PHYS 1444 – Section 002
Lecture #20

Wednesday, Apr. 22, 2020
Dr. Jaehoon Yu

CH 29:EM Induction & Faraday's Law

- Induced EMF and EM Induction
- Faraday's Law of Induction
- Lenz's Law
- Generation of Electricity
- Transformer
- Electric Field Due to Changing Magnetic Flux

Announcements

- Reading Assignments: 28.6 – 10, CH29.5 and 29.8
- Final comprehensive exam: 1:00 – 2:20pm Wed. May 6
  - Covers CH21.1 through what we finish Monday, May 4+ math refresher
- Planetarium Extra Credit: Due 1pm, May 6
  - Tape one end of the ticket stub on a sheet of paper with your name on
  - Send me the photos of the sheet with the front of the ticket stubs and of the sheet with them flipped over, showing the back of them
  - Email subject line must be: SP-Planetarium
- Special seminar in class coming Monday
  - Dr. Linda Lee on COVID-19 ➔ 30min talk + 15min Q&A
  - Extra credit will be given for participating in this seminar
  - Additional extra credit for asking questions relevant to her talk

Reminder: Special Project #5 – COVID-19

- Make comparisons of COVID-19 statistics between the U.S., South Korea and Germany from https://coronaboard.com on spreadsheet
  - Total 27 points: 1 point for each of the top 15 cells and 2 points for each of the 6 cells for testing
- Make a timeline from Jan. 15, 2020 through Apr. 15 for The World Health Organization (WHO), U.S.A. and South Korea in their actions in response to COVID-19: One in Jan., one in Apr. and two each in Feb. and Mar.
  - 2 points each, totaling 30 points
- What are the 3 most fundamental requirements for opening back up (2 points each, total 6 points)? Identify the two of these U.S. is ready (1 point each, total 2 points; do NOT just take politician's words!) for opening.
  - **Must be quantitative!**
- Due: 1pm Monday, May 4
  - Scan all pages of your special project into the pdf format
  - Save all pages into one file with the filename SP5-YourLastName-YourFirstName.pdf
- Spreadsheet has been posted on the class web page. Download ASAP.

PHYS1442-002, Spring 20, Special Project #5, COVID-19

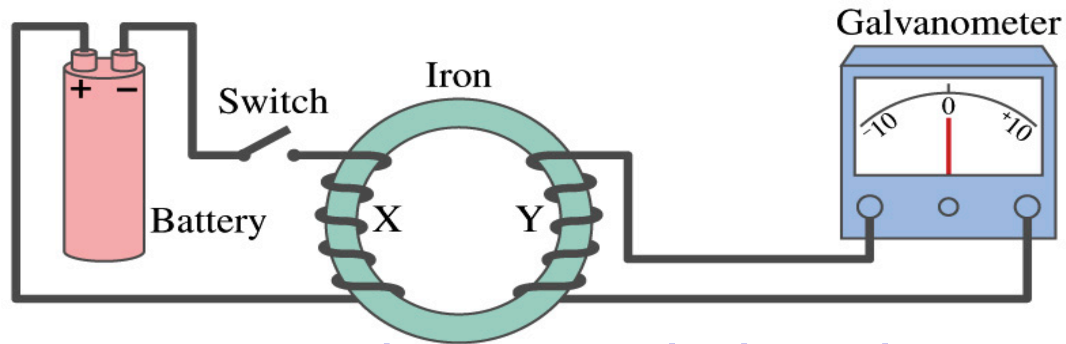
	Name:		Date of COVID-19 Data:	
Items		**U.S.A**	**South Korea**	**Germany**
Total Population				
COVID-19 Confirmed cases	Number			
	Cases per 1M people			
COVID-19 Deaths	Number			
	Death per 1M people			
COVID-19 Testing to date	Number			
	Per 1M people			

Induced EMF

- It has been discovered by Oersted and company in early 19^{th} century that
  - Magnetic field can be produced by the electric current
  - Magnetic field can exert force on the electric charge
- So if you were a scientist 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

