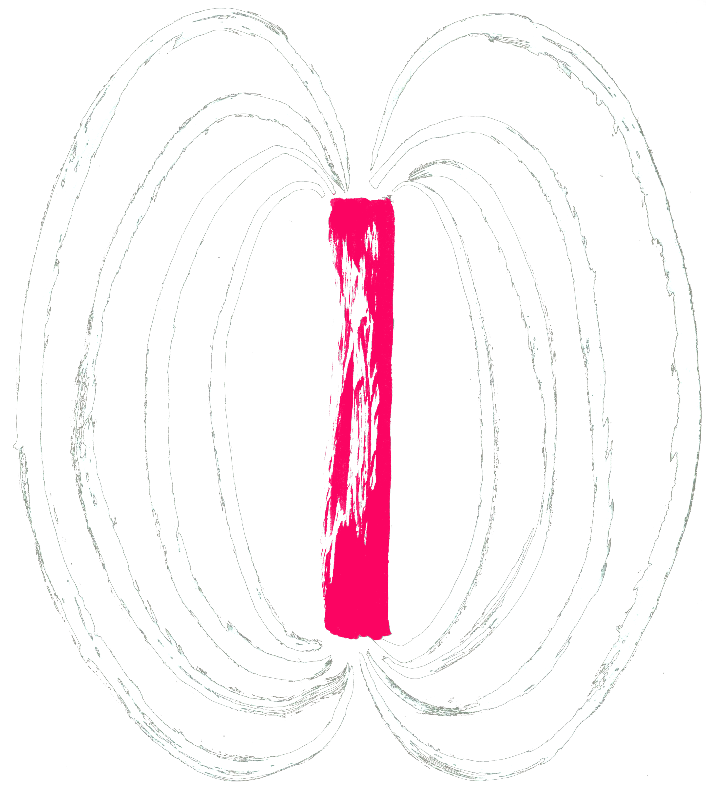
*The Commission on Higher Education*
*in collaboration with the Philippine Normal University*

*Teaching Guide for Senior High School*

# GENERAL PHYSICS 2



## STEM SUBJECT

This Teaching Guide was collaboratively developed and reviewed by educators from public and private schools, colleges, and universities. We encourage teachers and other education stakeholders to email their feedback, comments, and recommendations to the Commission on Higher Education, K to 12 Transition Program Management Unit - Senior High School Support Team at k12@ched.gov.ph. We value your feedback and recommendations.

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# Introduction

As the Commission supports DepEd's implementation of Senior High School (SHS), it upholds the vision and mission of the K to 12 program, stated in Section 2 of Republic Act 10533, or the Enhanced Basic Education Act of 2013, that "every graduate of basic education be an empowered individual, through a program rooted on...the competence to engage in work and be productive, the ability to coexist in fruitful harmony with local and global communities, the capability to engage in creative and critical thinking, and the capacity and willingness to transform others and oneself."

To accomplish this, the Commission partnered with the Philippine Normal University (PNU), the National Center for Teacher Education, to develop Teaching Guides for Courses of SHS. Together with PNU, this Teaching Guide was studied and reviewed by education and pedagogy experts, and was enhanced with appropriate methodologies and strategies.

Furthermore, the Commission believes that teachers are the most important partners in attaining this goal. Incorporated in this Teaching Guide is a framework that will guide them in creating lessons and assessment tools, support them in facilitating activities and questions, and assist them towards deeper content areas and competencies. Thus, the introduction of the **SHS for SHS Framework.**

## SHS for SHS Framework

The SHS for SHS Framework, which stands for "Saysay-Husay-Sarili for Senior High School," is at the core of this book. The lessons, which combine high-quality content with flexible elements to accommodate diversity of teachers and environments, promote these three fundamental concepts:

### **SAYSAY:** MEANING

*Why is this important?*

Through this Teaching Guide, teachers will be able to facilitate an understanding of the value of the lessons, for each learner to fully engage in the content on both the cognitive and affective levels.

### **HUSAY:** MASTERY

*How will I deeply understand this?*

Given that developing mastery goes beyond memorization, teachers should also aim for deep understanding of the subject matter where they lead learners to analyze and synthesize knowledge.

### **SARILI:** OWNERSHIP

*What can I do with this?*

When teachers empower learners to take ownership of their learning, they develop independence and self-direction, learning about both the subject matter and themselves.

# About this Teaching Guide

Earth Science is a Core Subject taken in the first semester of Grade 11. This learning area is designed to provide a general background for the understanding of the Earth on a planetary scale. It presents the history of the Earth through geologic time. It discusses the Earth's structure and composition, the processes that occur beneath and on the Earth's surface, as well as issues, concerns, and problems pertaining to Earth's resources.

Implementing this course at the senior high school level is subject to numerous challenges with mastery of content among educators tapped to facilitate learning and a lack of resources to deliver the necessary content and develop skills and attitudes in the learners, being foremost among these.

In support of the SHS for SHS framework developed by CHED, these teaching guides were crafted and refined by biologists and biology educators in partnership with educators from focus groups all over the Philippines to provide opportunities to develop the following:

***Saysay*** through meaningful, updated, and context-specific content that highlights important points and common misconceptions so that learners can connect to their real-world experiences and future careers;

***Husay*** through diverse learning experiences that can be implemented in a resource-poor classroom or makeshift laboratory that tap cognitive, affective, and psychomotor domains are accompanied by field-tested teaching tips that aid in facilitating discovery and development of higher-order thinking skills; and

***Sarili*** through flexible and relevant content and performance standards allow learners the freedom to innovate, make their own decisions, and initiate activities to fully develop their academic and personal potential.

These ready-to-use guides are helpful to educators new to either the content or biologists new to the experience of teaching Senior High School due to their enriched content presented as lesson plans or guides. Veteran educators may also add ideas from these guides to their repertoire. The Biology Team hopes that this resource may aid in easing the transition of the different stakeholders into the new curriculum as we move towards the constant improvement of Philippine education.

# Parts of the Teaching Guide

This Teaching Guide is mapped and aligned to the DepEd SHS Curriculum, designed to be highly usable for teachers. It contains classroom activities and pedagogical notes, and is integrated with innovative pedagogies. All of these elements are presented in the following parts:

1. **Introduction**
   - Highlight key concepts and identify the essential questions
   - Show the big picture
   - Connect and/or review prerequisite knowledge
   - Clearly communicate learning competencies and objectives
   - Motivate through applications and connections to real-life
2. **Motivation**
   - Give local examples and applications
   - Engage in a game or movement activity
   - Provide a hands-on/laboratory activity
   - Connect to a real-life problem
3. **Instruction/Delivery**
   - Give a demonstration/lecture/simulation/hands-on activity
   - Show step-by-step solutions to sample problems
   - Give applications of the theory
   - Connect to a real-life problem if applicable
4. **Practice**
   - Discuss worked-out examples
   - Provide easy-medium-hard questions
   - Give time for hands-on unguided classroom work and discovery
   - Use formative assessment to give feedback
5. **Enrichment**
   - Provide additional examples and applications
   - Introduce extensions or generalisations of concepts
   - Engage in reflection questions
   - Encourage analysis through higher order thinking prompts
6. **Evaluation**
   - Supply a diverse question bank for written work and exercises
   - Provide alternative formats for student work: written homework, journal, portfolio, group/individual projects, student-directed research project

# On DepEd Functional Skills and CHED College Readiness Standards

As Higher Education Institutions (HEIs) welcome the graduates of the Senior High School program, it is of paramount importance to align Functional Skills set by DepEd with the College Readiness Standards stated by CHED.

The DepEd articulated a set of 21st century skills that should be embedded in the SHS curriculum across various subjects and tracks. These skills are desired outcomes that K to 12 graduates should possess in order to proceed to either higher education, employment, entrepreneurship, or middle-level skills development.

On the other hand, the Commission declared the College Readiness Standards that consist of the combination of knowledge, skills, and reflective thinking necessary to participate and succeed - without remediation - in entry-level undergraduate courses in college.

The alignment of both standards, shown below, is also presented in this Teaching Guide - prepares Senior High School graduates to the revised college curriculum which will initially be implemented by AY 2018-2019.

| College Readiness Standards Foundational Skills | DepEd Functional Skills |
|---|---|
| Produce all forms of texts (written, oral, visual, digital) based on:<br>1. Solid grounding on Philippine experience and culture;<br>2. An understanding of the self, community, and nation;<br>3. Application of critical and creative thinking and doing processes;<br>4. Competency in formulating ideas/arguments logically, scientifically, and creatively; and<br>5. Clear appreciation of one's responsibility as a citizen of a multicultural Philippines and a diverse world; | Visual and information literacies, media literacy, critical thinking and problem solving skills, creativity, initiative and self-direction |
| Systematically apply knowledge, understanding, theory, and skills for the development of the self, local, and global communities using prior learning, inquiry, and experimentation | Global awareness, scientific and economic literacy, curiosity, critical thinking and problem solving skills, risk taking, flexibility and adaptability, initiative and self-direction |
| Work comfortably with relevant technologies and develop adaptations and innovations for significant use in local and global communities | Global awareness, media literacy, technological literacy, creativity, flexibility and adaptability, productivity and accountability |
| Communicate with local and global communities with proficiency, orally, in writing, and through new technologies of communication | Global awareness, multicultural literacy, collaboration and interpersonal skills, social and cross-cultural skills, leadership and responsibility |
| Interact meaningfully in a social setting and contribute to the fulfilment of individual and shared goals, respecting the fundamental humanity of all persons and the diversity of groups and communities | Media literacy, multicultural literacy, global awareness, collaboration and interpersonal skills, social and cross-cultural skills, leadership and responsibility, ethical, moral, and spiritual values |

# Table of Contents

# Table of Contents

*General Physics 2*

**60 MINS**

# Coulomb's Law

**Content Standard**

The learners demonstrate an understanding of Coulomb's Law.

**Performance Standard**

The learners are able to use theoretical and experimental approaches to solve multiconcept and rich-context problems involving electricity and magnetism

**Learning Competencies**

At the end of this session, the students should be able to:

1. Predict the trajectory of a point charge in a uniform electric field (**STEM_GP12EM-IIIa-10**)
2. Write down and explain Coulomb's law in vector form;
3. Use in calculations the relationship between the electric field and the electric force on a test charge (**STEM_GP12EM-IIIa-9**)

**Prerequisite Knowledge**

electric charge, conductors, insulators, induced charges

**Prerequisite Skills**

mathematical acumen (in vector analysis: especially vector addition), drawing skill (i.e. proper illustration or representation of problem)

## LESSON OUTLINE

| | |
|---|---|
| **Introduction** | Review on how ions are formed from atoms |
| **Instruction** | Observation activity |
| **Evaluation** | Individual experiment and discussion |
| **Enrichment** | Visual Representation and Calculation on the Net Electric Force |
| **Materials** | Illustration board containing schematics of different charge configurations |

**Resources**

(1) Young and Freedman. University Physics. 9th Edition.

(2) Tipler, Paul. University Physics. 4th Edition.

## INTRODUCTION

1. **Do a quick review** on how ions are formed from atoms (e.g. when a sodium atom Na0 loses an electron, it becomes a sodium cation $Na^{1+}$; when a chlorine atom gains an electron, it becomes a chlorine anion $Cl^{1-}$).

2. **Inquire about what happens** (or what bond exists) between a cation and an anion. Ask the students why (an ionic bond forms between a cation and an anion).

## MOTIVATION

1. **Show** an illustration board with 2 charges of +1 C placed along the endpoints of a line segment of known length.

2. **Ask** a student **to describe** what will happen to the 2 charges.

3. **Ask** another student **to draw** the electric force between the two charges. (Where is the electric force on the left +1-C charge? Where is the electric force on the right +1-C charge?)

4. **Show** an illustration board with 2 charges of +1 C and –1 C placed along the endpoints of a line segment of known length.

5. **Ask** a student **to describe** what will happen to the 2 charges.

6. **Ask** another student **to draw** the electric force between the two charges. (Where is the electric force on the left +1-C charge? Where is the electric force on the right –1-C charge?)

7. **Ask** the students **to describe** the difference between the answers in Question Nos. 3 and 6. (Focus on comparing the magnitude and direction of the electric force in each cas

## INSTRUCTION

Provide sample questions and demonstrate the solution. See Appendix A

## INDIVIDUAL WORK

1. **Put forward** these problems to the class: (a) Suppose the two +1-C charges in the (motivational) activity were replaced each by +2-C charges. Predict what will happen to the length of the electric force vector. (b) Suppose the +1-C charge and the –1-C charge in the (motivational) activity were replaced each by +2-C charge and a –2-C charge. Predict what will happen to the length of the electric force vector. (c) Suppose the two +1-C charges in the (motivational) activity were moved twice as far as the initial distance between them. Predict what will happen to the length of the electric force vector. (d) Suppose the +1-C charge and the –1-C charge in the (motivational) activity were moved twice as far as the initial distance between them. Predict what will happen to the length of the electric force vector.

2. **Group** the class and **have the groups discuss** their predictions for 5 minutes. **Remind** each group to have a scribe who will write the prediction(s) discussed on his/her notebook.

3. **Ask** each group **to share** one prediction.

4. **Summarize** the students' answers by writing down the equation:

$$\vec{\boldsymbol{F}}_{electric} = \frac{kq^1q^2}{r^2}\ \hat{\mathbf{r}} \text{ (Coulomb's law) where } k \approx 9 \times 10^9\ \frac{Nm^2}{C^2}$$

5. **Have the students write down** the meaning (and units) of each of the quantities in Coulomb's law.

