PHYS 1441 – Section 001
Lecture #15

Wednesday, July 1, 2020

Dr. Jaehoon Yu

CH 27: Magnetism and Magnetic Field

– Torque on a Current Loop

– Magnetic Dipole Moment

– The Hall Effect

CH 28: Sources of Magnetic Field

– Sources of Magnetic Field

Today's homework is homework #8, due 11pm, Monday, July 6!!

Announcements

- Reading Assignments: CH27.6 – 8 and CH28.6 – 10
- Course feedback survey
  - Starts today and continues to July 8
  - Please fill in the survey ASAP!
- Special seminar on COVID–19 Monday, July 6
  - Dr. Linda Lee, a frontline doctor
  - The second hour of the class (11:30 – 12:30)
    - Extra credit for attending the seminar
  - Questions will earn additional extra credit points

Reminder: Special Project #5 – COVID-19

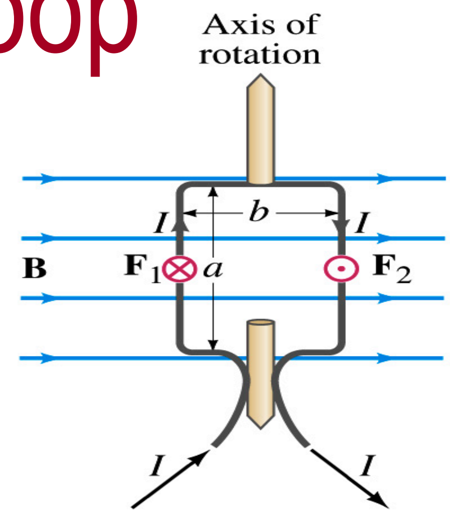
- Make comparisons of COVID-19 statistics between the U.S., South Korea, Italy and Texas from https://coronaboard.com on spreadsheet
  - Total 36 points: 1 point for each of the top 20 cells and 2 points for each of the 8 cells for testing
- What are the 3 fundamental requirements for opening up (2 points each, total 6 points)?
  - **Must be quantitative! (e.g. how many tests per capita per day for the present situation of pandemic)**
- Assess the readiness of the three fundamental requirements U.S. (2 point each, total 6 points; do NOT just take politician's words!). Must provide the independent scientific entity's reference you took the information from.
- Evaluate quantitatively the success/failure of the US responses to COVID-19 in 5 sentences. **Must provide quantitative reasons behind your conclusion!** (10 points)
- Assess quantitatively the effectiveness of wearing masks (4 points) and at least 4 reasons for it being effective (1 point each, 0.5 point extra after the first 4).
- Due: the beginning of the class Tuesday, July 7
  - Scan all pages of your special project into the pdf format, including the spreadsheet
  - Save all pages into **one file** with the filename SP5-YourLastName-YourFirstName.pdf
- Spreadsheet has been posted on the class web page. Download ASAP.

SP5 spreadsheet

PHYS1442-001, Summer 20, Special Project #5, COVID-19

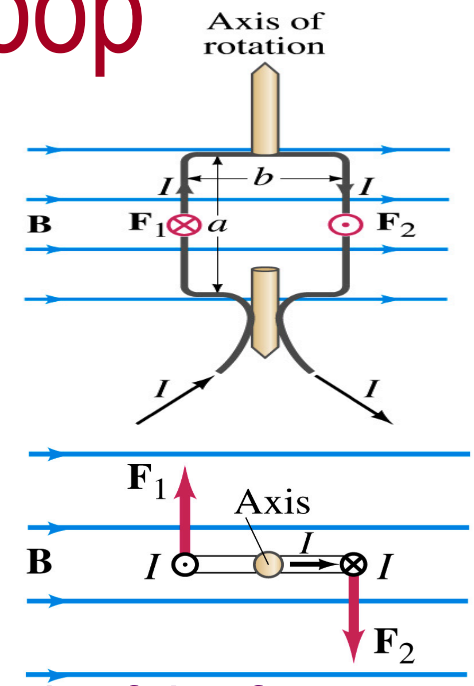
Name:			Date & time of your COVID-19 Data:		
Items		**U.S.A**	**South Korea**	**Italy**	**Texas**
Total Population					
COVID-19 Confirmed cases	Total				
	Cases per 1M people				
COVID-19 Deaths	Total				
	Death per 1M people				
COVID-19 Testing to date	Total				
	Per 1M people				