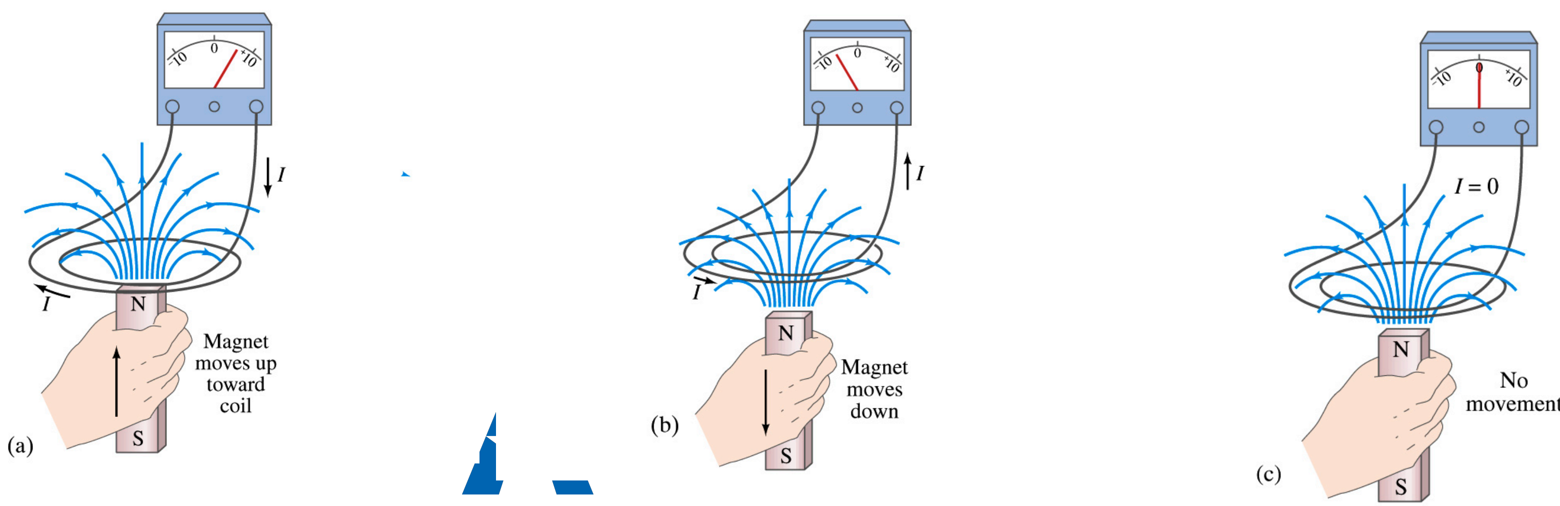
- Faraday used an apparatus below to show that magnetic field can induce current



- 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**

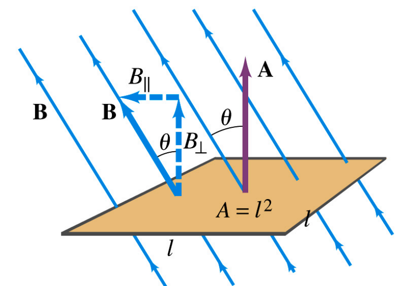
Electromagnetic Induction

- 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)
  - $$\boxed{\Phi_B = B_\perp A = BA\cos\theta = \vec{B}\cdot\vec{A}}$$
    - 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?
    - $T \cdot m^2$ or weber $\boxed{1Wb = 1T \cdot m^2}$
- If the area of the loop is not simple or B is not uniform, the magnetic flux can be written as $$\boxed{\Phi_B = \int \vec{B}\cdot d\vec{A}}$$

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

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

Faraday's Law of Induction

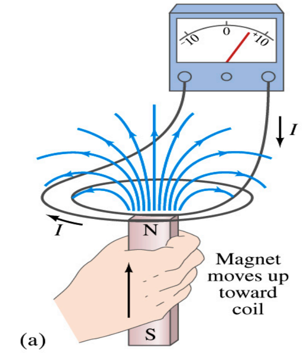
- If the circuit contains N closely wrapped loops, the total induced emf is the sum of the emf induced in each loop

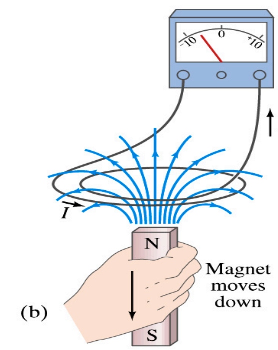
$$\boxed{\varepsilon = -N\frac{d\Phi_B}{dt}}$$

  - Why negative?
    - Has got a lot to do with the direction of induced emf…

Lenz's Law

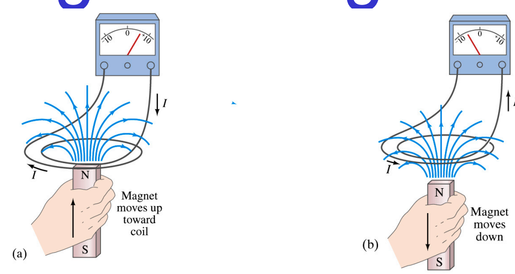
- It is experimentally found that
  - An induced emf gives rise to a current whose magnetic field opposes the original change in flux ➔ This is known as **Lenz's Law**
  - In other words, an induced emf is always in the direction that opposes the original change in the flux that caused it.
  - We can 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



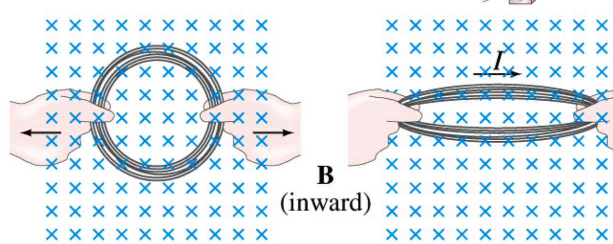


Induction of EMF

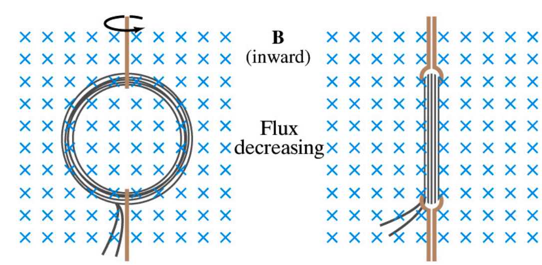
- How can we induce emf?
- Let's look at the formula for the magnetic flux
- $$\Phi_B = \int \vec{B} \cdot d\vec{A} = \int B \cos\theta \, dA$$
- What do you see? What are the things that can change with time to result in change of magnetic flux?
  - Magnetic field