6. **Have the students solve** these problems and **interpret the output as given by Coulomb's law**: Find $\vec{\boldsymbol{F}}_{electric}$ for each of the following configuration:
   a) $q_1 = q_2 = +1.0C$, $4 = 1.0m$
   b) $q_1 = +1.0C$, $q_2 = -1.0C$, $r = 1.0m$

## DISCUSSION

1. Have the students plot $\vec{\boldsymbol{F}}_{electric}$ - versus - $q_1q_2$. Have them **explain** the meaning of the plot.
2. Have the students plot $\vec{\boldsymbol{F}}_{electric}$ - versus - r. Have them **explain** the meaning of the plot.
3. **Ask** the students **the visual representation** of the unit vector $\pm\hat{\mathbf{r}}$. (What does this representation imply about the nature of the electric force?)

# EVALUATION AND ENRICHMENT

(Visual Representation and Calculation of the Net Electric Force):

1. Have the students **draw** the net electric force on a +1-C charge placed at the center of:
   (a) A line segment of length 1.0 m with a +1-C charge and a –1-C charge at its endpoints;
   (b) An equilateral triangle of side length 1.0 m with alternating +1-C, –1-C, and +1-C charges placed at its vertices;
   (c) A square of side length 1.0 m with alternating +1-C, –1-C, +1-C, and –1-C charges placed at its vertices

2. Have the students **calculate the magnitude** and **determine the direction** of the net electric force on the +1-C charge placed at the center of each of the above configurations.

60 MINS

# Electric Forces and Fields

**Content Standard**
The learners demonstrate an understanding of Electric forces and fields.

**Performance Standard**
The learners are able to use theoretical and experimental approaches to solve multiconcept and rich-context problems involving electricity and magnetism

**Learning Competencies**
At the end of this session, the students should be able to:

1. Describe an electric field as a region in which an electric charge experiences a force (**STEM_GP12EM-IIIa-6**)
2. Relate the electric field and electric force on a test charge;
3. Draw electric field lines of particular charge and charge distributions;
4. Calculate the electric field due to a system of point charges using Coulomb's law and the superposition principle (**STEM_GP12EM-IIIa-10**)

**Prerequisite Knowledge**
electric charge, electric force, Coulomb's law

**Prerequisite Skills**
mathematical acumen (in vector analysis: especially vector addition), drawing skill (i.e. proper illustration or representation of problem)

## LESSON OUTLINE

| | |
|---|---|
| **Introduction** | Inquiry on the content of the field |
| **Motivation** | Review of electric force and gravitational force |
| **Instruction** | Discussion proper |
| **Evaluation/ Enrichment** | Visual Representation and Calculation of the Net Electric Force |
| **Materials** | Illustration board containing schematics of different charge configurations |

**Resources**

(1) Young and Freedman. University Physics. 9th Edition.
(2) Tipler, Paul. University Physics. 4th Edition.

## INTRODUCTION

1. **Inquire about the concept** of a field. (What is a field? e.g.What is meant by a gravitational field? How do we know that a gravitational field exists in the room where we are in?)

2. **Have the students write down key words** that will define a gravitational field.

## MOTIVATION

1. Ask a student to compare and contrast the electric force from the gravitational force.
2. Ask another student to write down the electric and gravitational forces in vector form.
3. Define the gravitational field to be the ratio of the gravitational force and the mass experiencing the gravitational force. Have the students write this definition mathematically.
4. Ask the students to interpret the meaning of a gravitational field. (Note: Here the students should realize that writing is equivalent to ***g*** which is just the acceleration due to gravity.)
5. Ask the students to extend the definition in No. 3 to that of an electric field.

$$\frac{\vec{\boldsymbol{F}}_{grav}}{m}$$

## INSTRUCTION

1. From No. 5 of the Motivation Section, **ask** a student **to write down** the analogous definition of the electric field from No. 3 of the Motivation Section. (Here the student is expected to write: ***E*** = ) Ask the student to write down the meaning of each symbol (or word) used in the formulation. (Ask the student the physical meaning of the charge q. Here the teacher should bring out the idea that *q* is a test charge.)

$$\vec{\ } \quad \frac{\vec{\boldsymbol{F}}_{electric}}{q}$$

2. **Show** a schematic of two point charges Q and q separated by a distance r. Ask the students to calculate the electric force between Q and q (by using Coulomb's law) and then ask them how they will determine the electric field experienced by the test charge q. (Here the students are expected to write:

$$\boldsymbol{F}_{electric} = \quad \hat{\mathbf{r}};\ \mathbf{E} = \quad = \quad = \quad \hat{\mathbf{r}})$$

3. **Have the students write down** the meaning (and units) of each of the quantities in the electric field expression:

$$\vec{E} = \frac{\vec{F}_{electric}}{q} = \frac{\frac{kqQ}{r^2}\hat{r}}{q} = \frac{kQ}{r^2}\hat{r}$$

Ask the students the direction of ***E*** when Q is positive and when Q is negative. Ask the students to draw representative ***E*** lines when Q is positive and when Q is negative. (Ask the students the physical meaning of Q.)

4. Have the students solve these problems and interpret the output:
   (a) Find **E** 1.0 m away from a +1-C charge. Represent **E** schematically.
   (b) Find **E** 1.0 m away from a –1-C charge. Represent **E** schematically.

## DISCUSSION

1. Inquire about the factors that affect the electric field **E**.

2. Ask the students to represent **E** lines from a positive ***Q***.

3. Ask the students to represent **E** lines from a negative ***Q***.

4. Ask the students to represent **E** lines in between a ***+Q*** charge and a ***–Q*** charge separated by a distance *r*.

## EVALUATION AND ENRICHMENT

(Visual Representation and Calculation of the Net Electric Force):

1. Have the students **draw** the net electric field at the center of:
   (a) A line segment of length 1.0 m with a +1-C charge and a –1-C charge at its endpoints;
   (b) An equilateral triangle of side length 1.0 m with alternating +1-C, –1-C, and +1-C charges placed at its vertices;
   (c) A square of side length 1.0 m with alternating +1-C, –1-C, +1-C, and –1-C charges placed at its vertices

2. Have the students **calculate the magnitude** and **determine the direction** of the net electric field at the center of each of the above configurations.

60 MINS

# Electric Flux and Gauss Law

**Content Standards**

The learners demonstrate an understanding of electric flux and Gauss' Law.

**Performance Standards**

The learners shall be able to use theoretical and experimental approaches to solve multi-concept and rich-context problems involving electricity and magnetism.

**Learning Competencies**

The learners:

1. Calculate the electric flux through a surface given the electric field; **(STEM-GP12EM-IIIb-12)**
2. State Gauss' Law verbally and mathematically; and
3. Use Gauss' Law to infer the electric field due to uniformly distributed charges on long wires, spheres, and large plates. **(STEM-GP12-IIIb-13)**

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction** | Present Gauss' Law as a geometric relation between charge and electric field | 3 |
| **Motivation** | Comparison of the calculation of electric field using Coulomb's Law and Gauss' Law | 7 |
| **Instruction/ Delivery/ Discussion** | (a) Preliminaries<br>(b) "Proving" and Applying Gauss' Law<br>(c) Sample discussions on the issues and application of Gauss' Law<br>(d) Comments on the common misconceptions, mistakes, or difficulties | 40 |
| **Enrichment** | Homework and Essay | |
| **Evaluation** | Individual or by-pair quiz | 10 |

**Materials**

- For 2D illustration - ballpen (chalk) and paper (board)
- For 3D illustration - barbecue sticks, styrofoam spheres and cubes

**Resources**


(1) Chabay, R. W., & Sherwood, B.A. (2010). *Matter and Interaction II: Electric and Magnetic Interactions* (3rd ed.). New York, USA: J. Wiley & Sons, Inc.

(2) Halliday, D., Resnick, R., & Walker, J. (2013). *Fundamentals of Physics Extended* (10th ed.) New York, USA: J. Wiley & Sons, Inc.

(3) Young, H. D., Freedman, R. A., & Ford. A. L. (2011). *University Physics* (9th ed.). Boston: Addison-Wesley.

## INTRODUCTION (3 MINS)

1. Introduce **Gauss' Law**, ***a geometric relation between charge q and electric field*** $\bar{E}$, in equation and statement form:

$$\Phi = \oint_{\text{closed surface}} \vec{E} \cdot d\vec{A} = \frac{1}{\varepsilon_0} \sum_i^N q_{i,\text{enclosed}} \text{ (Equation 1)}$$

*"The electric flux Φ through any closed surface (Gaussian surface) is equal to the total sum of charges enclosed by the surface."*

2. Briefly demonstrate that if the closed surface and the charge enclosed form a symmetric configuration, one can obtain a simple formula for electric field magnitude:

   *If the Gaussian surface provides sufficient symmetry such that the surface area is independent of the electric field…*

$$\oint_{\text{closed surface}} E \cdot dA = \vec{E} \oint_{\text{closed surface}} d\vec{A} = \vec{E} * (\text{surface area of the closed surface}) = \frac{1}{\varepsilon_0} \sum_i^N q_{i,\text{enclosed}}$$

$$\rightarrow \vec{E} = \frac{\sum q_{i,\text{enclosed}}}{\varepsilon_0 * (\text{surface area of the closed surface})}$$

(Equation 2)

   *The sign of the electric field is determined from the direction of its arrow relative to the coordinate system.*

   (Comment: The approach is axiomatic because Gauss' Law was  aconsequence of the inverse square dependence of distance in Coulomb's Law. Coulomb's Law, which is equivalent to Gauss' Law, was discovered earlier from experiment.)

## MOTIVATION (7 MINS)

1. Show a previous example of a calculation of electric field using Coulomb's Law and ask the learners for any difficulties they encounter. Ensure that this charge configuration is the kind where Gauss' Law is also appropriate to use.learners

2. Show solution to the same problem but this time, using Gauss' Law. Ask the learners to compare, such as the length or number of lines of solution, and the final answer. *(See Appendix B)*

**Teacher Tips:**
Give a two-minute concept quiz/ game asking learners to determine electric field of infinite line charge of linear charge density, λ. It is alright if many learners do not finish. Note: Calculate the electric field in terms of the linear charge density, where it is equal to the ratio of total charge to the length of the wire. *(See Appendix A)*

## INSTRUCTION (30 MINS)

***Preliminaries***

1. Review the electric field patterns of several simple symmetric charge configurations using the Coulomb's Law.
2. Emphasize the relation between these two quantities, such that there are cases where one can guess the charge configuration basing on the electric field pattern. Elaborate particularly the case where the charge is hidden inside a closed imaginary surface, known as the Gaussian surface, such as a cube or a sphere and only the field piercing through is visible.
3. Point out that the electric field is represented as directed lines permeating in space starting from a positive point charge. For a negative point charge the lines are directed toward the point charge. With the importance of measurement in science as basis, argue for the need to define electric flux.
4. Introduce the key elements of electric flux: direction and magnitude of the electric field and the area of the Gaussian surface. Introduce "vectorized" unit area as a means to "measure" or "characterize" area. This is done by assigning a normal vector to the unit area. In closed surface, the convention is to assign the normal unit vector in the outward direction as positive..
5. To improve intuition, review the pattern and equation of the electric field of a single positive charge, +Q, at a point distance r = R from the charge, as calculated using Coulomb's Law. Note that that this is in spherical coordinates, where  is a unit vector.

$$\vec{E} = \frac{Q}{4\pi\ \varepsilon_0\ R^2}\ \hat{\mathbf{r}} \qquad \text{(Equation 3)}$$

6. 6. Calculate $\Phi = \oint_{\text{closed surface}} \vec{E} \cdot d\vec{A}$ of this configuration to show it is equal to $\frac{Q}{\varepsilon_0}$. Assume the

**Teacher Tips:**
A quick "guessing game" may be appropriate here.

shape of the Gaussian surface is spherical and the point charge is at the center.

$$\Phi = \oint_{\text{closed surface}} E \cdot dA = \int_0^{\pi} \int_0^{2\pi} \left( \frac{Q}{4\pi\, \varepsilon_0\, R^2} \hat{\mathbf{r}} \right) \cdot (R^2 \sin\theta d\theta d\Phi \hat{\mathbf{r}}) = \ldots = \frac{Q}{\varepsilon_0} \qquad \text{(Equation 4)}$$

***"Proving" the Gauss' Law***

7. Relate Coulomb's Law to Gauss' Law using dimensional analysis. Point out the similarity in the main quantities and emphasize the inverse square nature of Coulomb's Law as the crucial basis of the equivalence. Explain howGauss' Law is equivalent to Coulombs' law by showing the geometrical relation between a charge configuration and a field quantity that has a source-point – to – field-point distance follows an inverse square law.

8. Show that previous result holds for a Gaussian surface of any size by repeating the preceding calculation (Items 5 & 6) for two cases, i.e., $r = R_1$ and $r = R_2$ ($R_2 > R_1$).

9. Show that previous result holds for a Gaussian surface of any shape by repeating the calculation in items 5 & 6 for a cubic Gaussian surface and comparing the flux. The use of cubic Gaussian surface in this problem require more calculations than spherical Gaussian surface. Thus Gaussian surface with the most appropriate symmetry must always be used. Moreover computational methods can be done to produce graphical representation. Show that the charge configuration outside the Gaussian surface will have no contribution. This can be demonstrated by considering a point charge situated outside a cubic or a spherical Gaussian surface. Show using symmetry, that the electric flux through one face or hemisphere is opposite in direction to the flux in the other face or hemisphere and thus the net flux outside is zero.

