PHYS 1444 – Section 002
Lecture #18

Monday, Nov. 4, 2019

Dr. Jaehoon Yu

- Chapter 27: Magnetism & Magnetic Field
  - Magnetic Force on a Moving Charge
  - Charged Particle Path in a Magnetic Field
  - The cyclotron frequency
  - Magnetic dipole Moment
  - The Hall Effect
- Chapter 28:Sources of Magnetic Field
  - Sources of Magnetic Field

Today's Homework is #11 due 11pm, Wednesday, Nov. 20!!

Announcements

- Reading Assignments: CH27.6, 27.8 and 27.9
- 2nd non-comprehensive term exam: Nov. 11
  - Monday, Nov. 11 in class
  - Covers: CH25.5 through what we finish next Wednesday, Nov. 6
  - Bring your calculator but DO NOT input formula into it!
    - Cell phones or any types of computers cannot replace a calculator!
  - BYOF: You may bring a one 8.5x11.5 sheet (front and back) of **handwritten** formulae and values of constants for the quiz
  - No derivations, word definitions, set ups or solutions of any problems!
  - No additional formulae or values of constants will be provided!
- Quiz 3 results
  - Class average: 33.2/50
    - Equivalent to 66.4/100
    - Previous results: 56.4 an 46.2
  - Top score: 50/50
- Remember the triple extra credit colloquia
  - At 4pm next Wednesday, Nov. 13
  - Professor Hitoshi Murayama of U.C. Berkeley

Join us for our annual celebration of science!

UNIVERSITY OF TEXAS ARLINGTON | COLLEGE OF SCIENCE

SCIENCE WEEK

NOVEMBER 4-8, 2019

MONDAY, NOVEMBER 4

11:45 AM–1:15 PM Chemistry & Physics Building – COS Student Organizations Fair
Check-in CPB first floor, West Atrium. Featuring both undergraduate and graduate student organizations specific to science majors. Pizza and prizes for students visiting the fair. (*For all undergraduate and graduate science majors*)

TUESDAY, NOVEMBER 5

1-2 PM Chemistry & Physics Building Room 303 – Special Physics Colloquium
Featuring Sylvester James Gates Jr., Ph.D., Brown Theoretical Physics Center Director and Ford Foundation Professor of Physics, Brown University. Talk title: "SUSY RILLES: A Speculation on Superstring Signatures in the Cosmic Microwave Background." (*For physics students and faculty*)

5-6 PM UTA Planetarium – Special Public Lecture and Book Signing
Featuring Sylvester James Gates Jr., Ph.D., Brown Theoretical Physics Center Director and Ford Foundation Professor of Physics, Brown University. Talk title: "From SyFy and Marvel Comics to Superstring Theory, Evolution, and the CMB." Copies of Dr. Gates' book, Proving Einstein Right: The Daring Expeditions that Changed How We Look at the Universe, will be available for purchase and Dr. Gates will sign copies following the talk. Two UTA students will receive free signed copies in a raffle. ***(OPEN TO ALL)***

WEDNESDAY, NOVEMBER 6

12–1 PM Life Sciences Building Room 124 – Medical Alumni Panel
Co-hosted by UTA's MAPS chapter, moderated by COS Assistant Dean Greg Hale. Panelists include medical alumni Dr. Jocelyn Zee, D.O. '04, and Dr. David Partridge, M.D. and D.O. '76. (*For pre-med students*)

4–5 PM Science Hall Room 100 – Physics Colloquium
Featuring Xuejun Gu, Ph.D., Associate Professor, Department of Radiation Oncology, UTSW Medical Center. Talk title: "Medical Physics." ***(OPEN TO ALL)***

6–7 PM Planetarium, Chemistry & Physics Building – Special Physics Colloquium
Featuring Loren Acton, Ph.D., a solar astronomer and retired NASA astronaut who served as payload specialist aboard the Space Shuttle Challenger on the Spacelab 2 mission in 1985. His talk is titled "From Horseback to Spaceflight via the Sun." A reception will precede the talk at 5:30 PM in the Planetarium atrium. The event is free and open to the public, but tickets are required. Register at link found in events schedule at uta.edu/science/scienceweek. ***(OPEN TO ALL)***