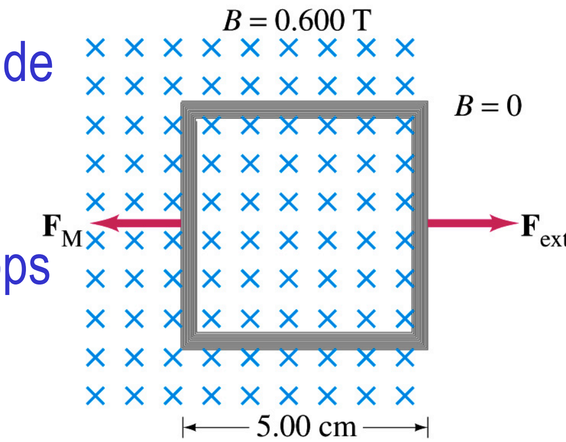
  - The area of the loop



  - The angle θ between the field and the area vector



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 $\Phi_B = \vec{B}\cdot\vec{A} = BA = 0.600T\cdot\left(5\times10^{-2}m\right)^2 = 1.50\times10^{-3}Wb$

The change of flux is $\Delta\Phi_B = 0 - 1.50\times10^{-3}Wb = -1.50\times10^{-3}Wb$

Thus the rate of change of the flux is

$$\frac{\Delta\Phi_B}{\Delta t} = \frac{-1.50\times10^{-3}Wb}{0.100s} = -1.50\times10^{-2}\,Wb/s$$

Example 29 – 5, cnt'd

Thus the total emf induced in this period is

$$\varepsilon = -N\frac{d\Phi_B}{dt} = -100\cdot\left(-1.50\times10^{-2}\,Wb/s\right) = 1.5V$$

The induced current in this period is

$$I = \frac{\varepsilon}{R} = \frac{1.5V}{100\Omega} = 1.50\times10^{-2}\,A = 15.0mA$$

Which direction would the induced current flow? Clockwise

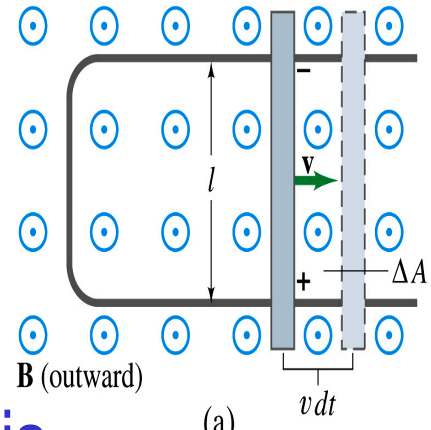
The total energy dissipated is

$$E = Pt = I^2Rt = \left(1.50\times10^{-2}\,A\right)^2\cdot100\Omega\cdot0.100s = 2.25\times10^{-3}\,J$$

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

$$\left|F\right| = NIlB = 100\cdot\left(1.50\times10^{-2}\,A\right)\cdot\left(4\times5\times10^{-2}\right)\cdot0.600T = 0.045N$$

EMF Induced on a Moving Conductor



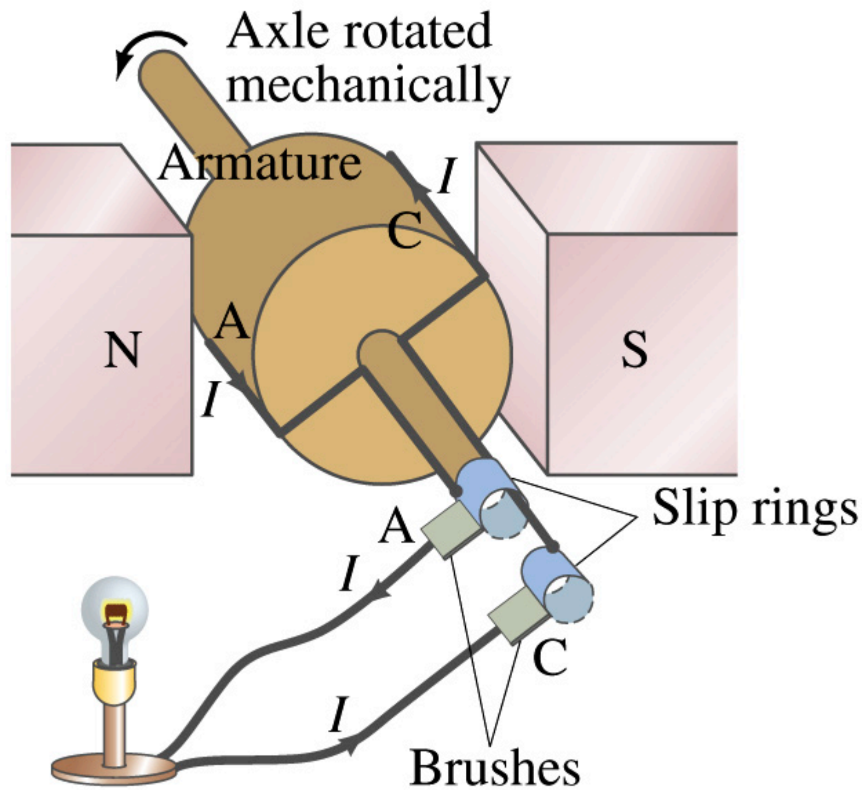
- Another way of inducing emf is using a U-shaped conductor with a movable rod resting on it.
- As the rod moves at speed v, it travels v**dt** in time **dt**, changing the area of the loop by **dA=**ℓv**dt**.
- Using Faraday's law, the induced emf for this loop is

$$|\varepsilon| = \frac{d\Phi_B}{dt} = \frac{BdA}{dt} = \frac{Blvdt}{dt} = Blv$$

  - This equation is valid as long as B, ℓ and v are perpendicular to each other. What do we do if not?
    - Use the scalar product of the vector quantities
- An emf induced on a conductor moving in a magnetic field is called the **motional emf**