***Applying Gauss' Law***

10. Explain that the practical use of Gauss' Law is for manually solving the electric field of symmetric charge configurations, or in conjunction with the Principle of Superposition, asymmetric charge configurations that are decomposable into several symmetric configurations.

11. Introduce the basic steps in solving electrostatic problems using Gauss' Law for manual calculation. (See Appendices C and D)
    a. (not part of L.C.)Imagine /draw the most effective Gaussian surface (sphere/ pillbox/cylinder). (See Appendix E)

**Teacher Tips:**
This is best delivered by discussing the same sample problem used in introducing Coulomb's Law.

b. Position the chosen Gaussian surface such that it is concentric or co-axial with that of charge distribution and the field point is in the Gaussian surface.
c. Apply Equation 2.
d. Determine the direction of the electric field vectors at the Gaussian surface. The direction is positive if it is in the outward direction and negative if it is directed inward.Apply the superposition principle to obtain the final answer (as needed).

## DISCUSSION (10 MINS, MAY BE INTERWOVEN INTO THE INSTRUCTION)

1. In what situation is it better to use Coulomb's Law or Gauss' Law? (*It depends on the situation. On one hand, some problems involving fewer charges are easier/ more straightforward to solve using Coulomb's Law. On the other hand Gauss' Law is best used for systems with symmetric configurations.*)

2. When is Gauss' Law true and useful? (*It is true all the time but useful for manual calculation if the configuration of the system has a special symmetry like Gaussian surfaces.*)

3. What are the usual symmetries? (*Spherical, cylindrical, and pillbox symmetry. Show the illustrations of these symmetrical configurations.*)

4. What is a Gaussian surface? (I*t is a closed imaginary surface that one defines depending on a problem. It is at this surface where one measures the magnitude and direction of the electric field.*)

5. How is Gauss' Law related to Coulomb's Law? (*They are both relating the electric field to the charge. Gauss' Law rests on the fact that Coulomb's Law is an inverse square law.*)

6. (*not included in the L.C*) What is the physical meaning of the dot product rule? (*In the context of Gauss's Law it is the length of the projection of the electric field onto the surface of the enclosing volume and multiplied to its surface area.*)

**Teacher Tips:**
The following are some of the misconceptions, mistakes and difficulties of the learners that you should look out for. It may also be helpful to discuss these things with the learners for emphasis, awareness, and/or benchmarking:

- Learners may fail to distinguish between electric flux and electric field. They might conclude that electric field is zero simply because electric flux's sign looks like a zero.
- The signs (polarities) of the charges and the direction of the field often get mixed up. Encourage the habit of including the sketch of the coordinate system in the diagram of the problem. The sign of the electric field is determined from the direction of its arrow relative to the coordinate system.
- Learners may fail to recognize and use symmetry arguments. Emphasize the importance of symmetry in manual calculation. Also encourage sketching of the field patterns.
- Learners may fail to recognize when the problem is better solved using Gauss' Law or Coulomb's Law.

## ENRICHMENT

- Unfinished items in the quiz (Evaluation) may be continued as a homework.

- As a homework, ask the learners to check if the relationship between the electric field patterns and charge distribution in metals is consistent with the description of Gauss' Law. Assume electrostatic equilibrium meaning charge inside the metal has no further motion about the surface of the metal and thus zero electrostatic force.

- As a homework, also ask the learners to reflect why the concept of electric field is necessary even if there is already the concept of electric force.

## EVALUATION (10 MINS)

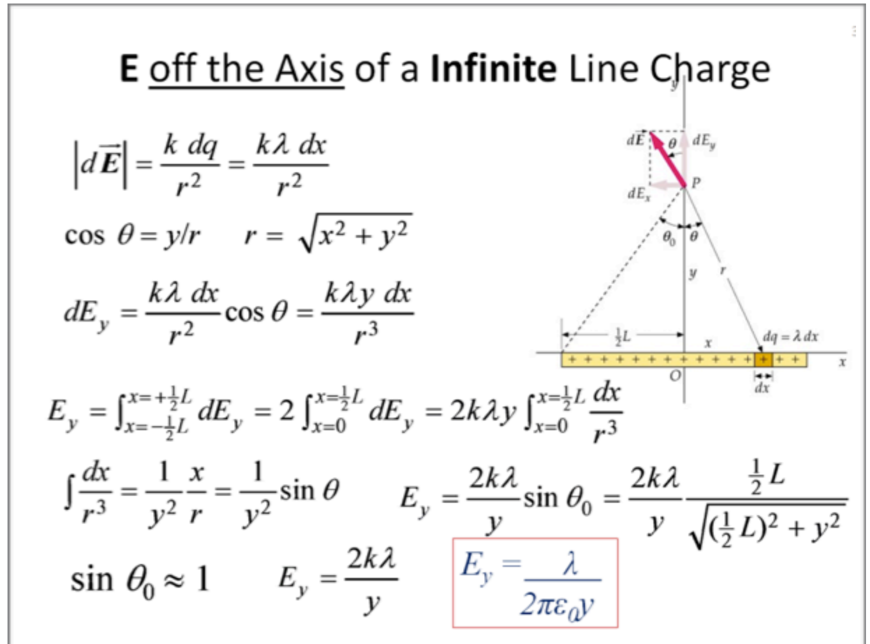
Determine the electric field of different charge configurations. The following are sample charge configurations to consider:

- single point
- three point charges of different signs (polarities) forming the vertices of a right triangle
- dielectric sphere (inside and outside) assuming uniform electric charge
- conducting sphere (inside and outside)
- infinite line of uniform charge
- three parallel infinite line charges of different signs (polarities) lying on the same plane
- single or multiple plane charges
- bulk dielectric cylinder (inside and outside)

(Please redraw all the figures/slide snapshots in the appendices.)

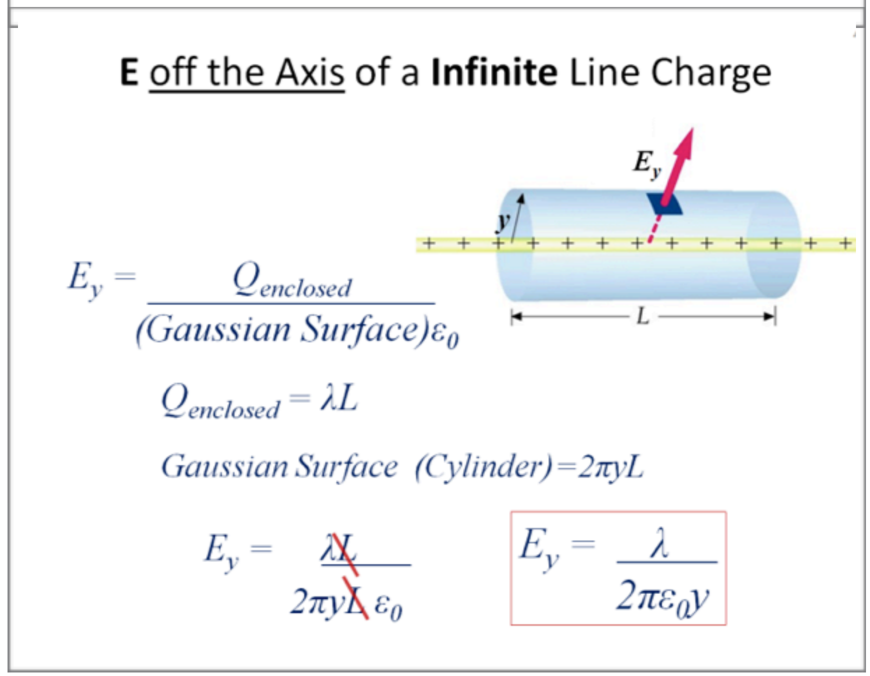
## Appendix A

Sample problem solved using (a differential version of) Coulomb's Law. Due to symmetry the net magnitude of electric field along the x direction is zero.



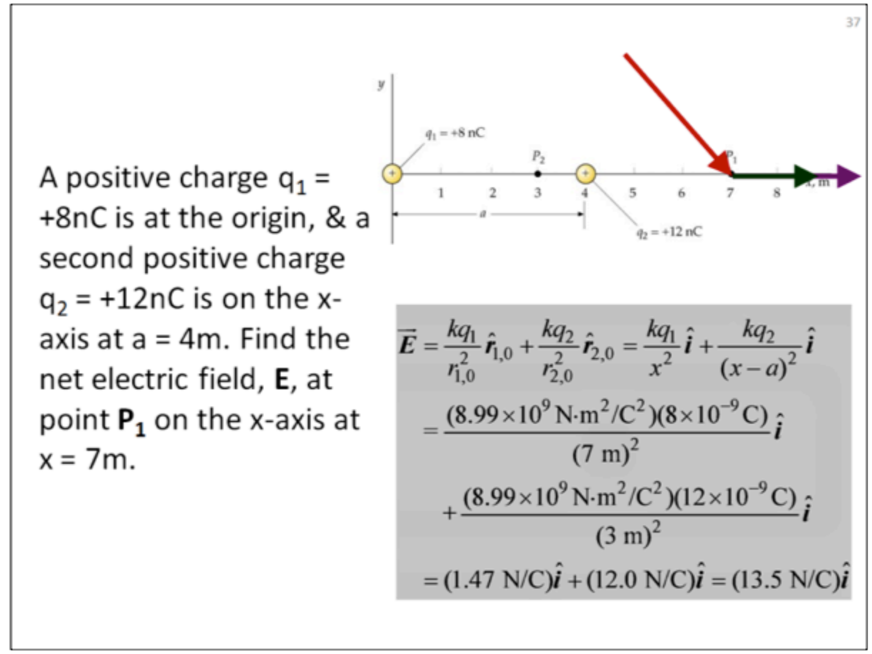

## Appendix B

Sample problem as in Appendix A solved using Gauss' Law



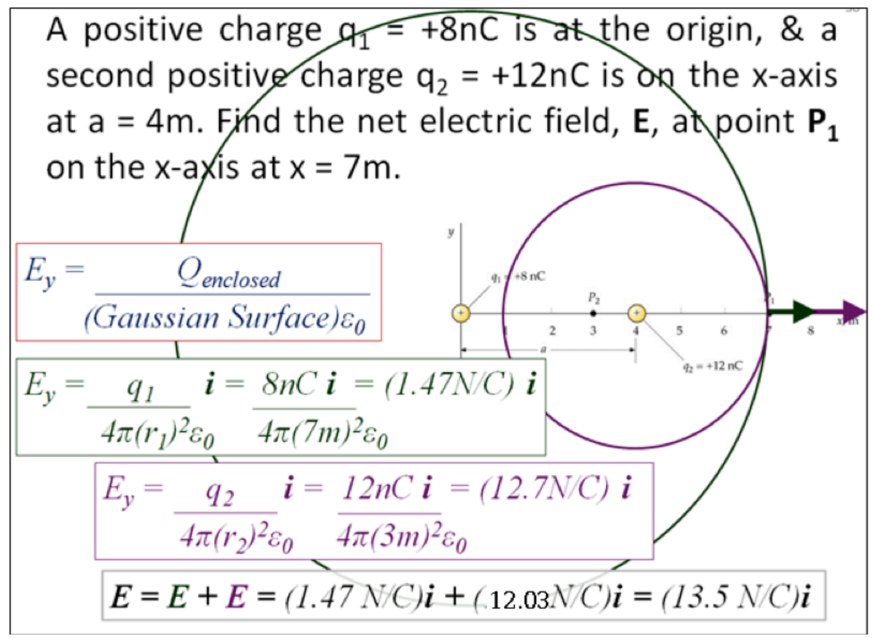
**Appendix C**

Sample problem solved using Coulomb's Law



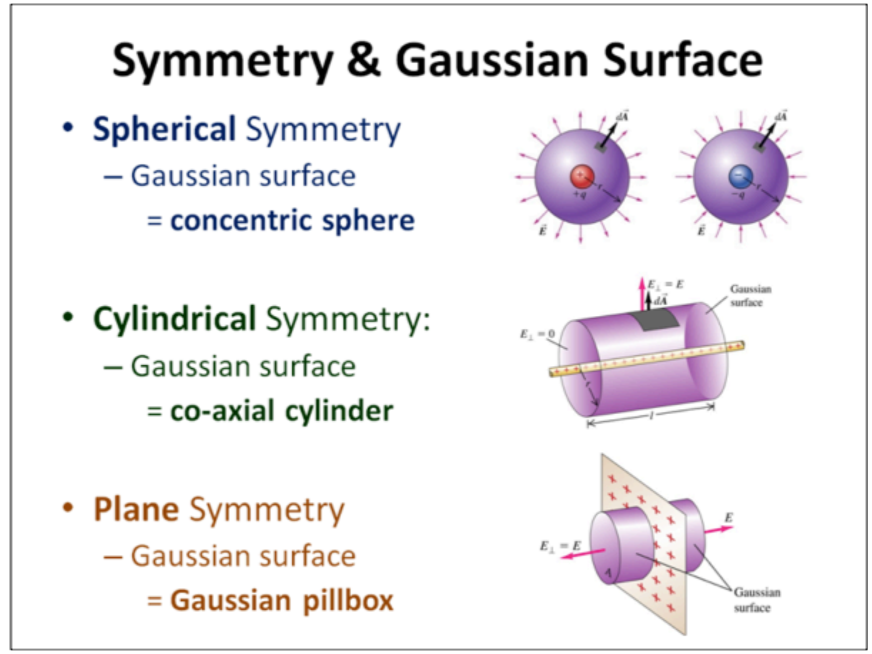

**Appendix D**

Sample problem as in Appendix A solved using Gauss' Law



**Appendix E**

Common Gaussian Surfaces



120 MINS

# Context-rich problems involving Electric Charge, Coulomb's Law, Electric Fields, Electric Flux, Gauss' Law

**Content Standards**

The learners demonstrate an understanding of

1. Electric Charge
2. Coulomb's Law
3. Electric Fields
4. Electric Flux
5. Gauss' Law

**Performance Standards**

The learners shall be able to use theoretical and experimental approaches to solve multi-concept and rich-context problems involving electricity and magnetism.

