PHYS 1444 – Section 002 Lecture #19

Wednesday, Nov. 13, 2019
Dr. Jaehoon Yu

- Chapter 28:Sources of Magnetic Field
 - Magnetic Materials
 - B in magnetic materials
 - Hysteresis

- Chapter 29:EM Induction & Faraday's Law
 - Induced EMF and EM Induction
 - Faraday's Law of Induction
 - Lenz's Law
 - Generation of Electricity

Announcements

- Reading Assignments: 28.6 10, CH29.5 and 29.8
- Final comprehensive: in class 1:00 2:20pm Wed. Dec. 4
- Planetarium Extra Credit: bring to class Mon. Dec. 2
 - Be sure to tape one end of the ticket stub on a sheet of paper with your name on it
- The \$1B integrity problem!!!
- Remember the triple extra credit colloquium
 - At 4pm today Wednesday, Nov. 13
 - Professor Hitoshi Murayama of U.C. Berkeley

UNIVERSITY OF TEXAS ARLINGTON PHYSICS DEPARTMENT

Colloquium: When a Symmetry Breaks

What is common among a magnet, a flounder, a rack of laundry, your heart on the left of your body, and the Higgs boson? The concept of spontaneous symmetry breaking is ubiquitous among many natural phenomena. I'll describe the basic concept and its applications. In particular, the original concepts from Anderson,

Nambu, Goldstone, and Higgs do not quite work in many systems that include a magnet on your fridge. I generalize the concept so that it is applicable to all known natural phenomena around us. I'll also mention possible connections to dark matter and dark energy.

Hitoshi Murayama University of California, Berkeley

WEDNESDAY, NOVEMBER 13
4PM ROOM 100 SCIENCE HALL
REFRESHMENTS AT 3:30PM IN 108 SCIENCE HALL

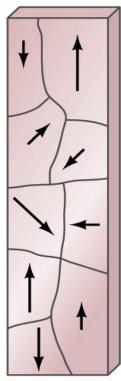


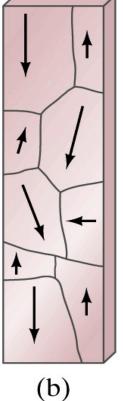
Magnetic Materials - Ferromagnetism

- Iron is a material that can turn into a strong magnet
 - This kind of material is called the <u>ferromagnetic</u> material
- In microscopic sense, ferromagnetic materials consist of many tiny regions called domains
 - Domains are like little magnets usually smaller than 1mm in length or width

 What do you think the alignment of domains are like when they are not magnetized?

- Randomly arranged
- What if they are magnetized?
 - The size of the domains aligned with the external magnetic field direction grows while those of the domains not aligned reduce
 - This gives magnetization to the material
- How do we demagnetize a bar magnet?
 - Hit the magnet hard or heat it over the Curie temperature





B in Magnetic Materials

- What is the magnetic field inside a solenoid?
- $B_0 = \mu_0 nI$
 - Magnetic field in a long solenoid is directly proportional to the current.
 - This is valid only if air is inside the coil
- What do you think will happen to B if we have something other than the air inside the solenoid?
 - B will be increased dramatically, when the current flows
 - Especially if a ferromagnetic material such as an iron is put inside, the field could increase by several orders of magnitude
- Why?
 - Since the domains in the iron aligns permanently by the external field.
 - The resulting magnetic field is the sum of that due to current and due to the iron

B in Magnetic Materials

 It is sometimes convenient to write the total field as the sum of two terms

- $\vec{B} = \vec{B}_0 + \vec{B}_M$
 - B₀ is the field due only to the current in the wire, namely the external field
 - The field that would be present without a ferromagnetic material
 - B_M is the additional field due to the ferromagnetic material itself;
 often B_M>>B₀
- The total field in this case can be written by replacing μ_0 with another proportionality constant μ , the magnetic permeability of the material $B = \mu nI$
 - $-\mu$ is a property of the magnetic material
 - μ is not a constant but varies with the external field

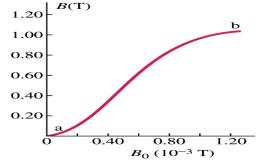
Hysteresis Iron Core Toroid

- What is a Toroid?
 - A solenoid bent into a shape
- Toroid can be used for magnetic field measurement
 - Why?
 - Since it does not leak magnetic field outside of itself, it fully contains all the magnetic field created within it.
- Consider an un-magnetized iron core Toroid, without any current flowing in the wire
 - What do you think will happen if the current slowly increases?
 - B₀ increases linearly with the current.
 - And B increases also but follows the curved line shown in the graph
 - As B₀ increases, the domains become more aligned until nearly all

are aligned (point b on the graph)

- The iron is said to be approaching saturation
- Point b is typically at 70% of the max