Electric Generators

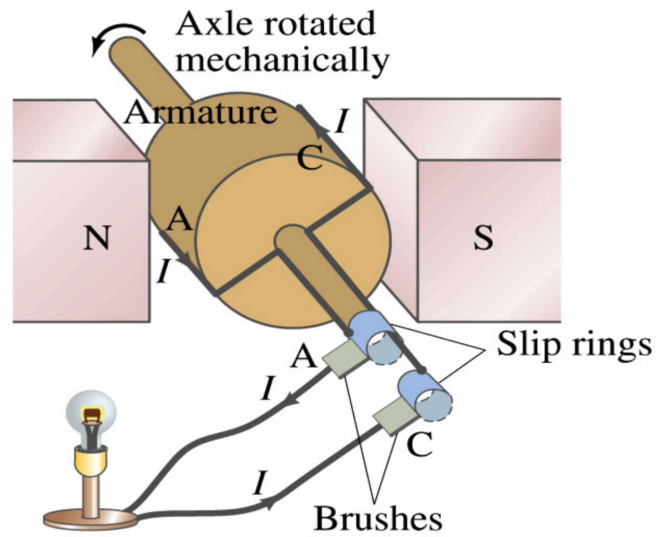
- What does a generator do?
  - Transforms mechanical energy into electrical energy
  - What does this look like?
    - An inverse of an electric motor which transforms electrical energy to mechanical energy
  - An electric generator is also called a dynamo



- Whose law does the generator based on?
  - Faraday's law of induction

How does an Electric Generator work?

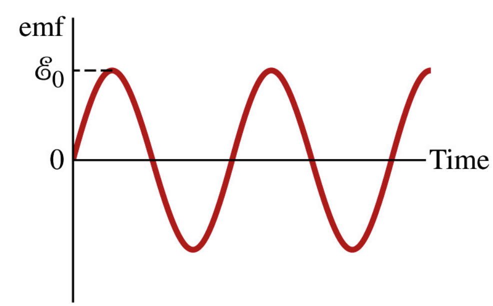
- An electric generator consists of
  - Many coils of wires wound on an armature that can rotate by mechanical means in a magnetic field (recall Faraday's law!)
- An emf is induced in the rotating coil
- Electric current is the output of a generator



- Which direction does the output current flow when the armature rotates counterclockwise?
  - The conventional current flows outward on wire A toward the brush
  - After half the revolution the wire A will be where the wire C is and the current flow on A is reversed
- Thus the current produced is alternating its direction

How does an Electric Generator work?

- Let's assume the loop is rotating in a uniform B field w/ a constant angular velocity ω. The induced emf is
- $$\varepsilon = -\frac{d\Phi_B}{dt} = -\frac{d}{dt}\int \vec{B}\cdot d\vec{A} = -\frac{d}{dt}\left[BA\cos\theta\right]$$
- What is the variable that changes above?
  - The angle θ. What is $d\theta/dt$?
    - The angular speed ω.
  - So $\theta=\theta_0+\omega t$
  - If we choose $\theta_0=0$, we obtain
  - $$\varepsilon = -BA\frac{d}{dt}\left[\cos\varpi t\right] = BA\varpi\sin\varpi t$$
  - If the coil contains N loops: $$\varepsilon = -N\frac{d\Phi_B}{dt} = NBA\varpi\sin\varpi t = \varepsilon_0\sin\varpi t$$
  - What is the shape of the output?
    - Sinusoidal w/ an amplitude $\varepsilon_0=NBA\omega$



- USA frequency is 60Hz. Europe is at 50Hz
  - Most the U.S. power is generated at steam plants

Example 29 – 9

An AC generator. The armature of a 60-Hz AC generator rotates in a 0.15-T magnetic field. If the area of the coil is $2.0 \times 10^{-2} m^2$, how many loops must the coil contain if the peak output is to be ε_0=170V?

The maximum emf of a generator is $\varepsilon_0 = NBA\varpi$

Solving for N $N = \frac{\varepsilon_0}{BA\varpi}$

Since $\varpi = 2\pi f$ We obtain

$$N = \frac{\varepsilon_0}{2\pi BAf} = \frac{170V}{2\pi \cdot (0.15T) \cdot (2.0 \times 10^{-2} m^2) \cdot (60 s^{-1})} = 150 turns$$

Name: Solution Keys

Circle your choice of answer clearly. Be sure to write down the proper units and vector notations when necessary. Each problem is 10 points. The maximum possible score is 70 points, You MUST show the detailed work to obtain any credit for free response problems. <u>You will get 0 points if you only write down an answer even if the answer is correct!</u>