**Learning Compentency**

Solve problems involving electric charges, dipoles, forces, fields, and flux in contexts such as, but not limited to, systems of point charges, classical models of the atom, electrical breakdown of air, charged pendulums, control of electron and proton beams, electrostatic ink-jet printers (**STEM_GP12EM-IIIb-14**)

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction/ Motivation** | Rationale and characteristics of context-rich problem solving | 5 |
| **Logistics and Instructions for Teachers** | Grouping, assignment, grading system | 30 |
| **Context-rich Problems** | 14 examples | |
| **Materials** | 1. writing materials<br>2. other materials to be determined by the students depending on the problem | |

**Resources**

(1) P. Heller and K. Heller. Cooperative Group Problem Solving in Physics. (University of Minnesota, 1999).

(2) G. Pólya, How to Solve It, (Doubleday, New York, 1957.)

(3) R.D. Knight, Physics for Scientists and Engineers: A Strategic Approach with Modern Physics and Mastering Physics, 2nd Ed. (Benjamin Cummings, 2007).

(4) R.W. Chabay, B.A. Sherwood. Matter and Interaction II: Electric and Magnetic Interactions, 3rd Ed. (J. Wiley & Sons, Inc., 2010).

(5) H.D. Young, R.A. Freedman, A.L. Ford, University Physics, 11th Ed. (Addison-Wesley, 2011). Paul Hewitt, Conceptual Physics, 11th Ed. Addison-Wesley, 2009).

(6) D. Halliday, R. Resnick, J. Walker. Fundamentals of Physics Extended, 10th Ed. (J. Wiley & Sons, Inc., 2013).

## INTRODUCTION

Solving context rich problems provide students the opportunities to practice implementing the physics concepts and techniques in realistic scenarios. This learning experience is consistent with the fact that **charge, electric field and forces**, and other related concepts relevant to many aspects of our daily lives.

The context rich problems are designed such that the students are part of the story and are often required to interact with other people in preparing and reporting their solutions. Unlike in the typical end-of-chapter problems, students usually need to refine the definition of the problems, specify the unknowns, design their own problem-solving strategy, use several concepts, make assumptions, recall or invoke prior knowledge or "common-sense", supply additional information, perform experiments, and interact with experts and non-experts.

## LOGISTICS AND INSTRUCTIONS FOR TEACHERS (30 MINS)

1. Discuss the rationale of solving context-rich problems in physics as articulated in the Introduction.

2. Discuss the steps or framework for problem-solving and specify the template or distribute the problem-solving sheet.

3. Discuss the grading system for this particular activity. The recommended system is to grade each step, either in equal weights in the scale of 1 to 5 (or 1 to 10) or in unequal weights, usually giving more premium to analysis than to the final answer. Allocating portions for peer- and self-evaluation in the final grade is also recommended.

4. Group the students (the recommended number is three to five students per group) and arrange their seats (the arrangement should be conducive for long discussions). Due effort should be exerted to achieve heterogeneous distribution of students in terms of gender and class-performance. Encourage the students to device a system that would allow every member of the group to contribute to the discussion for every step and to rotate the roles among themselves, especially the role of secretary or scribe.

5. Arrange the schedule for problem solving and reporting to class. It is recommended that each group should solve at least one problem for each topic in this chapter.

6. Let the students spend the remaining class time to start solving the problems. Then they will have to solve the rest after the class and submit their final output later, e.g., after one week.

7. If there is opportunity, group reporting of output in front of the class is recommended because it will allow students be familiar with problems that they are not assigned to solve.

   [You may adopt the problem solving sheet designed by Kenneth Heller and Patricia M. Heller of University of Minnesota (see Chapter 2 of their book "Cooperative Group Problem Solving in Physics," which is publicly available). The steps they advocate, which is consistent or similar with those of the famous mathematician G. Polya, are as follows: focus on the problem; describe the physics; plan a solution; execute the plan; and evaluate the solution. They also have discussions and recommendation for the grading system, role assignment, and student distribution.]

## CONTEXT-RICH PROBLEMS

The following are examples of context-rich problems. The major concept(s) being considered is indicated after the problem. You may design more problems considering the characteristics of context-rich problems described above.

1. Your classmates often complain of painful electric shock whenever they open the door to leave the new fully-carpeted auditorium of your school. Write a letter to the principal about the problem explaining the physics behind the phenomenon and suggesting simple changes to the auditorium (at least in the area near the door) to prevent this nuisance. (charging/discharging)

2. You are a fieldtrip when a thunderstorm struck. Making matters worse, your school bus malfunctioned while it is in the middle of the road traversing a wide plain of rice fields. There is a "nipa" hut and a mango tree near the place you are stuck. Convince your classmates that it is safer to stay inside the bus while waiting for help.  (Faraday cage, charging/ discharging, conductor)

3. Your friend told you about her problem. She bought some replacement electronic parts for her personal computer a week ago and only found out yesterday that these were not working. When she tried to return them to the store, the salesman refused and told her it was her mishandling that ruined the electronic parts. She said that she was careful that the devices were no subjected to vibrations. She said all she did was remove and throw away the metallic film-coated shipping bags that used to contain the devices. Explain to her why it is possible that indeed she is at fault. (electrostatic protection, charging/ discharging, conductor)

4. Your grandmother gave you silver-plated kitchen wares. These are old such that some parts of the plating are already worn off. Design an electroplating set up to restore this heirloom pieces. (electrolysis)

5. An energy saving advocacy group released an cartoon "infomercial" portraying old electric appliances as greedy monsters eating a lot of electric charges. While you support their advocacy, you want their information to be accurate. Write a friendly letter to the advocacy group pointing out their error and suggesting some changes to their "infomercial." You also design a simple demonstration to support your argument. (conservation of charge)

6. You are in charge of first aid during your Biology Club camping. Unfortunately, one of your club members got sick and dehydrated. Explain to him why it is advisable to drink the sugar and salt solution that you prepared. (electrolytes)

7. You are an advocate of disaster prevention and preparedness. Use a van de Graaff generator to teach small children to be careful but not too afraid of thunder and lightning. Make sure that you explain the rules on safety in using the van de Graaff generator. (charging/ discharging, conductors)

8. You work in an architectural firm specializing in restoration of old building. Convince your boss to invest in replacement of rusty and broken lightning rods in the building, explaining especially the effect of rust and breaks in the rod. (Charging/ discharging, conductors)

9. You are a volunteer teacher in a first-aid class. Demonstrate how to help a victim of electrocution and explain the reasons behind the various precautionary measures. (charging/ discharging, conductors)

10. You are discussing the hazards, risk and possible solutions of photocopiers and printers with the CEO and the building manager of your company. The CEO asked you why there is bright light during photocopy, why print-outs are usually hot and if these heat sources can be avoided. You want that a separate air-conditioned room be set aside for photocopiers and printers. Use your answer to the CEO's questions as opportunity to explain the basic mechanisms of these devices and to push your proposal. (charging/ discharging)

11. Using the principle of superposition, explain to a skeptic why Coulomb's law is able to explain a lot of different phenomena involving charge despite describing only two charged object. (Coulomb's Law)

12. Using order of magnitude estimate, ratio-and-proportion, explain why we are interested in "unreal" charged configurations like "uniformly charged" objects, "very long" charged rod/wire, and "infinite or very wide" charged plane. (Coulomb's Law)

13. Create a cartoon or poster explaining the difference between an insulator and a conductor, particularly in terms of the mobility of the electrons, using as analogy (e.g., prisoners and ordinary persons, children before and after a curfew, people in the city during night time and day time). (insulators and conductors)

14. Make a leaflet illustrating the inability of Coulomb's law in explaining the (planetary) model of the atom. (Coulomb's Law)

60 MINS

# Electric Potential

**Content Standards**

The learners demonstrate an understanding of

1. Electric potential energy
2. Electric potential
3. Equipotential surfaces
4. Electric field as a potential gradient
5. Electric potential

**Performance Standards**

The learners shall be able to use theoretical and experimental approaches to solve multi-concept and rich-context problems involving electricity and magnetism.

**Learning Competencies**

At the end of the session, the students should be able to :

1. Define operationally the electric potential;
2. Relate the electric potential with work, potential energy, and electric field (**STEM_GP12EM-IIIb-15**)
3. Evaluate the potential at any point in a region containing point charges (**STEM_GP12EM-IIIb-16**)
4. Draw and represent equipotential lines or equipotential curves.
5. Calculate the electric potential due to a charge distribution.

**Prerequisite Knowledge**

electric field, electric force, electric charge, work done by a variable force

**Prerequisite Skills**

mathematical acumen (in integration, variation analysis), drawing skill (i.e. proper illustration or representation of problem)

## LESSON OUTLINE

| | |
|---|---|
| **Introduction** | Review the concept of work |
| **Motivation** | Computation activity |
| **Instruction** | Discussion Proper |
| **Evaluation/ Enrichment** | Calculation of the Total Electric Potential |
| **Materials** | Illustration board containing schematics of different charge configurations |

**Resources**

(1) Young and Freedman. University Physics. 9th Edition.

(2) Tipler, Paul. University Physics. 4th Edition.

## INTRODUCTION

1. **Review the concept of work.** Suppose an object is under the action of a constant force. Make sketches (using arrows) showing the relative directions of the force and object's displacement when the work done by the force is: **positive, negative, zero**.

2. Suppose an object travels from point A to point B. Suppose also that two constant opposite forces $\mathbf{F_1}$ and $\mathbf{F_2}$ act on the object. When might the *net work* done on the object be positive, negative, zero? Illustrate your answers.

## MOTIVATION

1. Ask a student to determine the electric force **F** experienced by a test charge +q in the presence of an electric field **E**. [Here the student is expected to invoke the definition of the electric field **E** = **F**/q so that **F** = q**E** and that since q is positive then **F** is in the same direction as **E**.]

2. Now, suppose the charge in No. 1 is made to move at constant velocity from point A to point B against the direction of **E**. Determine the magnitude of the force $\mathbf{F_2}$ that must be applied to carry this out. [Here the student is expected to answer $\mathbf{F_2} = -\mathbf{F} = -q\mathbf{E}$.]

3. Ask a student to write down the expression for the infinitesimal work done in moving the charge +q from point A to some other displacement towards point B at constant velocity against **E**. [Here the student is expected to answer $dW = \mathbf{F_2} \cdot \mathbf{dr} = -q\mathbf{E} \cdot \mathbf{dr}$] Then, ask for the total work done in doing the same. [Here the student is expected to answer $W = \int_A^B dW = \int_A^B -q\mathbf{E} \cdot \mathbf{dr} = -q\int_A^B \mathbf{E} \cdot \mathbf{dr}$].

4. The ratio of the total work done in moving the charge from A to B to the charge q is called the electric potential difference or simply the electric potential $V = V_B - V_A = W_{A\text{->}B} / q = -\int_A^B \mathbf{E} \cdot \mathbf{dr}$.

## INSTRUCTION

1. Write down the expression for the electric field **E** at a distance *r* away from a source charge +**Q**. You can do this in two ways: first, by calculating $\mathbf{F}_{electric}$ between +**Q** and some test charge +*q* separated by a distance *r*, and then using the definition of the electric field **E**, or second, by invoking Gauss's law.
[Here the expected answer is $E = \vec{E} = \frac{kQ}{r^2}\,\hat{\mathbf{r}}$.]

2. Now, write down the expression for the potential $V = V_B - V_A$ in moving a test charge *q* from point A to point B against the electric field **E**.

[Here the expected answer is $V = \frac{W_{A->B}}{q} = -\int_A^B \mathbf{E} \cdot \mathbf{dr} = -\int_A^B \vec{\mathbf{E}} \cdot \vec{\mathbf{dr}} = -\int_A^B \frac{kQ}{r^2} \hat{\mathbf{r}} \cdot dr\hat{\mathbf{r}} = -kQ\int_A^B r^{-2}dr = -kQ \left[ -\frac{1}{r} \right]_A^B = kQ \left[ \frac{1}{r_B} - \frac{1}{r_A} \right]$]

3. Rewrite your answer in No. 2, assuming $r_B = r$ and $r_A = \infty$. So that now, the electric potential *V* at a distance *r* away from a source charge Q is given by the expression: $V = \frac{kQ}{r}$. What makes this expression much easier to interpret than the expression for the electric field **E**?

4. **Have the students solve** these problems and **interpret the output**:
   a. Find *V* 1.0 m away from a +1-C charge. Draw where t*his V* is measured in (i) 1 dimension, (ii) 2 dimensions, and (iii) in 3 dimensions.
   b. Find *V* 1.0 m away from a –1-C charge. Draw where this V is measured in (i) 1 dimension, (ii) 2 dimensions, and (iii) in 3 dimensions.