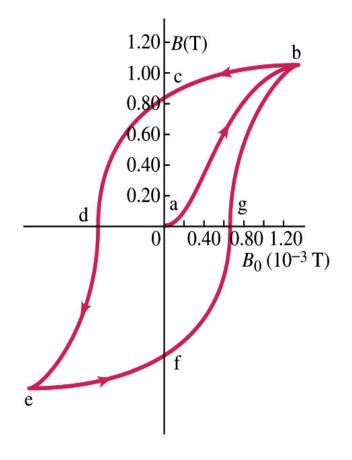
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Hysteresis

- What do you think will happen to B if the external field B₀ is reduced to 0 by decreasing the current in the coil?
 - OUrse it goes to Oll
 - Wrong! Wrong! They do not go to 0. Why not?
 - The domains do not completely return to random alignment state
- Now if the current direction is reversed, the external magnetic field direction is reversed, causing the total field B passed 0, and the direction reverses to the opposite side
 - If the current is reversed again, the total field B will increase but never goes through the origin
- This kind of curve whose path does not retrace themselves and does not go through the origin is called the **Hysteresis**.





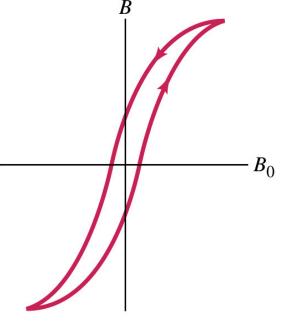
Magnetically Soft Material In a hysteresis cycle, much energy is transformed to

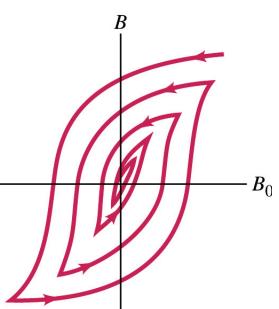
thermal energy. Why?

- Due to the microscopic friction between domains as they change directions to align with the external field
- The energy dissipated in the hysteresis cycle is proportional to the area of the hysteresis loop
- Ferromagnetic material with a large hysteresis area is called magnetically hard while the small ones are called soft
 - Which one do you think are preferred in electromagnets or transformers?
 - Soft. Why?
 - Since the energy loss is small and much easier to switch off the field
- Then how do we demagnetize a ferromagnetic material?
 - Keep repeating the Hysteresis loop, reducing the range of B₀.

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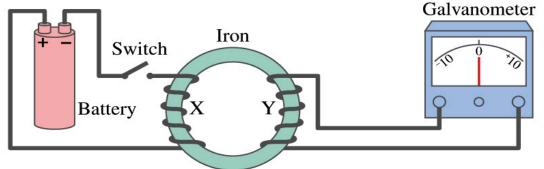
Induced EMF

- It has been discovered by Oersted and company in early 19th century that
 - Magnetic field can be produced by the electric current
 - Magnetic field can exert force on the electric charge
- So if you were scientists at that time, what would you wonder?
 - Yes, you are absolutely right! You would wonder if the magnetic field can create the electric current.
 - An American scientist Joseph Henry and an English scientist
 Michael Faraday independently found that it was possible
 - Though, Faraday was given the credit since he published his work before Henry did
 - He also did a lot of detailed studies on magnetic induction

Electromagnetic Induction

Faraday used an apparatus below to show that magnetic

field can induce current

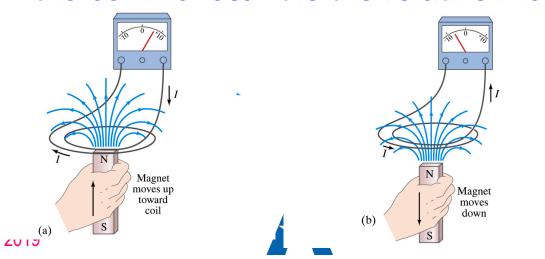


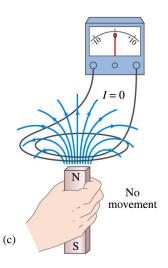
- Despite his hope he did not see steady current induced on the other side when the switch is thrown
- But he did see that the needle on the Galvanometer turns strongly when the switch is initially thrown and is opened
 - When the magnetic field through coil Y changes, a current flows as if there were a source of emf
- Thus he concluded that an induced emf is produced by a changing magnetic field

 Electromagnetic Induction

Electromagnetic Induction

- Further studies on electromagnetic induction taught
 - If a magnet is moved quickly into a coil of wire, a current is induced in the wire.
 - If a magnet is removed from the coil, a current is induced in the wire in the opposite direction
 - By the same token, the current can also be induced if the magnet stays put but the coil moves toward or away from the magnet
 - Current is also induced if the coil rotates.
- In other words, it does not matter whether the magnet or the coil moves. It is the relative motion that counts.





Magnetic Flux

- So what do you think is the induced emf proportional to?
 - The rate of changes of the magnetic field?
 - the higher the changes of the field the higher the induction?
 - Not really, it rather depends on the rate of change of the **magnetic** flux, Φ_B .
 - Magnetic flux is defined as (just like the electric flux)

$$\Phi_B = B_{\perp} A = BA \cos \theta = \vec{B} \cdot \vec{A}$$

- θ is the angle between **B** and the area vector **A** whose direction is perpendicular to the face of the loop based on the right-hand rule
- What kind of quantity is the magnetic flux?
 - Scalar. Unit?