1. If the potential at a distance d from a dipole is V_O for distances large compared to the length of the dipole, then what is the potential at twice the distance from the dipole?
   a. V_O b. $V_O/2$
   c. $V_O/4$ d. $V_O/8$

2.If the potential is given by $V = xy^2 - 3z^{-2}/y + x^2 z$, what is the y component of the electric field?

$$\vec{E} = -\nabla V = -\left(\frac{\partial}{\partial x}\vec{i} + \frac{\partial}{\partial y}\vec{j} + \frac{\partial}{\partial z}\vec{k}\right)V \Rightarrow E_y = -\frac{\partial}{\partial y}\left(xy^2 - 3z^{-2}/y + x^2 z\right) = -2xy - 3z^{-2}/y^2\left(V/m\right)$$

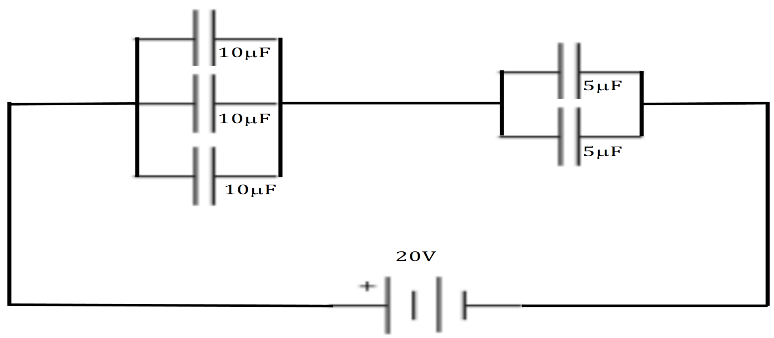
3. If a dielectric of dielectric constant 4 is inserted between the plates of a fully charged parallel plate capacitor filling the gap without a connected battery, what happens to the electric field in the gap?
   a. unaffected b. increases by a factor of 4
   c. decreases by a factor of 4 d. increases by a factor of 16

4. What is the energy a particle with the electric charge +2e would gain if it went across a potential difference of 3kV? Compute in unit of J and then convert it to eV.

$$U = qV = 2e\cdot V = 2e\cdot 3\times10^3 = 2\times1.6\times10^{-19}\cdot3\times10^3\cdot = 9.6\times10^{-16}\left(J\right) = 9.6\times10^{-16}/1.6\times10^{-19} = 6\times10^3\left(eV\right)$$

5 – 7] A circuit consists of a parallel combination of three 10μF capacitors, another parallel combination of two 5μF capacitors, and a 20 V battery connected in series.

5. Draw the circuit diagram. Make sure the values of all devices are clearly marked on each device.



6. Compute the equivalent capacitance of this circuit.

$$C_1^{eq} = 3\times10 = 30\left(\mu F\right); C_2^{eq} = 2\times5 = 10\left(\mu F\right); \frac{1}{C^{eq}} = \frac{1}{C_1^{eq}} + \frac{1}{C_2^{eq}} = \frac{1}{30} + \frac{1}{10} = \frac{4}{30} \Rightarrow C^{eq} = \frac{30}{4} = 7.5\left(\mu F\right)$$

7. What is the total energy stored in all five capacitors?

$$U = \frac{1}{2}CV^2 = \frac{1}{2}C^{eq}V^2 = \frac{1}{2}\cdot7.5\times10^{-6}\cdot(20)^2 = \frac{1}{2}\cdot7.5\times10^{-6}\cdot4\times10^2 = 1.5\times10^{-3}\left(J\right)$$

This print-out should have 18 questions. Multiple-choice questions may continue on the next column or page – find all choices before answering.

001 5.0 points

What will cause the electric resistance of certain materials known as superconductors to suddenly decrease to essentially zero?

1. Stretching the material to a wire of sufficiently small diameter

2. Increasing the voltage applied to the material beyond a certain threshold votage

3. Placing the material in a sufficiently large magnetic field

4. Cooling the material below a certain threshold temperature **correct**

5. Increasing the pressure applied to the material beyond a certain threshold pressure

Explanation:

Cooling the material below a certain threshold temperature (known as the critical temperature) will make it superconducting.

Stretching the material to a wire of smaller diameter will only increase its electric resistance.

Applying a sufficiently large magnetic field will destroy the superconductivity of the material.

002 6.0 points

The *rms* potential difference across high-voltage transmission lines in Great Britain is 2.2×10^5 V.

What is the maximum potential difference?

Correct answer: 3.11127×10^5 V.

Explanation:

Let : $V_{rms} = 2.2 \times 10^5$ V .

The *rms* voltage is

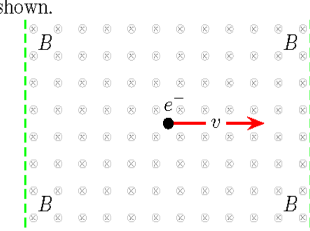
$$\Delta V_{rms} = \frac{\sqrt{2}}{2}\,\Delta V_{max} = \frac{\Delta V_{max}}{\sqrt{2}}\,,$$

so the maximum potential difference is

$$\begin{aligned}\Delta V_{max} &= \Delta V_{rms}\,\sqrt{2}\\ &= \sqrt{2}\,(2.2\times10^5\text{ V})\\ &= \boxed{3.11127\times10^5\text{ V}}\,.\end{aligned}$$

003 5.0 points

An electron is in a uniform magnetic field **B** that is directed into the plane of the page, as shown.