## DISCUSSION

1. Inquire about the factors that affect the electric potential *V*.

2. The locus of points having the same potential *V* is called an equipotential line or an equipotential curve. Draw the equipotential lines around a positive source charge Q.

3. Draw the equipotential lines around a positive source charge Q.

## EVALUATION AND ENRICHMENT

(Calculation of the Total Electric Potential):

1. Have the students calculate the total electric potential at the center of:
   a. A line segment of length 1.0 m with a +1-C charge and a –1-C charge at its endpoints;
   b. An equilateral triangle of side length 1.0 m with alternating +1-C, –1-C, and +1-C charges placed at its vertices;
   c. A square of side length 1.0 m with alternating +1-C, –1-C, +1-C, and –1-C charges placed at its vertices

2. How did your answers in No. 1 compare with you electric field calculations for similar configurations.

60 MINS

# Capacitors in Series and Parallel pt. 1

**Content Standards**

The learners demonstrate an understanding of capacitors in series and parallel.

**Performance Standards**

The learners shall be able to use theoretical and experimental approaches to solve multi-concept and rich-context problems involving electricity and magnetism.

**Learning Competencies**

At the end of the session, the students should be able to :

1. Draw a circuit diagram of capacitors in series and in parallel;
2. Explain what happens to the electric charge, voltage and capacitance for capacitors in series and in parallel;
3. Explain why a series connection is a voltage divider and why a parallel connection is a current (charge) divider;
4. Calculate the equivalent capacitance of a network of capacitors connected in series/parallel (**STEM_GP12EM-IIId-24**)
5. Explain the use of capacitors in series and in parallel.

**Prerequisite Knowledge**

electric charge, electric potential, electric field, electric force

**Prerequisite Skills**

comprehension of ratio and proportion, variational analysis, visualization techniques, integration techniques

## LESSON OUTLINE

| | |
|---|---|
| **Introduction** | Review of prerequisite knowledge |
| **Motivation** | Experiment activity |
| **Instruction** | Discussion proper |
| **Evaluation/ Enrichment** | Calculation of Total Electric Potential |
| **Materials** | Illustration board containing schematics of different charge configurations |

**Resources**

(1) Young and Freedman. University Physics. 9th Edition.

(2) Tipler, Paul. University Physics. 4th Edition.

## INTRODUCTION

1. Inquire about the operational and geometric definitions of capacitance C.

   [$C = \frac{Q}{V} = \varepsilon_0 \frac{A}{d}$, please refer to previous lesson on capacitance.]

2. **Have the students write down the meaning of each of the symbols** present in the above definitions.

## MOTIVATION

1. Present **circuit diagrams of 2 capacitors in series and in parallel** (without actually mentioning the words series and parallel). Ask a student to **differentiate the electric current across the circuits** (assuming the system of capacitors is connected to the same DC-voltage source). Query: Which circuit has the same current throughout? Which circuit has current that changes across the electric path (loop)? Why?

2. From the above circuit diagrams ask a student to **differentiate the electric potential between the 2 circuits** (assuming the system of capacitors is connected to the same DC-voltage source). Query: Which circuit has the same electric potential throughout? Which circuit has electric potential that changes across the loop(s)? Why?

3. At this point, **allow the class to have discussion(s) according to groups**. Ask them to write their group answers on the blackboard (whiteboard).

## INSTRUCTION

1. Electric charge Q is a conserved physical quantity. This means that the total charge in a circuit stays the same. As a charge Q, therefore, passes through a SERIES (or a one-path system) connection of capacitors, each capacitor gets the same total charge Q such that $Q_1 = Q$ and $Q_2 = Q$. Moreover, when Q passes through a PARALLEL (or a multi-path system) connection of capacitors, Q splits up according to the number of paths present. In this case, $Q = Q_1 + Q_2$.

2. From 1, we see that charge Q splits or divides in a parallel connection. What stays the same in a parallel connection? The answer is the electric potential V. Recall that $V = \frac{W}{Q}$. And, in a parallel connection, the same work W is done on the charge Q no matter which parallel

path is taken. Therefore, we have: $V = V_1 = V_2$. What about the electric potential in a series connection? Since the electric potential V is related to the scalar work W done to move the same charge Q across the series circuit when $W = W_1 + W_2$ or more simply, $V = V_1 + V_2$.

3. Let's summarize what we have so far: For a SERIES connection of capacitors: $Q = Q_1 = Q_2$ and $V = V_1 = V_2$. For a PARALLEL connection of capacitors: $Q = Q_1 + Q_2$ and $V = V_1 + V_2$.

## DISCUSSION

1. Using the definition $C = Q/V$, show that for a SERIES connection of capacitors: $1/C = 1/C_1 + 1/C_2$. What does this equation mean? What happens to C as more and more capacitors are connected in series?

2. Using the definition $C = Q/V$, show that for a PARALLEL connection of capacitors: C = C1 + C2. What does this equation mean? What happens to C as more and more capacitors are connected in parallel?

## EVALUATION AND ENRICHMENT

(Circuit Diagrams and Calculation Problems):

1. Consider two capacitors $C_1 = 200\mu F$ and $C_2 = 600\mu F$ connected in series across a source of voltage V = 4 volts. Draw the circuit diagram for this situation. Determine: (a) C, (b) Q, (c) $Q_1$ and $Q_2$, and (d) $V_1$ and $V_2$.

2. Consider two capacitors $C_1 = 200\mu F$ and $C_2 = 600\mu F$ connected in parallel across a source of voltage V = 4 volts. Draw the circuit diagram for this situation. Determine: (a) C, (b) Q, (c) $V_1$ and $V_2$, and (d) $Q_1$ and $Q_2$.

3. From 1 and 2, why are (c) and (d) swapped in positions in terms of solving the unknowns?

4. Repeat 1 and 2 but this time add a third capacitor $C_3 = 800\mu F$. Summarize your answers using a C-Q-V table like below:

| Capacitor # | C (in μF) | Q (in μC) | V (in Volts, V) |
|---|---|---|---|
| 1 | 200 | | |
| 2 | 600 | | |
| 3 | 800 | | |
| Equivalent | | | 4 |

60 MINS

# Capacitors in Series and Parallel pt. 2

**Content Standards**

The learners demonstrate an understanding of capacitors in series and parallel.

**Performance Standards**

The learners shall be able to use theoretical and experimental approaches to solve multi-concept and rich-context problems involving electricity and magnetism.

**Learning Competencies**

At the end of the session, the students should be able to :

1. Define operationally capacitance;
2. Define geometrically capacitance;
3. Draw a schematic diagram of a capacitor;
4. Determine the potential energy stored inside the capacitor given the geometry and the potential difference across the capacitor (**STEM_GP12EM-IIId-26**)
5. Describe the effects of inserting dielectric materials on the capacitance, charge, and electric field of a capacitor (**STEM_GP12EM-IIId-29**)
6. Identify certain types of capacitors.

**Prerequisite Knowledge**

electric charge, electric field, electric potential, dielectric

**Prerequisite Skills**

mathematical acumen (in integration, variation analysis), drawing skill (i.e. proper illustration or representation of problem)

## LESSON OUTLINE

| | |
|---|---|
| **Introduction** | Show an image of a parallel-plate capacitor |
| **Motivation** | Compare and contrast capacitors |
| **Instruction** | Discussion on Concepts of Capacitance |
| **Enrichment/ Evaluation** | Effect on the capacitance when a dielectric is inserted between the places of the capacitor |
| **Materials** | Images of parallel-plate capacitors, cylindrical, spherical capacitors<br>[Note: It would be best if there will be capacitors that the students can Actually see and touch |

**Resources**

(1) Young and Freedman. University Physics. 9th Edition.
(2) Tipler, Paul. University Physics. 4th Edition.
(3) https://dornsife.usc.edu/assets/sites/75/imgs/electrostatistics/c1.JPG
(4) https://upload.wikimedia.org/wikipedia/commons/b/b9/Capacitors_(71895597135).jpg
(5) http://astarmathsandphysics.com/university-physics/electricity-and-magnetism/parallel-plate-capacitors-html-9fd61e5.gif
(6) http://www.electrotechservices.com/electronics/images/capacitor_symbols.jpg
(7) https://courses.cit.cornell.edu/ee476/FinalProjects/s2007/cc399_ya43/476%20webpage/index2_files/index_files/image015.gif
(8) https://upload.wikimedia.org/wikipedia/commons/thumb/3/35/Parallel_plater.svg/2000px-Parallel_plate_capacitor.svg.png

## INTRODUCTION

1. **Show an image of a parallel-plate capacitor** like the figure below (Best to show an actual capacitor as a circuit element.):

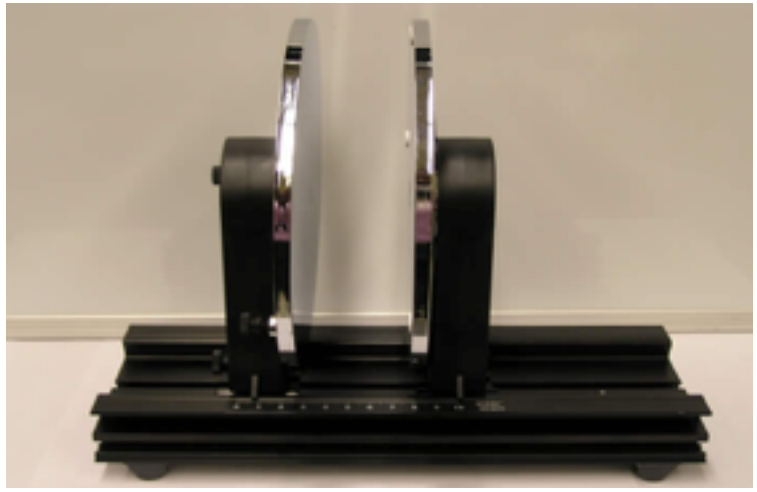


Fig 1.A parallel-plate capacitor

2. **Have the students identify the parts of the parallel-plate capacitor** shown above.

## MOTIVATION

1. Ask a student to compare and contrast the capacitors shown in the diagram below. (Best to show different types of capacitors that the students can actually see and touch and identify.)


Fig. 2. Sample capacitors

2. Ask a student to give examples of devices and/or gadgets that make use of capacitors.

3. Ask a student to give possible uses and/or functions of capacitors in the aforementioned devices and/or gadgets.

## INSTRUCTION

1. **Introduce the concept of capacitance.** Capacitance is the ability of an object (in this case a circuit element) to store an electric charge Q. The circuit element that has this property is called a capacitor. When a capacitor is connected in series to a power supply (in this case, a DC-power supply of potential V), charges – Q and + Q are stored in the plates of the capacitor when they are connected to the negative and positive terminals of the DC-power supply, respectively. The potential across the plates of this capacitor is then equal to the potential V of the power supply. This is best illustrated in the diagram below.

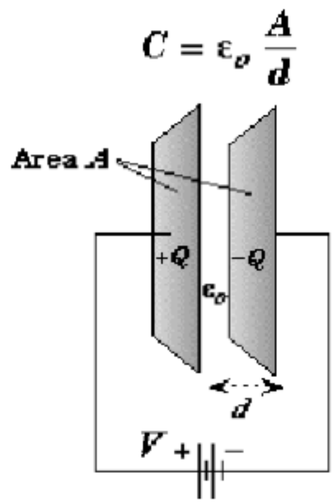



Fig.3. Charging a parallel-plate capacitor

2. **Have the students explain:** (a) why the charges in the plates are ±Q, (b) why the potential between the plates is V.

3. **Discuss the operational definition of capacitance.** Capacitance C is defined as the ratio of the charge Q = |±Q| stored in each plate to the potential V between the plates. That is, $C = \frac{Q}{V}$ .

4. **Ask a student what the unit of capacitance is.** (The answer which is the Coulomb per Volt (C/V) is equivalent to the Farad (F). This unit is named after Michael Faraday.

5. **Ask a student to discuss the relationship** among C, Q and V.

6. **Discuss the geometric definition of capacitance.** Moreover, the capacitance C as a circuit element depends on the area A of each plate and the distance d between the plates. That is, $C = \varepsilon_0 \frac{A}{d}$

7. **Ask a student to discuss the relationship** among C, A and d.