5:30–8:30 PM SEIR Building Room 298 & atrium – Health & Science Careers Panel
Co-hosted by the Science Constituency Council and the Health Professions Leadership Board. A mixer with pizza begins at 5:30 PM in the second floor atrium. A panel discussion with representatives from a variety of science and health-related careers begins at 6:15 PM in Room 298, followed by an opportunity for students to network with the speakers in the atrium at 7:30 PM. (*For students interested in careers in science and health fields*)

THURSDAY, NOVEMBER 7

12–1 PM Pickard Hall Room 204 – Psychology Colloquium
The Department of Psychology and Wiley Publishing Company present Catherine A. Sanderson, Ph.D., Professor of Psychology, Amherst College. Talk title: "The Psychology of Good and Evil." ***(OPEN TO ALL)***

4–5 PM SEIR Building Room 198 – COS Distinguished Women in Science Speaker Series
Featuring Ami Radunskaya, Ph.D., Professor of Mathematics at Pomona College and past president of the Association for Women in Mathematics. Talk title: "From Music to Mathematics to Medicine: One Woman's Journey." A reception will precede the talk at 3:30 PM in the SEIR first floor atrium. ***(OPEN TO ALL)***

FRIDAY, NOVEMBER 8

12–1 PM Life Sciences Building Room 100 – Dental Careers Seminar
Co-hosted by UTA's Pre-Dental Society. Alumni speaker Scott Parsinen, '94, CEO of Cadmus Dental, will speak on "Alternative Career Opportunities in Dentistry." (*For students interested in careers in the field of dental health*)

12–1 PM Geosciences Building Room 104 – Environmental Careers Panel Discussion
Featuring COS alumni and experts in environmental science fields. ***(OPEN TO ALL)***

2–3:15 PM Lockheed Martin Career Development Center – Resume Writing Workshop *(OPEN TO ALL)*

3:30–5 PM Lockheed Martin Career Development Center – Job Interview Workshop *(OPEN TO ALL)*

3-4 PM Chemistry & Research Building Room 114 – Chemistry & Biochemistry Seminar
Featuring Mercouri Kanatzidis, Ph.D., Professor of Chemistry, Northwestern University. Talk title: "Poor Man's High Performance Semiconductors: The Amazing Perovskites." ***(OPEN TO ALL)***

7-9 PM (Off-campus event) New Main Brewing Co., 3533 Marathon St., Pantego – Tap Talks: Science Distilled
Sponsored by the College of Science, Tap Talks: Science Distilled is a monthly informal science talk series held at local breweries. It's fun, free, and family friendly! This month's speakers are Hanli Liu, Adam Mitchell, and Ariel Leslie. ***(OPEN TO ALL)***

The schedule is also available online at uta.edu/science/events/scienceweek

Reminder: Special Extra Credit #4

- **Civic Duty Participation Exercise**
- You can submit up to four “I Voted” stickers for 20 points total
  - If voted, they give 3 pieces of paper of which one has precinct info.
- Be sure to tape one side of the stickers on a sheet of paper with your name on it along with the following info for each sticker
  - The number and the name of the precinct the vote was cast
  - The full name of the person voted next to the relevant sticker
  - The signature of the person voted next to the full name
- None of the stickers can be from the same person on someone else’s extra credit or yours
- Deadline: Beginning of the class this Wednesday, Nov. 6

Reminder: Special Project #5

- Make a list of the power consumption and the resistance of all electric and electronic devices at your home and compile them in a table. (10 points total for the first 10 items and 0.5 points each additional item.)
- Estimate the cost of electricity for each of the items on the table using your own electric cost per kWh (if you don't find your own, use $0.12/kWh) and put them in the relevant column. (5 points total for the first 10 items and 0.2 points each additional items)
- Estimate the the total amount of energy in Joules and the total electricity cost per day, per month and per year for your home. (8 points)
- Spreadsheet: http://www-hep.uta.edu/%7Eyu/teaching/fall19-1444-002/sp5-spreadsheet.xlsx
- Due: Beginning of the class Monday, Nov. 11