When the electron is moving in the plane of the page in the direction indicated by the arrow, the force on the electron is directed

1. into the page.

2. toward the top of the page.

3. toward the right

4. toward the left

5. out of the page.

6. toward the bottom of the page. **correct**

Explanation:

The force on the electron is

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

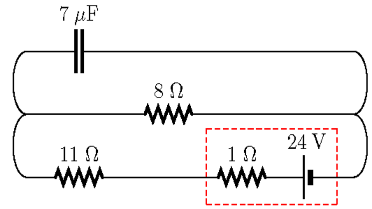
The direction of the force is thus

$$\widehat{F} = -\widehat{v}\times\widehat{B}\,,$$

pointing $\boxed{\text{toward the bottom of the page}}$, using right hand rule for $\widehat{v}\times\widehat{B}$, and reversing the direction due to the negative charge on the electron.

004 6.0 points

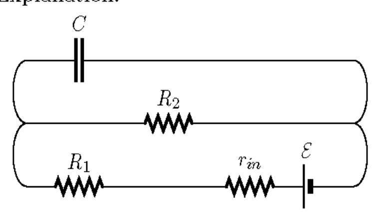
In the figure below, the 24 V battery has an internal resistance of 1.0 Ω, as shown. The circuit has been connected for a long time.



Find the charge on the 7 μF capacitor if $R_1 = 11\ \Omega$ and $R_2 = 8\ \Omega$.

Correct answer: 67.2 μC.

Explanation:



$$\begin{aligned}\text{Let :}\quad R_1 &= 11\ \Omega\,,\\ R_2 &= 8\ \Omega\,,\\ r_{in} &= 1\ \Omega\,,\\ V &= 24\text{ V}\,,\quad\text{and}\\ C &= 7\ \mu\text{F}\,.\end{aligned}$$

The equivalent resistance of the three resistors in series is

$$\begin{aligned}R &= R_1 + R_2 + r_{in}\\ &= (11\ \Omega) + (8\ \Omega) + (1\ \Omega)\\ &= 20\ \Omega\,.\end{aligned}$$

so the current in the circuit is $I = \dfrac{V}{R}$, and the voltage across R_2 is

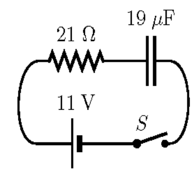
$$\begin{aligned}V_2 &= I\,R_2\\ &= \frac{R_2}{R}\,V\\ &= \frac{(8\ \Omega)}{(20\ \Omega)}\,(24\text{ V})\\ &= 9.6\text{ V}\,.\end{aligned}$$

Then the charge on the capacitor is

$$\begin{aligned}Q &= C\,V\\ &= (7\ \mu\text{F})\,(9.6\text{ V})\\ &= \boxed{67.2\ \mu\text{C}}\,.\end{aligned}$$

005 (part 1 of 2) 6.0 points

Consider the circuit

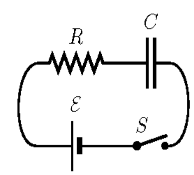


How long after the switch is closed does the voltage across the resistor drop to $V_f = 5.2$ V?

Correct answer: 0.000298945 s.

Explanation:

$$\begin{aligned}\text{Let :}\quad R &= 21\ \Omega\,,\\ V_f &= 5.2\text{ V}\,,\\ C &= 19\ \mu\text{F} = 1.9\times10^{-5}\text{ F}\,,\quad\text{and}\\ \mathcal{E} &= 11\text{ V}\,.\end{aligned}$$



Since the current in an RC circuit is

$$I = \frac{\mathcal{E}}{R} e^{-t/(RC)}$$

and the voltage across the resistor is $V = I\,R$,

$$\begin{aligned}\frac{V_f}{R} &= \frac{\mathcal{E}}{R}\, e^{-t/(RC)} \\ t &= -R\,C \log\left(\frac{V_f}{\mathcal{E}}\right) \\ &= -(21\ \Omega)(1.9\times10^{-5}\ \text{F})\log\left(\frac{5.2\ \text{V}}{11\ \text{V}}\right) \\ &= \boxed{0.000298945\ \text{s}}\,.\end{aligned}$$

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006 (part 2 of 2) 6.0 points

What is the charge on the capacitor at this time?

Correct answer: 0.0001102 C.

Explanation:

At this time the charge on the capacitor is given by $Q = C\,V$. Since we know the capacitance, and we know that the voltage drop across the capacitor must be the total voltage, $\mathcal{E}$, minus the voltage V_f across the resistor, we have

$$\begin{aligned}Q &= C\,(\mathcal{E} - V_f) \\ &= (1.9\times10^{-5}\ \text{F})(11\ \text{V} - 5.2\ \text{V}) \\ &= \boxed{0.0001102\ \text{C}}\,.\end{aligned}$$

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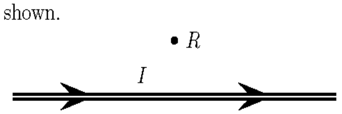
007 5.0 points

Consider a straight wire carrying current I, as shown.



What is the direction of the magnetic field at point R caused by the current I in the wire?

