vec{v}_d \times \vec{B},$$






- Thus the electrons will tend to move nearer to face D than face C.
- There will thus be a potential difference between faces C and D of the conductor.
- This potential difference builds up until the electric field $E_h$ that it produces exerts a force, $eE_H$, on the moving charges that is equal and opposite to the magnetic force.






- This effect is called the Hall effect after E. H. Hall, The difference of potential produced is called the **Hall emf**
- The electric field due to the separation of charge is called the *Hall field,* $\mathbf{E_H}$
- **In equilibrium, the force due to this electric field is balanced by the magnetic force** $ev_dB$,

$$eE_H = ev_d B.$$

$$E_H = v_d B.$$

- **The Hall emf**

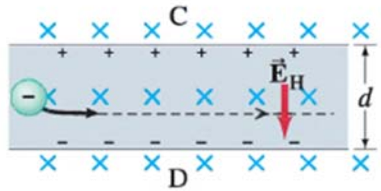
$$\mathscr{E}_H = E_H d = v_d B d,$$

- The magnitude of the Hall emf is proportional to the strength of the magnetic field.
- The Hall effect can thus be used to measure magnetic field strengths.
- First the conductor, called a *Hall probe,* is calibrated with known magnetic fields.
- Then, for the same current, its emf output will be a measure of *B.*



# Example 02

- A long copper strip 1.8 cm wide and 1.0 mm thick is placed in a 1.2-T magnetic field as in Fig
- When a steady current of 15 A passes through it, the Hall emf is measured to be 1.02 *uV.*
- Determine the drift velocity of the electrons and the density of free (conducting) electrons (number per unit volume) in the copper.






- L=1.8 cm wide
- D=1.0 mm thick is placed in a
- B=1.2-T
- I= 15 A
- Hall emf =1.02 *uV*
- *Drift velocity*

$$v_d = \frac{\mathscr{E}_H}{Bd} = \frac{1.02 \times 10^{-6}\,\text{V}}{(1.2\,\text{T})(1.8 \times 10^{-2}\,\text{m})} = 4.7 \times 10^{-5}\,\text{m/s}.$$



- **The density of charge carriers** *n*

$$I = nev_d A,$$

$$n = \frac{I}{ev_d A} = \frac{15\,\text{A}}{(1.6 \times 10^{-19}\,\text{C})(4.7 \times 10^{-5}\,\text{m/s})(1.8 \times 10^{-2}\,\text{m})(1.0 \times 10^{-3}\,\text{m})}$$

$$= 11 \times 10^{28}\,\text{m}^{-3}.$$

**Thanks,..**

**See you next week (ISA),…**