<u>**PHYS1442-002, Fall 19, Special Project #5**</u>

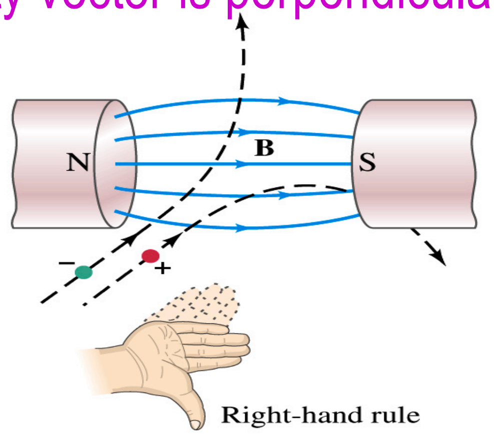
Your Name						Electricity Rate					c/kWh
Item Name	**Rated power (W)**	**Number of devices**	**Number of Hours per day**	**Daily Power Consumption (kWh)**	**Energy Cost per kWh (cents)**	**Daily Energy Consumption (J).**	**Daily Energy Cost ($)**	**Monthly Energy Consumption (J)**	**Monthly Energy Cost (S)**	**Yearly Energy Consumption (J)**	**Yearly Energy Cost ($)**
Light Bulbs	30	4									
	40	6									
	60	15									
Heaters	1000	2									
	1500	1									
	2000	1									
Home Appliances (Fans, vacuum cleaners, hair dryers, pool pumps, etc)											
Air Conditioners											
Kitchen Appliances (Fridges, freeezers, cook tops, microwave ovens, toaster ovens, etc)											
Computing devices (desktop, laptop, ipad, mobile phones, printers, chargers, etc))											
Tools (power tools, electric mower, electric cutter, etc)											
Medical Devices (blood pressure machine, thermometer, etc)											
Transporations (electric cars, electric bicycles, electric motor cycles, etc											
Total											

Magnetic Forces on a Moving Charge

- Will moving charge in a magnetic field experience force?
  - Yes
  - Why?
  - Since the wire carrying current (moving charge) experiences force in a magnetic field, a free moving charge must feel the same kind of force…☺
- OK, then how much force would it experience?
  - Let's consider **N** moving particles with charge **q** each, and they pass by a given point in a time interval **t**.
    - What is the current? $I = Nq/t$
  - Let **t** be the time for the charge **q** to travel a distance ℓ in a magnetic field **B**
    - Then, the length vector ℓ becomes $\vec{l} = \vec{v}t$
    - Where **v** is the velocity of the particle
- Thus the force on N particles by the field is $\vec{F} = I\vec{l} \times \vec{B} = Nq\vec{v} \times \vec{B}$
- The force on one particle with charge q, $\boxed{\vec{F} = q\vec{v} \times \vec{B}}$

Magnetic Forces on a Moving Charge

- This can be an alternative way of defining the magnetic field.
  - How?
  - The magnitude of the magnetic force on a particle with charge **q** moving with a velocity **v** in a field **B** is
    - $F = qvB\sin\theta$
    - What is θ?
      - The angle between the magnetic field and the direction of particle's movement
    - When is the force maximum?
      - When the angle between the field and the velocity vector is perpendicular.
    - $F_{\max} = qvB$ ➔ $B = \frac{F_{\max}}{qv}$
  - The direction of the force follows the right-hand-rule and is perpendicular to the direction of the magnetic field



Example 27 – 5

Magnetic force on a proton. A proton with the speed of 5×10^6 m/s in a magnetic field feels the force of $F = 8.0 \times 10^{-14}$ N toward West when it moves vertically upward. When moving horizontally in a northerly direction, it feels zero force. What is the magnitude and the direction of the magnetic field in this region?

What is the charge of a proton? $q_p = +e = 1.6 \times 10^{-19} C$

What does the fact that the proton does not feel any force in a northerly direction tell you about the magnetic field?

The field is along the north-south direction. Why?

Because the particle does not feel any magnetic force when it is moving along the direction of the field.

Since the particle feels force toward West, the field should be pointing to …. North

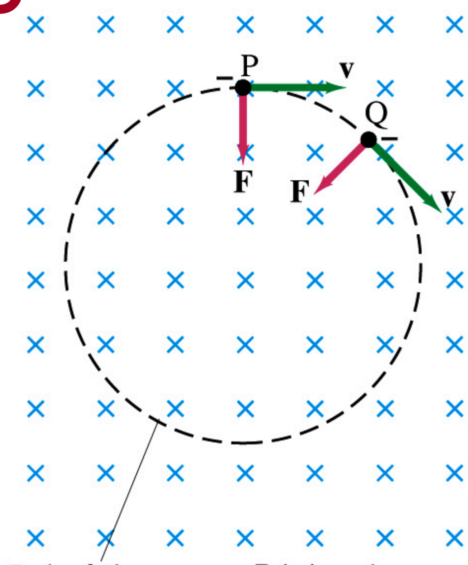
Using the formula for the magnitude of the field B, we obtain

$$B = \frac{F}{qv} = \frac{8.0 \times 10^{-14} N}{1.6 \times 10^{-19} C \cdot 5.0 \times 10^6 m/s} = 0.10T$$

We can use magnetic field to measure the momentum of a particle. How?