8. **In a circuit, the schematic symbols for a capacitor is shown below:**

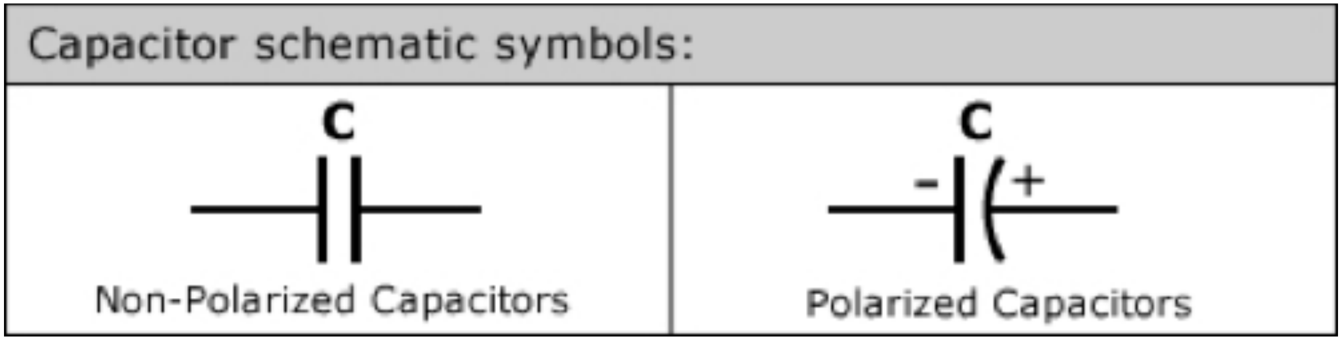



Fig. 4.Some schematics for capacitors

9. **In a charged parallel-plate capacitor, the stored charges ±Q in the plates give rise an electric field E between the plates**. This is illustrated in the figure below:

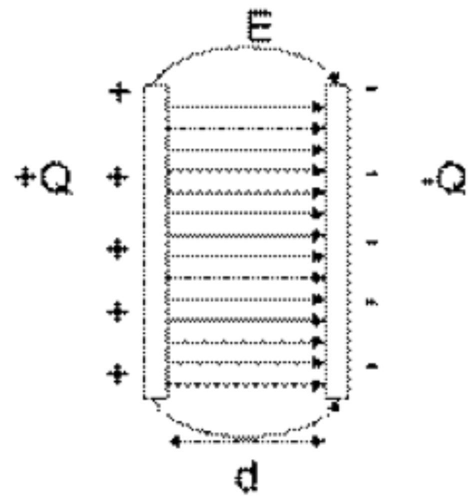



Fig. 5.Electric field in a charged parallel-plate capacitor

## DISCUSSION

1. What is the relationship between the electric field $\vec{\mathbf{E}}$ and the electric potential V between the plates of the capacitor? Explain.

2. Where is the energy stored in a parallel-plate capacitor? Explain.

3. Let the energy stored "in the capacitor" be U. Show that U is given by the expression: $U = \frac{1}{2}\frac{Q^2}{C}$

   [Hint: The power P in the capacitor is given by $P = \frac{dU}{dt} = IV$ where $I = \frac{dQ}{dt}$. This is a simple exercise on integration.]

## EVALUATION AND ENRICHMENT

(Effect on the capacitance when a dielectric is inserted between the plates of the capacitor):

**1. Have the students recall the definition of a dielectric. Have them write down the definition on the board.**

**2. Have the students discuss in groups the result that happens when a dielectric is inserted between the plates of the parallel-plate capacitor. The general schematic for this situation is shown in the figure below:**

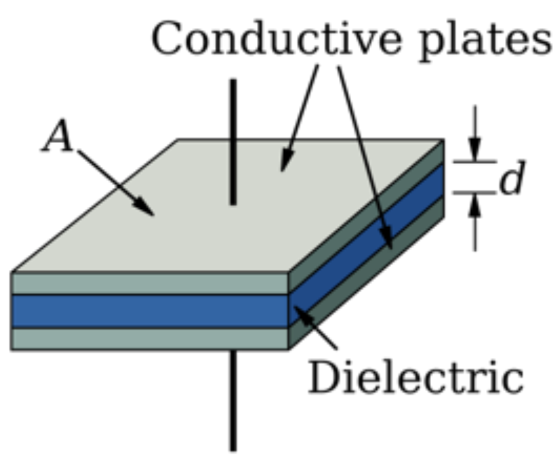



Fig. 6.Dielectric inserted between the plates of a parallel-plate capacitor

3. **Have the students answer the following questions as guide to their analysis:**
   a) When a dielectric is inserted between the plates of the capacitor, what happens to the dielectric?
   b) What then happens to the net electric field $\vec{\mathbf{E}}_{net}$ between the plates?
   c) What the effect of your answer in (b) to the potential V between the plates? Why?
   d) What is the effect of your answer in (c) to the capacitance C? Explain.

60 MINS

# Huygens Principle and the Principle of Superposition

**Content Standards**

The learners demonstrate an understanding of Huygen's Principle.

**Performance Standards**

The learners shall be able to:

1. Use theoretical and, when feasible, experimental approaches to solve multiconcept, rich-context problems using concepts from electromagnetic waves, optics, relativity, and atomic and nuclear theory
2. Apply ideas from atomic and nuclear physics in contexts such as, but not limited to, radiation shielding and inferring the composition of stars

**Learning Competencies**

At the end of the session, the students should be able to :

1. Solve problems involving interference and diffraction using concepts such as path length, phase difference , and path difference. **(STEM_GP12OPT-Ivf-g36)**
2. Relate the geometry of the diffraction experiment set-up (slit size, and screen to slit distance) and properties of light (wavelength) to the properties of the diffraction pattern (width, location of intensity of the fringes). **(STEM_G12OPT-IVf35)**
3. Determine the conditions (superposition, path and phase difference, polarization, amplitude) for interference occur, emphasizing the properties of a laser (as a monochromatic and coherent light source) **(STEM_GP12OPT-Ivf-32)**

**Prerequisite Knowledge**

Wavelength, frequency, and wave speed.

$\Psi (x,t) = A \cos(k x - \omega t)$

**Prerequisite Skills**

STEM_GP12PM-IId-31, STEM_GP12PM-IId-32, STEM_GP12PM-IId-35

## LESSON OUTLINE

| | |
|---|---|
| **Introduction** | Examine the behavior of water waves |
| **Instruction/ Discussion** | Lecture Proper |
| **Enrichment/ Evaluation** | Short Quiz |

**Resources**

(1) Crowell, Benjamin, *Simple Nature: An Introduction to Physics for Engineering and Physical Science Students*, www.lightandmatter.com (last accessed October 10, 2015)
(2) Arons, Teaching Introductory Physics
(3) Giancoli, Physics, 6th ed.
(4) https://www.khanacademy.org/science/physics/light-waves/interference-of-light-waves/v/youngs-double-split-part-1

## INTRODUCTION

Tell students that light, as we currently know it, behaves in a wave-like manner. So far, we have concentrated on the aspects of light that can be explained by a particle model (geometric or ray optics). We now need to examine the ways in which light behaves like a wave.

We will examine the behaviour of water waves, and use the knowledge gained to make predictions of analogous behaviour of light as a wave, e.g. interference and diffraction.

A ripple tank is usually a glass or transparent plastic container filled with shallow water. (You can start with 5 mm depth and then adjust the depth using glass plates.) A substitute for this tank is a washbasin filled with shallow water.

The following may be done as a demo, or as a challenge for students to perform.
A good detailed source is the Nuffield Foundation's website: http://www.nuffieldfoundation.org/practical-physics/basic-experiments-ripple-tanks A video of ripple tank demonstrations can be found at https://www.youtube.com/watch?v=3QiK4gR8Svs Or you can perform a keyword search for videos using google with keywords "ripple tank experiments."

It is strongly advised that the teacher perform the demonstrations long before coming to class.

1. Use a ripple tank to produce a spherical pulse by letting a water drop fall into a ripple tank.

2. Use a ripple tank to produce spherical waves by letting your finger go up down the water surface at regular intervals. Adjust the period of oscillation (the time it takes your finger to repeat its up and down motion) and see how the wavelength and speed changes as the frequency is changed.

   You may use an image of the circular waves produced by letting your finger or a motorized cylinder to review the concept of wavelength, frequency, and wave speed.

3. Now let two droplets fall down simultaneously on two opposite sides of the ripple tank. Pay special attention to how the waves from each droplet combine at another point. (This can be used as the starting point of the discussion of Huygens Principle. *The demos from 5 onwards may be done on the same day, or on the other days when diffraction through a single slit and a double slit are discussed*)

4. Use a ripple tank and a ruler with its edge bobbing up and down to produce plane waves on shallow water.

5. Usually, a small motor is used to make the ruler or straight edge oscillate if we want plane waves. If the ruler is replaced by small cylinder bobbing up and down, one can produce circular waves. If available, you can use a motor to automatically produce the water waves. The advantage of a motor is the frequency of oscillation can be regulated. For manually driven water waves, we are usually limited to small frequencies.

6. In succeeding lessons, you may use the ripple tank to produce refraction of waves. The way to produce this is to place a thin plate (around 3mm) so that there will be shallower and deeper portions on the ripple tank. If you now generate a plane wave and make it travel towards the boundary between the deeper and the shallower edge, you can produce refraction in water waves. You can adjust the angle of incidence and see how the angle of refraction changes as a result

   Ask students to observe the wavelengths. How does the wavelength change as the plane wave travels from deeper to shallower water? How does the frequency change as it goes from deeper to shallower water? How does the speed change as it goes from deeper to shallower water? (Longer wavelengths in deeper water. No change in frequency. Faster speeds in shallower water.)

7. To produce single-slit diffraction, one can place a divider with a slit for plane water to pass through. Adjust the slit size. As the slit gets larger, the diffraction effect gets smaller.

8. To produce double slit diffraction, place a divider with two slits for plane water waves to pass through. Ensure that the slit size is of the same order of magnitude as the wavelength of the water wave.

## INSTRUCTION

**Teacher Tip:**
The goal is to extract Huygens Principle from the experiments.

Each of these points should be made:

1. In the following discussion, we will assume *coherent sources.* This means the sources should satisfy the following conditions:
   A. single wavelength
   B. of the same phase along directions perpendicular to the direction of propagation of the wave.

2. Huygens Principle can be motivated using the droplet falling on the ripple tank. The landing point of the droplet acts as a source of a pulse or wave that propagates away from the source point. If we have many sources, each of these sources must affect a point where the disturbance is measured.

3. *Huygens Principle* may be stated in this way: Each point on a wavefront acts as a source of spherical waves. At an observation point a distance d away from the wavefront, the contribution of the point on the wavefront to the total wavefunction $\Psi_{total}$ at the observation point is given by

$$\Psi = sin( \frac{2 \pi}{\lambda}d +\phi)$$

where $\phi$ is the phase. Since there are an infinite number of points on a wavefront, the wavefunction $\Psi_{total}$ at the observation point should be an (infinite) sum over all the contributions of each point on the wavefront.

$$\Psi_{total} = \sum \Psi$$

4. For two point sources, we only need to add the contribution of two points. Suppose point A and B are two point sources with the same phase, frequency, and amplitude. Let point C be the observation point. Then the wavefunction at the point C is given by (with $\phi$ as the phase)

$$\Psi_C =sin( \frac{2 \pi}{\lambda}d_A +\phi)+sin( \frac{2 \pi}{\lambda}d_B +\phi)$$

if we simplify this, we end up with (with $k\equiv \frac{2\pi}{\lambda}$ )

$$\Psi_C = 2 sin (k(d_A+d_B)/2 +\phi/2) cos(k(d_A-d_B)/2)$$

what determines constructive or destructive interference is the cosine term.

The argument of the cosine term $\frac{\pi (d_A-d_B)}{\lambda}$is known as the *phase difference*.

If the phase difference is $\frac{\pi}{2} +n \pi$ with an integer, the cosine is zero, and we have totally *destructive interference*. On the other hand, if the phase difference is $n\pi$, then we have totally *constructive interference.*

5. Instead of calculating everything using wavefunctions, it is helpful to just calculate the *path length difference*, if we want to find out if two point sources interfere constructively or destructively at the observation point..

6. In terms of the *path difference* $(d_A-d_B) = (n+1/2) \lambda$ leads to *destructive interference*, while if the path difference is $(d_A-d_B) = n \lambda$ leads to *constructive interference*.

7. *Visualizing interference from two point sources.* Suppose you have two coherent point sources 3 cm apart. Call one point A, and call the second point B. Assume that the wavelength is 1 cm. Draw the two sources on a piece of paper, and ensure a 3 cm separation. Draw concentric circles of radius $R_n = n$ (1 cm) around each point. Use blue ink for the circles with center A, and black ink for circles with center at B. Points on which the circles intersect will be places where the waves will be at a maximum.

8. Path difference change when passing through a medium with an index versus in air.

9. *Optical path length when light is reflected by a medium with an index.* If the medium that reflects has a higher index of refraction, then the phase is shifted by $\pi$. This leads to an effective additional path length (or *path length shift*) of $\frac{\lambda}{2}$

   If the medium that reflects has a lower index of refraction, then there is zero phase shift, and zero change in the optical path length.

## DISCUSSION

Provide sample questions and demonstrate the solution

## INDIVIDUAL WORK

1. Assign a question similar to one of the sample questions.

2. Check student work.

## EVALUATION

Ask a multiple choice question similar to the one in Appendix A

## HOMEWORK

Do the homework in Appendix A

## ENRICHMENT

Ask the student to do the optional part of the homework. This will require knowledge of hyperbolae. (A hyperbola is defined as the locus of all points such that the difference of the distances from a point on the hyperbola to one focus

### APPENDIX A

**Sample Problem 1**

Two sources of radio waves separated by a distance of 3k produce coherent waves of wavelength 100 m. As you walk in a straight line from one radio source to the other, the signal on your radio receiver alternately gets strong and weak. Calculate whether the signal is trong or weak after walking

A. 100m
B. 125 m
C. 250 m.

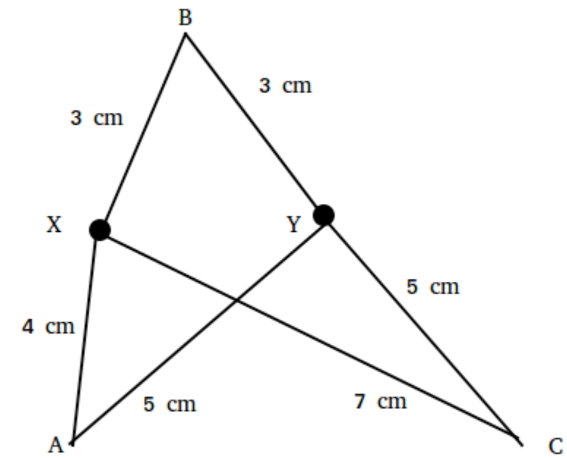
Answer:

A. path length difference =(3000 m-100 m)-(100 m) =2800 m
   2800 m/100 m= 28, an integer. This means we have a strong signal

B. B. path length difference =(3000 m-125 m)-(125 m) =2750 m
   2750m/100m =27.5, an integer and a half. This means we have a weak signal.