Torque on a Current Loop



- What do you think will happen to a closed rectangular loop of wire with an electric current as shown in the figure?
  - It will rotate! Why?
  - The magnetic field exerts 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 in 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

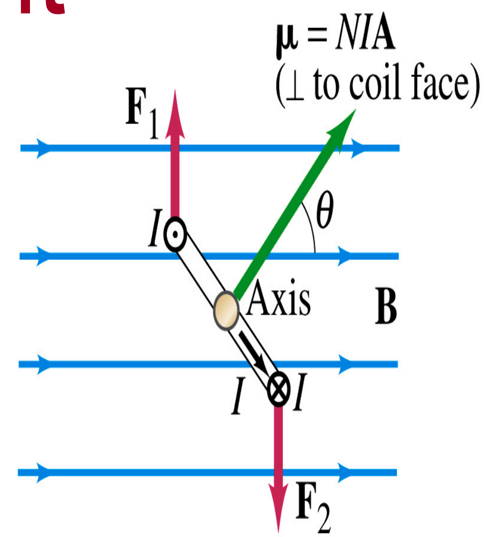
$$\tau = IaB\frac{b}{2} + IaB\frac{b}{2} = IabB = IAB$$

    - 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 NIA is called the **magnetic dipole moment of the coil**
  - It is a vector quantity $\boxed{\vec{\mu} = NI\vec{A}}$ (Poll 1)
    - 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 fingers cup around the loop in the same direction of the current
  - The tendency of an object to interact with an external magnetic field
  - Using the definition of magnetic moment, the torque can be rewritten in vector form

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

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 θ=π/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 $F = \dfrac{e^2}{4\pi\varepsilon_0 r^2} = \dfrac{m_e v^2}{r}$

Solving for v

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

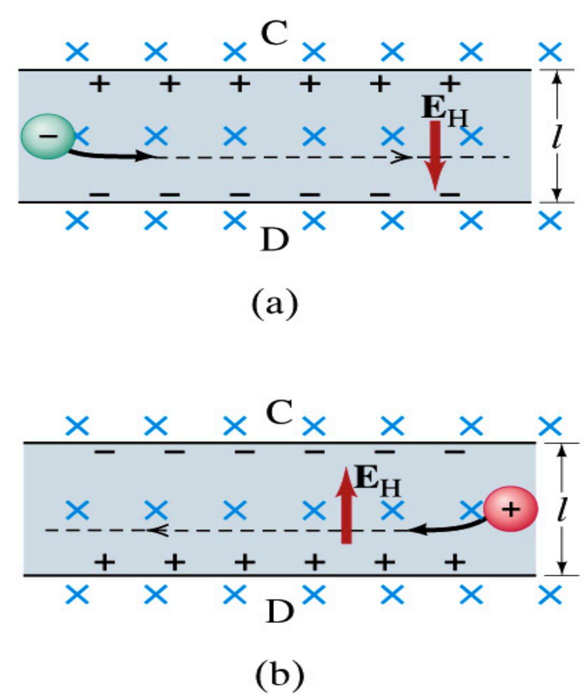
Since the electric current is the charge that passes through the given point per unit time, we can obtain the current $I = \dfrac{e}{T} = \dfrac{ev}{2\pi r}$

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

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

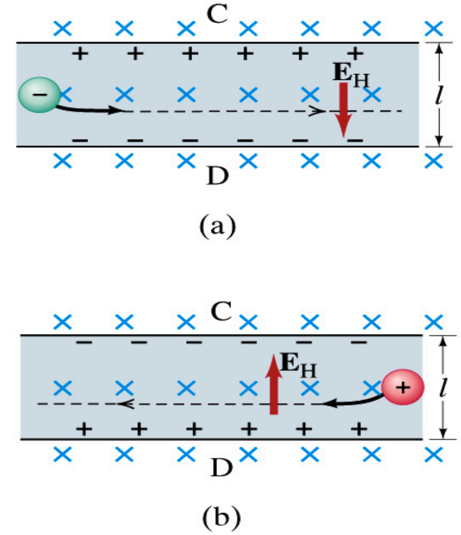
The Hall Effect

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



The Hall Effect

- In an 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
- 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