Charged Particle's Path in Magnetic Field

- What shape do you think is the path of a charged particle on a plane perpendicular to a uniform magnetic field?
  - Circle!! Why?
  - An electron moving to right at the point P in the figure will be pulled downward



  - At a later time, the force is still perpendicular to the velocity
  - Since the force is always perpendicular to the velocity, the magnitude of the velocity is constant
  - The direction of the force follows the right-hand-rule and is perpendicular to the direction of the magnetic field
  - Thus, the electron moves in a circular path with a centripetal force F.

Example 27 – 7

Electron's path in a uniform magnetic field. An electron travels at the speed of 2.0×10^7 m/s in a plane perpendicular to a 0.010-T magnetic field. What is the radius of the electron's path?

What is formula for the centripetal force? $F = ma = m\frac{v^2}{r}$

Since the magnetic field is perpendicular to the motion of the electron, the magnitude of the magnetic force is

$$F = evB$$

Since the magnetic force provides the centripetal force, we can establish an equation with the two forces

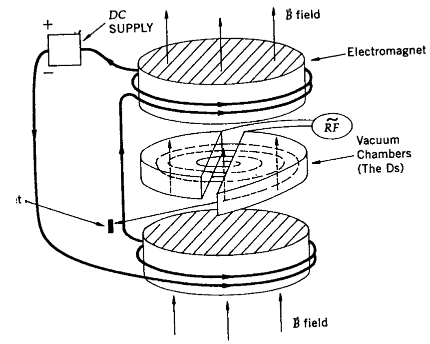
$$F = evB = m\frac{v^2}{r}$$

Solving for r

$$r = \frac{mv}{eB} = \frac{\left(9.1\times10^{-31}\,kg\right)\cdot\left(2.0\times10^{7}\,m/s\right)}{\left(1.6\times10^{-19}\,C\right)\cdot\left(0.010T\right)} = 1.1\times10^{-2}\,m$$

Cyclotron Frequency

- The time required for a particle of charge **q** moving w/ a constant speed **v** to make one circular revolution in a uniform magnetic field, $\vec{B} \perp \vec{v}$, is



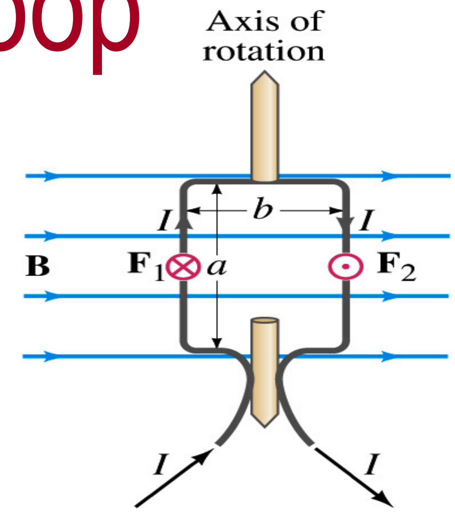
$$T = \frac{2\pi r}{v} = \frac{2\pi}{v}\frac{mv}{qB} = \frac{2\pi m}{qB}$$