C. C. path length difference =(3000 m-250 m)-(250 m) =2500 m
   2500 m/ 100 m = 25, an integer. This means we have a strong signal.

**Sample Problem 2**



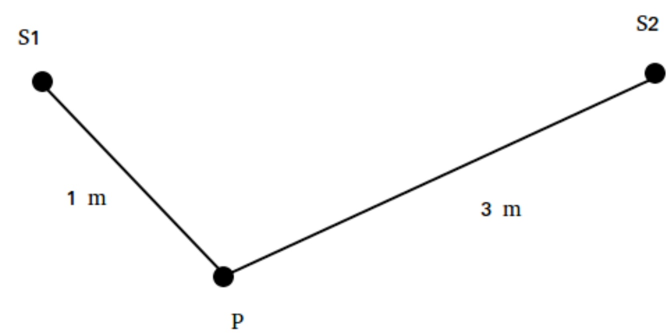

X and Y in the Figure are coherent sources of 2 cm waves. (The wavelength is 2 cm) Will they interfere constructively or destructively at points A, B, and C?

Answers:

A. destructive (path difference =1 cm)
B. constructive (path difference =0 cm)
C. constructive (path difference= 2 cm)

**Sample Multiple Choice Question 1**

Water waves of wavelength 2.0 m are produced by two sources S1 and S2 . The sources vibrate in phase.




Point P is 1 m from S1 and 3 m from S2 . S1 alone and S2 alone each produce a wave of

amplitude A at P. Which one of the following is the amplitude of the resultant wave at point P when S1 and S2 are both emitting waves?

A. 2A
B. A
C. (½) A
D. Zero

Answer: A.

**Sample Homework**

*Visualizing interference from two point sources.* Suppose you have two coherent point sources 3 cm apart. Call one point A, and call the second point B. Assume that the wavelength is 1 cm.

1. Draw the two sources on a piece of paper, and ensure a 3 cm separation. Draw concentric circles of radius $R_n = n$ (1 cm) around point A for n=1, 2, 3. Use blue ink for the circles with center at A.

2. Draw the two sources on a piece of paper, and ensure a 3 cm separation. Draw concentric circles of radius $R_n = n$ (1 cm) around point B for n=1, 2, 3. Use blue ink for the circles with center at B.

3. Draw concentric circles of radius $R_n = (n + 1/2)$(1 cm) around point B. Use black ink for the circles with center B.

4. At points where the blue and black circles intersect, do the waves interfere constructively or constructively?

For exceptional students:

5. What figure is formed from the locus of all points for which the path difference from A and B is equal to 0.5 cm, 1.5 cm, 2.5 cm? (Answer: hyperbolae). Sketch these figures using red ink.

6. What figure is formed from the locus of all points for which he path difference from A and B is equal to an integer multiple of the wavelength? Sketch these figures for path difference 1cm, 2 cm, 3 cm. Sketch these figures using green ink.

7. If the sources are EM waves, and we place a line detector on the surface of the paper, locate the places where the detector finds constructive and destructive interference.

60 MINS

# Current, Resistance, and Resistivity; Ohm's Law II

**LESSON OUTLINE**

| | |
|---|---|
| **Introduction** | Explain electrical phenomena |
| **Motivation** | Connecting the phenomena to real-life situations |
| **Instruction** | Lecture Proper |
| **Evaluation** | Short activity |
| **Enrichment** | Brief Presentation |

**Resources**

(1) Arons, Teaching Introductory Physics
(2) Giancoli, Physics, 6th ed.

**Content Standards**

The learners demonstrate an understanding of

1. current, resistivity, and resistance
2. Ohm's Law

**Performance Standards**

The learners shall be able to use theoretical and experimental approaches to solve multi-concept and rich-context problems involving electricity and magnetism.

**Learning Competencies**

At the end of the session, the students should be able to :

1. Calculate the power consumption of a circuit element when the voltage applied and the current passing through the circuit element is known.
2. Calculate the power consumption of a resistor given two of the following: the resistance, applied voltage, current through the resistor.
3. Relate the drift velocity of a collection of charged particles to the electrical current and current density. **(STEM_GP12EM-III-e34)**
4. Draw a circuit diagram for a simple battery and bulb circuit.

**Prerequisite Knowledge**

electric potential, potential difference , Leyden jars, electrostatic charging and discharge.

**Prerequisite Skills**

Reasoning with ratios and proportions

## INTRODUCTION

Write the technical terms current and resistance on the board, and tell them that we will study what these terms mean. Our goal is to explain electrical phenomena such as electric shocks.

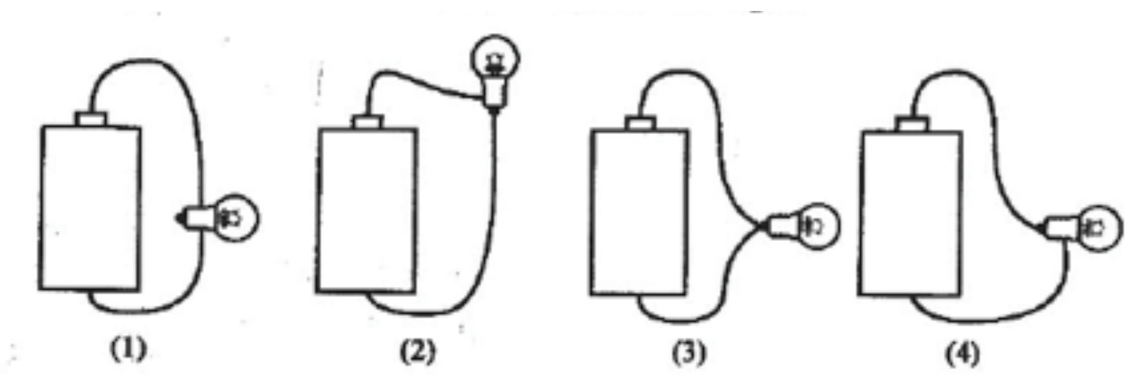
**Teacher Tip:**

Before the class starts, it would be useful to assign homework or do a lab activity. See Appendix 2

## MOTIVATION

1. Ask students to give common situations where these (technical terms -current, resistance, etc) are used in everyday life.

2. Draw possible ways of connecting the wire, the battery, and the bulb. Ask students to identify which arrangements cause the bulb to light up.




3. Draw the wire and battery setup. Ask students if the wire's temperature increased, decreased or stay the same.

4. State that today's lesson is about bringing together these observations, and to introduce operational definitions of current and resistance.

## INSTRUCTION

Each of these points should be made:

1. In a direct current simple circuit, the current is conventionally assumed to be a positive fluid flowing from the positive terminal of the battery, then through the bulb, and then through the wire, and then back to the negative terminal of the battery. To make a *complete circuit*, we must also assume that charge flows from the negative terminal through the battery and then comes out again at the positive terminal.

2. *Current* is the rate at which charge flows through a cross-sectional area of the wire or through a circuit element. In a simple circuit, current flow is the same all throughout, since we do not observe charge buildup at any point of the circuit.

3. Wires heat up when current is passing through. The heating effect, assuming fixed voltage, increases when the thickness of the wire decreases, or when the wire becomes shorter. (The heating rate can be estimated using P= V^2/R, where P is the power, but this will be discussed in the next lesson.) This phenomenon is called *Joule heating*.

4. Current depends on the applied voltage. This leads to the definition of resistance as R=V/I . (This is also called *chordal resistance*, since it is the slope of the line or chord connecting the origin of a current versus voltage graph to a point on the V-I curve. Another definition of resistance, which we will not use, is the *differential resistance* dV/dI, which is the slope of the tangent line to the V versus I graph)

5. An early experiment on comparing resistances can be found in the Cavendish manuscripts. Cavendish used a frictional generator to produce a fixed voltage relative to the ground, and thus a fixed amount of charge. He then let this charge pass through a metal wire, through his body, and then to the ground. The metal wires were varied in length and the kind of metal used. By recording how painful the discharge was, Cavendish was able to rank objects by what we now know as resistance.

6. A graph of V versus I can be used to characterize the (current) response of a circuit element to an

**Teacher Tip:**

The goal is to extract, from experiments and a discussion of these experiments, the need for the concepts of current, resistance, resistivity, and conductivity. After these, we need to state the definitions. See Appendix 1 for a possible discussion sequence.

applied voltage. If the voltage is proportional to the current, the circuit element is said to be ohmic resistor. Ohmic resistors are said to follow Ohm's law: Voltage is proportional to current.

$$V = I\,R$$

7. The light bulb is not an ohmic circuit element, thus a calculation of resistance will show that it depends on the applied voltage. A light bulb will not follow Ohm's law. (One joke is "Ohm's law is a law, except for when it isn't.") A sample current versus voltage graph for a light bulb:

An ohmic resistor, on the other hand, will show a linear V versus I graph that passes through the origin. An experimental way of determining whether a material is ohmic or not is to measure the current response of a circuit element to an applied voltage, and then plot the result.

Plotting the current response of a light bulb versus the applied voltage is a good experiment for students to do, since it shows that making a linear fit to the graph is sometimes not appropriate.

8. *Pouillet's law.* The resistance of a wire is proportional to the length L of the wire inversely proportional to the cross-sectional area A. The proportionality constant is defined to be the *resistivity* $\rho$.

$$R= \rho \frac{L}{A}$$

9. *Conductivity* $\sigma$ is defined to be the multiplicative inverse of resistivity $\rho$.

$$\sigma= \frac{1}{\rho} =\frac{L}{A R}$$

10. *Resistance is temperature dependent.* For small temperature intervals, the resistance has a linear dependence on temperature.

$$R(T)= R_0 [1+ \alpha (T-T_0)]$$

where $\alpha$ is either experimentally determined, or found in a table.

11. Common electrical symbols need to be introduced. See Appendix 3. For today, you will only need the following symbols: light bulb, the cell, the battery. For the homework, you will need to include symbols for the voltmeter and ammeter.

12. *Microscopic model of currents.* Many currents can be interpreted as the motion of electrons. In resistors and wires, the current is due to electrons moving in the direction opposite to the electric field; that is, from lower to higher electric potential. The electrons travel at an average velocity known as the drift velocity; the field does not increase the speeds, on average, since electrons also undergo collisions and lose energy. The energy lost is macroscopically seen as Joule heating.

The electron paths are modeled using a random walk, with drift.

The drift velocity $v_d$ can be calculated in a metal wire can be calculated assuming the other quantities are known:

$$I = n\, e\, A\, v_d$$

where

n is the electron density (number of electrons divided by the volume containing these electrons)

e is the electron charge

A is the cross-sectional area of the metal wire.

## DISCUSSION

Provide sample questions and demonstrate the solution. See Appendix 4

## INDIVIDUAL WORK

1. Assign a short exercise for students to solve in class. See Appendix 4.

2. Check student work.

## EVALUATION

Ask students to list the experiments we discussed. For each experiment, what concept needed to be defined. Write the symbols used for each concept, and the defining equations, with all symbols used identified.

| **Experiment** | **Concepts and Equations** |
|---|---|
| Wire and Battery | |
| Wire, Bulb, and Battery | |
| Cavendish electrical shock experiments | |

## HOMEWORK

Draw the symbols for a voltmeter and ammeter, and then assign Question 7 from appendix 4.

## ENRICHMENT

Ask students prepare a presentation on the following:

1. What is chordal and differential resistance?
2. Electrical temperature sensors in phones and computers.

## APPENDIX 1: Pre-Lesson Lab or Homework

### Homework

Materials

One battery (1.5V),

1 incandescent light bulb rated 1.5 W or less (this the kind found in non-LED flashlights)

a wire

Instructions

1. Connect the light bulb, the battery, and the wire in as many ways as you can. Sketch each of the possible ways in your notebook. For each arrangement, annotate if the bulb lights up or not.
2. There should be at least four possible arrangements that make the light bulb light up. Draw these arrangements, and submit on the designated class meeting.
3. Connect one end of the wire to the positive end of the battery (this end usually has a plus sign) and the other end to the negative end. Do this only for a short time, since it uses up the energy content of the battery. This is known as shorting a battery. What happens to the temperature of the wire? What happens to the temperature of the battery?
4. Examine the wire inside the light bulb. Note that it is much thinner than the wire you may have used.  In what way is shorting the wire similar to how a light bulb operates?
5. The following is a diagram of an incandescent light bulb. Draw the rest of the setup (wire and battery) that made the light bulb light up. Assuming the light bulb is lit by the flow of charge, trace the path that the charges must take as they go into and out of the light bulb, through the wire, and through the battery.
6. Explain why there is an insulator between the metal base and the bottom contact.