1. To the left

2. Toward the wire

3. Out of the page **correct**

4. Into the page

5. To the right

6. Away from the wire

Explanation:

Use the right-hand rule to determine the direction of the magnetic field surrounding a long, straight wire carring a current (thumb). We find that the magnetic field points Out of the page at point R (fingers).

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008 6.0 points

A long straight wire lies on a horizontal table and carries a current of 0.56 μA. A proton with charge $q_p = 1.60218\times10^{-19}$ C and mass $m_p = 1.6726\times10^{-27}$ kg moves parallel to the wire (opposite the current) with a constant velocity of 36200 m/s at a distance d above the wire.

The acceleration of gravity is 9.8 m/s^2.

Determine this distance of d. You may ignore the magnetic field due to the Earth.

Correct answer: 3.96295 cm.

Explanation:

$$\begin{aligned}\text{Let :}\quad q_p &= 1.60218\times10^{-19}\ \text{C}\,, \\ v &= 36200\ \text{m/s}\,, \\ I &= 0.56\ \mu\text{A}\,, \\ m_p &= 1.6726\times10^{-27}\ \text{kg}\,,\quad \text{and} \\ \mu_0 &= 1.25664\times10^{-6}\ \text{T}\cdot\text{m/A}\,.\end{aligned}$$

Let the current I flow to the right; then it creates a magnetic field

$$B = \frac{\mu_0\, I}{2\,\pi\, d}$$

at the proton's location

This magnetic field induces an upward force on the proton which balances the weight, so we have

$$\begin{aligned}m_p\, g &= q_p\, v\, \frac{\mu_0\, I}{2\,\pi\, d} \\ d &= \frac{q_p\, v\, \mu_0\, I}{2\,\pi\, m_p\, g} \\ d &= \frac{(1.60218\times10^{-19}\ \text{C})\,(36200\ \text{m/s})}{2\,\pi\,(1.6726\times10^{-27}\ \text{kg})\,(9.8\ \text{m/s}^2)} \\ &\quad\times(1.25664\times10^{-6}\ \text{T}\cdot\text{m/A})\,(0.56\ \mu\text{A}) \\ &= \boxed{3.96295\ \text{cm}}\,.\end{aligned}$$

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009 6.0 points

An electron is accelerated by a 5 kV potential difference.

The charge on an electron is 1.60218×10^{-19} C and its mass is 9.10939×10^{-31} kg.

How strong a magnetic field must be experienced by the electron if its path is a circle of radius 5.8 cm?

Correct answer: 0.00411113 T.

Explanation:

$$\begin{aligned}\text{Let :}\quad r &= 5.8\ \text{cm} = 0.058\ \text{m}\,, \\ V &= 5\ \text{kV} = 5000\ \text{V}\,, \\ m &= 9.10939\times10^{-31}\ \text{kg}\,,\quad \text{and} \\ q &= 1.60218\times10^{-19}\ \text{C}\,.\end{aligned}$$

From Newton's second law,

$$\begin{aligned}F = q\,v\,B &= \frac{m\,v^2}{r} \\ v &= \frac{q\,B\,r}{m}\,.\end{aligned}$$

The kinetic energy is

$$K = \frac{1}{2} m\,v^2 = \frac{q^2\,B^2\,r^2}{2\,m} = q\,V\,,$$

so the magnitude of the magnetic field is

$$\begin{aligned}B &= \frac{1}{r}\sqrt{\frac{2\,V\,m}{q}} \\ &= \frac{1}{0.058\ \text{m}} \\ &\quad\times\sqrt{\frac{2\,(5000\ \text{V})\,(9.10939\times10^{-31}\ \text{kg})}{(1.60218\times10^{-19}\ \text{C})}} \\ &= \boxed{0.00411113\ \text{T}}\,.\end{aligned}$$

Dimensional analysis: The voltage must be converted from kV to V and the radius from cm to m.

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010 (part 1 of 3) 6.0 points

An alpha particle has a mass of 5.68×10^{-27} kg and bears a double elementary positive charge. Such a particle is observed to move through a 5 T magnetic field along a circular path of radius 0.19 m.

The charge on a proton is 1.60218×10^{-19} C.

What speed does it have?

Correct answer: 5.3594×10^7 m/s.

Explanation:

$$\begin{aligned}\text{Let :}\quad m &= 6.6\times10^{-27}\ \text{kg}\,, \\ r &= 0.19\ \text{m}\,, \\ q &= 2\,e = 3.20435\times10^{-19}\ \text{C}\,,\quad \text{and} \\ B &= 5\ \text{T}\,.\end{aligned}$$

The magnetic force supplies the circular motion, so

$$\begin{aligned}q\,v\,B &= \frac{m\,v^2}{r} \\ v &= \frac{q\,B\,r}{m} \\ &= \frac{(3.20435\times10^{-19}\ \text{C})\,(5\ \text{T})\,(0.19\ \text{m})}{5.68\times10^{-27}\ \text{kg}} \\ &= \boxed{5.3594\times10^7\ \text{m/s}}\,.\end{aligned}$$

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011 (part 2 of 3) 6.0 points

What is its kinetic energy?

Correct answer: 8.15737×10^{-12} J.

Explanation:

Its kinetic energy is

$$E = \frac{1}{2}\, m\, v^2 = \boxed{8.15737\times10^{-12}\ \text{J}}\,.$$

012 (part 3 of 3) 6.0 points
What potential difference in MV would be required to give it this kinetic energy?