- Since T is the period of rotation, the frequency of the rotation is

$$\boxed{f = \frac{1}{T} = \frac{qB}{2\pi m}}$$

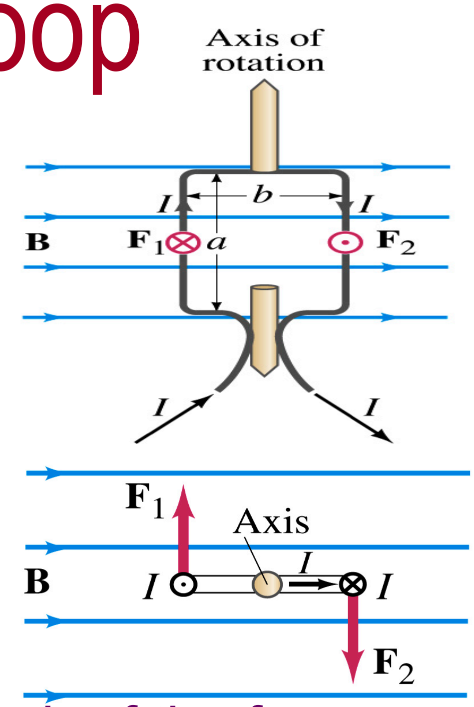
- This is the cyclotron frequency, the frequency of a particle with charge q in a cyclotron accelerator
  - While r depends on v, the frequency is independent of v and r.

Torque on a Current Loop



- What do you think will happen to a closed rectangular loop of wire with electric current as shown in the figure?
  - It will rotate! Why?
  - The magnetic field exerts a force on both vertical sections of wire.
  - Where is this principle used in?
    - Ammeters, motors, volt-meters, speedometers, etc
- The two forces on the different sections of the wire exerts net torque to the same direction about the rotational axis along the symmetry axis of the wire.
- What happens when the wire turns 90 degrees?
  - It will not turn unless the direction of the current changes

Torque on a Current Loop



- So what would be the magnitude of this torque?
  - What is the magnitude of the force on the section of the wire with length a?
    - $F_a = IaB$
    - The moment arm of the coil is $b/2$
  - So the total torque is the sum of the torques by each of the forces

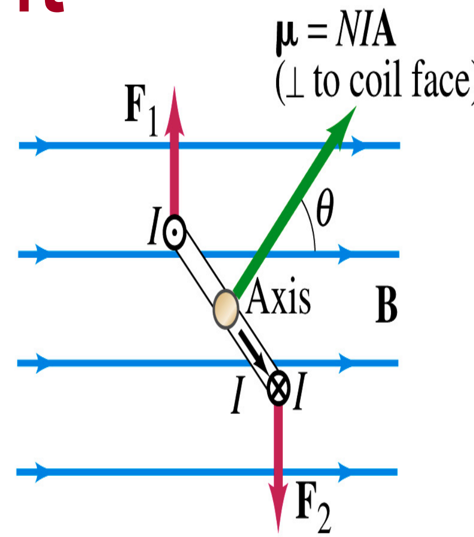
$$\tau = IaB\frac{b}{2} + IaB\frac{b}{2} = IabB = IAB$$

    - Where $A = ab$ is the area of the coil loop
  - What is the total net torque if the coil consists of N loops of wire?

$$\boxed{\tau = NIAB}$$

  - If the coil makes an angle θ w/ the field $\boxed{\tau = NIAB\sin\theta}$

Magnetic Dipole Moment



- The formula derived in the previous page for a rectangular coil is valid for any shape of the coil
- The quantity N$I\mathcal{A}$ is called the **magnetic dipole moment of the coil**
  - It is considered a vector $\boxed{\vec{\mu} = NI\overrightarrow{A}}$
    - Its direction is the same as that of the area vector **A** and is perpendicular to the plane of the coil consistent with the right-hand rule
      - Your thumb points to the direction of the magnetic moment when your finer cups around the loop in the direction of the current
  - Using the definition of magnetic moment, the torque can be written in vector form $\boxed{\vec{\tau} = NI\overrightarrow{A} \times \vec{B} = \vec{\mu} \times \vec{B}}$

Magnetic Dipole Potential Energy

- Where else did you see the same form of the torque?
  - Remember the torque due to electric field on an electric dipole? $\vec{\tau} = \vec{p} \times \vec{E}$
  - The potential energy of the electric dipole is
  - $U = -\vec{p} \cdot \vec{E}$
- How about the potential energy of a magnetic dipole?
  - The work done by the torque is
  - $U = \int \tau d\theta = \int NIAB \sin\theta \, d\theta = -\mu B \cos\theta + C$
  - If we chose U=0 at $\theta=\pi/2$, then C=0
  - Thus the potential energy is $\boxed{U = -\mu B \cos\theta = -\vec{\mu} \cdot \vec{B}}$
    - Very similar to the electric dipole

Example 27 – 12

Magnetic moment of a hydrogen atom. Determine the magnetic dipole moment of the electron orbiting the proton of a hydrogen atom, assuming (in the Bohr model) it is in its ground state with a circular orbit of radius 0.529×10^{-10}m.