2019

• $T \cdot m^2$ or weber

$$1Wb = 1T \cdot m^2$$

If the area of the loop is not simple or B is not uniform, the

Faraday's Law of Induction

- In terms of magnetic flux, we can formulate Faraday's findings
 - The emf induced in a circuit is equal to the rate of change of magnetic flux through the circuit

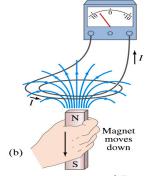
$$\varepsilon = -\frac{d\Phi_B}{dt}$$

Faraday's Law of Induction

- If the circuit contains N closely wrapped loops, the total induced emf is the sum of the emf induced in each loop $d\Phi_{R}$
 - Why negative?
 - Has got a lot to do with the direction of induced emf...

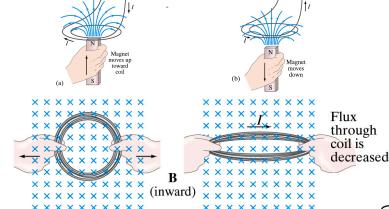
Lenz's Law

- It is experimentally found that
 - An induced emf gives rise to a current whose magnetic field opposes the original change in flux → This is known as Lenz's Law
 - In other words, an induced emf is always in the direction that opposes the original change in the flux that caused it.
 - We can use Lenz's law to explain the following cases in the figures
 - When the magnet is moving into the coil
 - Since the external flux increases, the field inside the coil takes the opposite direction to minimize the change and causes the current to flow clockwise
 - When the magnet is moving out
 - Since the external flux decreases, the field inside the coil takes the opposite direction to compensate the loss, causing the current to flow counter-clockwise
- Which law is Lenz's law result of?
 - Energy conservation. Why?



Induction of EMF

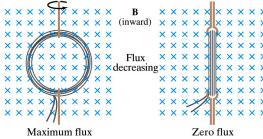
- How can we induce emf?
- Let's look at the formula for the magnetic flux
- $\Phi_B = \int \vec{B} \cdot d\vec{A} = \int B \cos \theta dA$
- What do you see? What are the things that can change with time to result in change of magnetic flux?
 - Magnetic field
 - The area of the loop



The angle θ between the field and the area vector

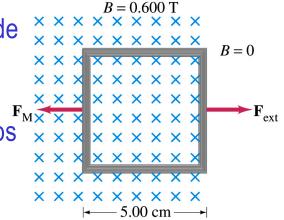
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Example 29 – 5

Pulling a coil from a magnetic field. A square coil of wire with side 5.00cm contains 100 loops and is positioned perpendicular to a uniform 0.600-T magnetic field. It is quickly and uniformly pulled from the field (moving perpendicular to B) to a region where B drops abruptly to zero. At t=0, the right edge of the coil is at the edge of the field. It takes 0.100s for the whole coil to reach the field-free



region. Find (a) the rate of change in flux through the coil, (b) the emf and the current induced, and (c) how much energy is dissipated in the coil if its resistance is 100Ω . (d) what was the average force required?

What should be computed first? The initial flux at t=0.

The flux at t=0 is
$$\Phi_B = \vec{B} \cdot \vec{A} = BA = 0.600T \cdot \left(5 \times 10^{-2} \, m\right)^2 = 1.50 \times 10^{-3} \, Wb$$

The change of flux is $\Delta \Phi_B = 0 - 1.50 \times 10^{-3} \, Wb = -1.50 \times 10^{-3} \, Wb$

Thus the rate of change of the flux is

$$\frac{\Delta\Phi_B}{\Delta t} = \frac{-1.50 \times 10^{-3} Wb}{0.100s} = -1.50 \times 10^{-2} Wb/s$$



Example 29 – 5, cnt'd

Thus the total emf induced in this period is

$$\varepsilon = -N \frac{d\Phi_B}{dt} = -100 \cdot (-1.50 \times 10^{-2} Wb/s) = 1.5V$$

The induced current in this period is

$$I = \frac{\varepsilon}{R} = \frac{1.5V}{100\Omega} = 1.50 \times 10^{-2} A = 15.0 \text{mA}$$

Which direction would the induced current flow? Counter-clockwise

The total energy dissipated is

$$E = Pt = I^{2}Rt = (1.50 \times 10^{-2} A)^{2} \cdot 100\Omega \cdot 0.100s = 2.25 \times 10^{-3} J$$

Force for each coil is $\overrightarrow{F} = I \overrightarrow{l} \times \overrightarrow{B}$ Force for N coil is $\overrightarrow{F} = N I \overrightarrow{l} \times \overrightarrow{B}$

$$|F| = NIIB = 100 \cdot (1.50 \times 10^{-2} A) \cdot (4 \times 5 \times 10^{-2}) \cdot 0.600T = 0.045N$$