Correct answer: 25.4571 MV.

Explanation:

$$\text{Let :}\quad \Delta E = E\,, \quad \text{and}$$
$$q = 2\,e = 3.20435 \times 10^{-19}\ \text{C}\,.$$

The potential difference is

$$\begin{aligned}\Delta V &= \frac{\Delta E}{q} \\ &= \frac{8.15737 \times 10^{-12}\ \text{J}}{3.20435 \times 10^{-19}\ \text{C}} \\ &= (2.54571 \times 10^{7}\ \text{V})\,(\frac{1\ \text{MV}}{1 \times 10^{6}\ \text{V}}) \\ &= \boxed{25.4571\ \text{MV}}\,.\end{aligned}$$

013 6.0 points
The alternating voltage of a generator is represented by the equation

$$\mathcal{E} = \mathcal{E}_0\, \sin \omega\, t\,,$$

where $\mathcal{E}$ is in volts, $\mathcal{E}_0 = 130$ V, $\omega = 518$ rad/s, and t is in seconds.

Find the frequency of the electric potential $\mathcal{E}$.

Correct answer: 82.4423 Hz.

Explanation:

$$\text{Let :}\quad \mathcal{E}_{max} = \mathcal{E}_0 = 130\ \text{V}\,, \quad \text{and}$$
$$\omega = 518\ \text{rad/s}\,.$$

$$\omega = 2\,\pi\,f$$
$$f = \frac{\omega}{2\,\pi} = \frac{518\ \text{rad/s}}{2\,\pi} = \boxed{82.4423\ \text{Hz}}\,.$$

014 (part 1 of 3) 6.0 points
A proton ($m_p = 1.673 \times 10^{-27}$ kg) travels with a speed of 2.9×10^{6} m/s at an angle of 160° west of north. A magnetic field of 3.4 T points to the north.

Find the magnitude of the magnetic force on the proton. (The magnetic force experienced by the proton in the magnetic field is proportional to the component of the proton's velocity that is perpendicular to the magnetic field.)

Correct answer: 5.39571×10^{-13} N.

Explanation:

$$\begin{aligned}\text{Let :}\quad v &= 2.9 \times 10^{6}\ \text{m/s}\,, \\ \theta &= 160°\ \text{west of north}\,, \\ B &= 3.4\ \text{T north}\,, \\ q &= 1.60 \times 10^{-19}\ \text{C}\,, \quad \text{and} \\ m &= 1.673 \times 10^{-27}\ \text{kg}\,.\end{aligned}$$

$$\begin{aligned}F_{mag} &= q\,v\,B \\ &= (1.6 \times 10^{-19}\ \text{C})\,(2.9 \times 10^{6}\ \text{m/s}) \\ &\quad \times (3.4\ \text{T})\,(\sin 160°) \\ &= \boxed{5.39571 \times 10^{-13}\ \text{N}}\,.\end{aligned}$$

015 (part 2 of 3) 5.0 points
What is its direction?

1. None of these

2. West

3. North

4. out of the Earth

5. East

6. into the Earth **correct**

7. South

Explanation:
Right-hand rule (positive charge): Force directed out of the palm of the hand, fingers in the direction of the field, thumb in the direction of the velocity.

The fingers point north, thumb points west, so palm faces down.

016 (part 3 of 3) 6.0 points
Find the magnitude of the proton's acceleration as it moves through the magnetic field.

Correct answer: 3.22517×10^{14} m/s^2.

Explanation:
By Newton's second law,

$$\begin{aligned}F &= m\,a \\ a &= \frac{F_{mag}}{m} \\ &= \frac{5.39571 \times 10^{-13}\ \text{N}}{1.673 \times 10^{-27}\ \text{kg}} \\ &= \boxed{3.22517 \times 10^{14}\ \text{m/s}^2}\,.\end{aligned}$$

017 (part 1 of 2) 6.0 points
The power supplied to a typical black-and-white television is 45.0 W when the set is connected across a potential difference of 125 V.

a) How much electrical energy does this set consume in 3.5 h?

Correct answer: 5.67×10^{5} J.

Explanation:

$$\text{Let :}\quad P = 45.0\ \text{W} \quad \text{and}$$
$$\Delta t = 3.5\ \text{h}\,.$$

$$\begin{aligned}P &= \frac{E}{\Delta t} \\ E &= P\,\Delta t \\ &= (45\ \text{W})\,(3.5\ \text{h})\,(3600\ \text{s/h}) \\ &= \boxed{5.67 \times 10^{5}\ \text{J}}\,.\end{aligned}$$

018 (part 2 of 2) 6.0 points
A color television set draws about 2 A of current when connected to a potential difference of 125 V.

b) How much time is required for it to consume the same energy that the black-and-white model consumes in 3.5 h?

Correct answer: 37.8 min.

Explanation:

$$\text{Let :}\quad \Delta V = 125\ \text{V} \quad \text{and}$$
$$I = 2\ \text{A}\,.$$

$$\begin{aligned}\Delta t &= \frac{E}{P} = \frac{E}{I\,\Delta V} \\ &= \frac{5.67 \times 10^{5}\ \text{J}}{(2\ \text{A})\,(125\ \text{V})} \times \frac{1\ \text{min}}{60\ \text{s}} \\ &= \boxed{37.8\ \text{min}}\,.\end{aligned}$$