What provides the centripetal force? The Coulomb force

So we can obtain the speed of the electron from

$$F=\frac{e^2}{4\pi\varepsilon_0 r^2}=\frac{m_e v^2}{r}$$

Solving for v

$$v=\sqrt{\frac{e^2}{4\pi\varepsilon_0 m_e r}}=\sqrt{\frac{\left(8.99\times10^9\,N\cdot m^2/C^2\right)\cdot\left(1.6\times10^{-19}\,C\right)^2}{\left(9.1\times10^{-31}\,kg\right)\cdot\left(0.529\times10^{-10}\,m\right)}}=2.19\times10^6\,m/s$$

Since the electric current is the charge that passes through the given point per unit time, we can obtain the current

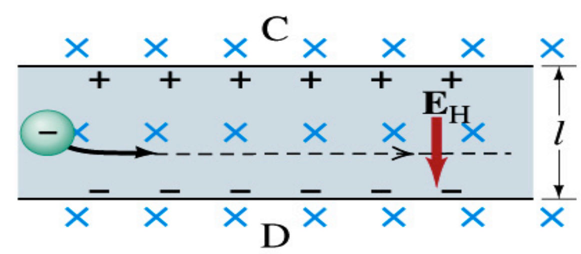
$$I=\frac{e}{T}=\frac{ev}{2\pi r}$$

Since the area of the orbit is $A=\pi r^2$, we obtain the hydrogen magnetic moment

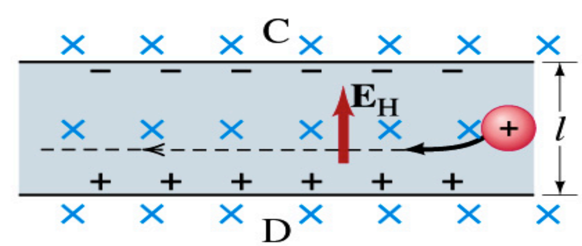
$$\mu=IA=\frac{ev}{2\pi r}\pi r^2=\frac{evr}{2}=\frac{er}{2}\sqrt{\frac{e^2}{4\pi\varepsilon_0 m_e r}}=\frac{e^2}{4}\sqrt{\frac{r}{\pi\varepsilon_0 m_e}}$$

The Hall Effect

- What do you think will happen to the electrons flowing through a conductor immersed in a magnetic field?
  - Magnetic force will push the electrons toward one side of the conductor. Then what happens?
    - $\vec{F}_B = -e\vec{v}_d \times \vec{B}$
  - A potential difference will be created due to continued accumulation of electrons on one side. Till when? Forever?
  - Nope. Till the electric force inside the conductor is equal and opposite to the magnetic force



(a)

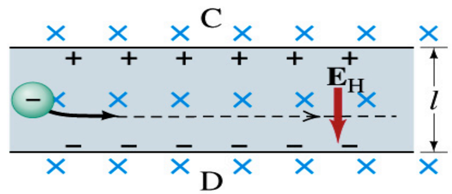


(b)

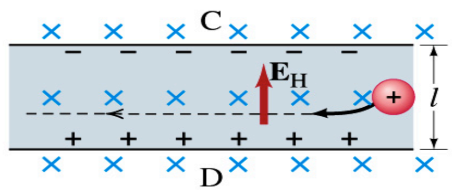
- This is called the **Hall Effect**
  - The potential difference produced is called
    - The Hall emf
  - The electric field due to the separation of the charge is called the Hall field, $\mathbf{E}_H$, and it points to the direction opposite to the magnetic force

The Hall Effect

- In the equilibrium, the force due to Hall field is balanced by the magnetic force ev_dB, so we obtain
- $eE_H = ev_d B$ and $E_H = v_d B$
- The Hall emf is then $\varepsilon_H = E_H l = v_d Bl$
  - Where l is the width of the conductor



(a)



(b)

- What do we use the Hall effect for?
  - The current of negative charge moving to right is equivalent to the positive charge moving to the left
  - The Hall effect can distinguish these since the direction of the Hall field or direction of the Hall emf is opposite
  - Since the magnitude of the Hall emf is proportional to the magnetic field strength ➔ can measure the B-field strength
    - Hall probe