**APPENDIX 2: Instruction Strategy**

**Homework**

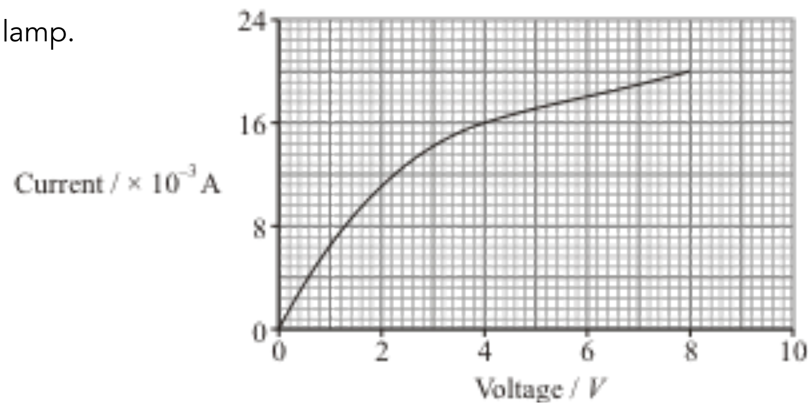
1. Ask students to explain why the wire heats up using the idea of moving charges. (They should describe a temperature increase.) Ask students to explain, in terms of charges, what is happening to the wire.
2. Using a drawing of the battery and wire experiment, trace the flow of charge from the positive terminal of the battery, through the wire, the negative terminal, and then through the interior of the battery, and then back to the positive terminal. Tell students that we are assuming that the charge flowing through the wire is positive. (The same phenomenon, by the way, can be explained by negative charge flowing in the opposite direction. Further experiments are needed, if we want to determine whether the charges flowing are positive or negative. )
3. Tell students that the heating of the wire when current passes through is how an incandescent light bulb works. The main difference is the wires used are very thin, and are place either in an airless container, or one filled with a noble gas. Using this hint, ask students to trace how charge flows through the battery and bulb setups that made the bulb light up.
4. Define current passing through the material as charge passing through DeltaQ divided by the amount of time it takes for this charge to pass through Delta_t. State the SI units (the Ampere) in terms of Coulombs and seconds.
5. Tell students about the Cavendish comparisons of what we now know as resistance. Cavendish used a frictional generator to produce a fixed voltage relative to the ground, and thus a fixed amount of charge. He then let this charge pass through a metal wire, and then through his body. He noticed that the longer the wire used, the less painful the shock. (Draw this and trace the path of the current) Instead of using wires of different lengths, one can substitute different materials, and compare how painful the discharge is. We are therefore led to the idea of resistance. Materials have different current responses to a given voltage.
6. Define resistance as (voltage applied)/(current produced)
7. Go back to the example of the light bulb. Recall that the current or response of the wire to the applied voltage depends on how thin the wire is. this will lead to the concept of resistivity. The resistance of the wire increases when the length increases, from the Cavendish experiments. The resistance increases also when the cross-sectional area decreases. This means resistance is proportional to length, inversely proportional to the cross-sectional area of the wire. This leads to a proportionality constant that we will identify as resistivity. Define resistivity as resistance multiplied by area, divided by the length.
8. Define conductivity as the multiplicative inverse of resistivity.
9. State that resistance also depends on temperature. Some temperature sensors apply a fixed voltage and then current is measured. For small temperature intervals, the resistance has a linear dependence on temperature.

**APPENDIX 4: Sample Problems and Exercises**

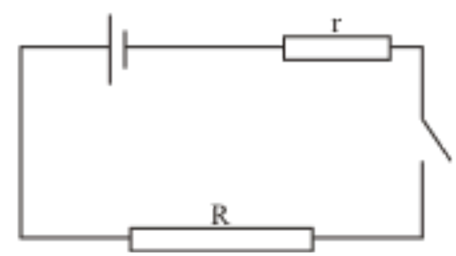
**Multiple Choice:**

1. The drift velocity of the electrons in a copper wire in which there is an electric current is
   A. equal to the speed of light.
   B. close to that of the speed of light.
   C. of the order of a few kilometres per second.
   D. of the order of a few millimetres per second.

2. The graph below shows the current versus voltage characteristics of a filament lamp.
   The resistance of the filament at 4.0 V is ____________________.
   A. 250 Ω.
   B. 4 000 Ω.
   C. 8 000 Ω.
   D. 64 000 Ω.




3. The current in the circuit shown on the right is constant when the switch is closed.




   The energy transfer in the internal resistance r of the battery is 15 J when a charge of 40 C passes through it. For the same amount of charge, 45 J of energy is transferred in the resistor R.

   Which of the following gives the emf of the battery?

   A. $\frac{15}{40}$ V

B. $\frac{30}{40}$ V

C. $\frac{45}{40}$ V

D. $\frac{60}{40}$ V

4. The element of an electric heater has a resistance R when in operation. What is the resistance of a second heater that has a power output three times as large at the same operating voltage?

A. $\frac{R}{9}$

B. $\frac{R}{3}$

C. 3R

D. 9R

5. Which of the following is a correct statement of Ohm's law?

A. The resistance of a conductor is always constant.

B. The current in a conductor is always proportional to the potential difference across the conductor.

C. The resistance of a conductor increases with increasing temperature.

D. The resistance of a conductor is constant only if the temperature of the conductor is constant.

6. Which of the following is a unit for electrical resistance?

A. $WA^{-2}$

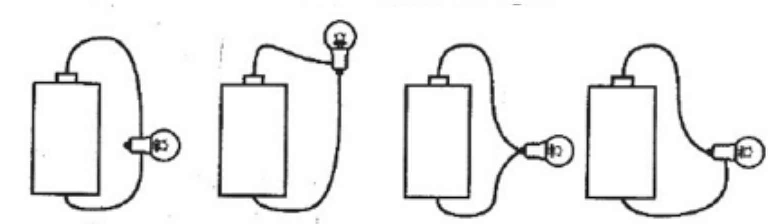
B. $AV^{-1}$

C. $VW^{-2s}$

D. $WV^{-2}$

**Short Response:**

1. Using the symbols for the battery, wire, and light bulb, draw the circuit diagrams for the following:
(Note that you should obtain two diagrams with a shorted battery.)



(1) (2) (3) (4)

2. An 800 mA current is passing through a resistor. The voltage applied to the resistor is 5.0 V. What is the value of the resistance of the resistor?
**Ans.** 6.25 Ohms

3. A resistor has a resistance of 3.20 kΩ. A voltage of 12.0 V is applied across the resistor. What is the value of the current through the resistor?
**Ans.** 3.75 x 10^{-3} A.

4. The resistance of a household water heater is 25.0 Ohms. If the current passing through the heater is 4.40 A, what is the voltage applied?
**Ans.** 110 V

5. In one home audio system, the wires connecting a speaker to the stereo is 20.0 m long. To keep the losses low, we need to ensure that the resistance is no more than 0.10 Ohms per wire. If we use copper wire,
   a) What cross-sectional area should the copper wire have?
   b) What is the radius of the copper wire?
   Note that when buying copper wire, we usually ask for the gauge (or diameter) of the wire. See the American Wire Gauge standards for details.

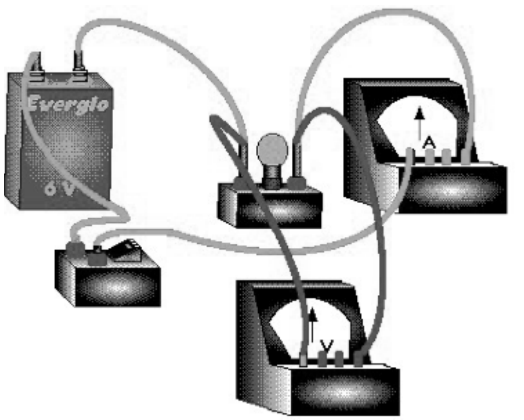
c) f a current of 4.0 A passes through the wire, what is the potential difference or voltage drop, across each wire?

**Ans.** 3.4 x 10^{-6} m^2 ; 1.04 mm; 0.40 V

6. Copper wire in houses typically have a diameter of about 1.5 mm. How long should the copper wire be to have a resistance of 1.0 Ohm?

   **Ans.**

7. Consider the following light bulb, voltmeter, ammeter, and battery setup.




Draw a circuit diagram for this circuit.

60 MINS

# Energy and Power in Electric Circuits

**Content Standards**

The learners demonstrate an understanding of energy and power in electric circuits

**Performance Standards**

The learners shall be able to use theoretical and experimental approaches to solve multi-concept and rich-context problems involving electricity and magnetism.

**Learning Competencies**

At the end of the session, the students should be able to :

1. Define electromotive force (emf) as the work done by a source in driving a unit charge around a complete circuit **(STEM_GP12EMIIIe-39)**
2. Given an emf source connected to a resistor, determine the power supplied or dissipated by each element in the circuit **(STEM_GP12EM-III-e42)**
3. Given the emf and internal resistance of a battery, and the magnitude and direction of the current, determine the rate at which energy is supplied or absorbed by a reversible battery.
4. Given the current passing through a resistor where two of the following three quantities are known (current I, potential difference V, and (chordal) resistance R), calculate the rate P at which energy is dissipated.
5. Solve problems involving current, resistivity, resistance, and Ohm's law in contexts such as, but not limited to, batteries and bulbs, household wiring, selection of fuses, and accumulation of surface charge in the junction between wires made of different materials. **(STEM_GP12EM-III-e44)**

## LESSON OUTLINE

| | |
|---|---|
| **Introduction** | Finding the rates at which energy is dissipated, supplied, or absorbed |
| **Motivation** | Simple observation experiment |
| **Instruction** | Lecture proper |
| **Individual Work** | Short Exercise |
| **Evaluation** | Making a concept map |
| **Enrichment** | Additional activities and sample experiments |
| **Resources** | See appendix |

**Prerequisite Knowledge**

Voltage, current, and resistance. Simple battery and bulb circuit.

**Prerequisite Skills**

1. Solving one equation algebraically for one unknown in terms of other known variables.
2. (If the teacher wants students to setup the circuits and perform the measurements) Measuring voltage across a DC circuit element, and current passing through a DC circuit element.
3. Use the relationship R=V/I to solve problems. **(STEM_GP12EM-III-e41)**

## INTRODUCTION

1. Sketch a simple circuit involving a battery and a light bulb, along with strategically placed voltmeters and ammeters. If possible, setup or have students setup the circuit, along with a voltmeter and ammeter so that the currents and voltages may be measured.

2. The measured or theoretical values (if the actual circuit is not constructed in-class) of the current and voltage should be labeled on the diagram on the board.

3. Explain that the goal for today is to find the rates at which energy is dissipated, supplied, or absorbed. Ask students to explain why this is useful.

## MOTIVATION

1. Inside a box, draw a simple light bulb and battery circuit with the light bulb labeled A, the battery B. In another box, draw a mobile phone battery being charged by a solar charger. Label the battery used here as C.

2. Ask students in which of the following situations is energy being dissipated or absorbed.

3. State that today's lesson is about learning to calculate the rate at which energy is being dissipated or absorbed. These ideas can be applied to water heaters, charging and discharging batteries.

4. Show your students a bill from your local electric utility or electric cooperative. Tell your students that one goal of this lesson is to be able to understand how the bill is computed.

## INSTRUCTION

Each of these points should be made:

**Teacher Tip:**

No recommended approach here. The default is to give a short lecture on how to calculate the rates, and then have students deduce other ways of calculating power using the definition of resistance

1. When a current I is passing through a circuit element with a measured voltage of V, then the rate at which energy is absorbed or released is given by P=IV.

2. For batteries and resistive elements, there are three cases of interest.

   Case 1: A current I is passing through a resistive element/ resistor, and the measured potential difference is V. For this case, *energy is always dissipated* at the rate of P=IV.

   Case 2: A current I leaves through the positive terminal of a reversible battery, and enters through the negative terminal. The measured potential difference across the terminals of the battery is V. For this case, *the battery is supplying energy to the rest of the circuit* at the net rate P= IV, where V is the *terminal voltage* of the battery.

   When a current flows from the positive terminal of the battery and enters the negative terminal, we commonly say that the battery is discharging. (In reality, the battery is not a storehouse of charge. Instead, there is actually a chemical reaction occurring that when a battery is supplying energy.)

   Case 3: A current enters through the positive terminal of the battery and leaves through the negative terminal of the battery. The measured potential difference across the terminals of the battery is V. For this case, *energy is being supplied to the battery* at the net rate P= IV. Some of this energy is absorbed by the battery to "recharge" or bring it back to its original energy content, while a portion is dissipated as heat, since real batteries have electrical resistance.

   When a current flows into the positive terminal of the battery and exits the negative terminal, we say that the battery is charging. (There is actually a chemical reaction occurring that is the reverse of the chemical reaction happening when a battery is supplying power.)

3. The fundamental equation here is P=IV. All other possible expressions for the power is obtained by using the definition of resistance $R= \frac{V}{I}$. We have four variables P, V, I, and R. The students should, later at home, try to get expressions for each variable in terms of two others. These alternative expressions, should not be memorized; instead, the students should be able to start from P=IV and the definition of resistance $R = \frac{V}{I}$ to obtain all the other possibilities. There are twelve possible forms in total. (You may wish to do a web search using the key words "Ohm's Law Pie Chart" )

   For power, for example, we have the following possibilities:

$$P= IV = \frac{V^2}{R} =I^2 R$$

Example: Deduce that $P= \frac{V^2}{R}$.

Solution: We wish to eliminate the current I in favor of V and R. From The definition of resistance $R= \frac{V}{I}$ , $I =\frac{V}{R}$. Replace I in P=IV with $\frac{V}{R}$ to obtain $P=\frac{V}{R} V$ and simplify.

4. For more complicated circuits, the same rules for power will still apply.

5. There are at least two more alternative energy units in common use: the kilowatt-hour and the ampere-hour.

   The *kilowatt-hour* is a common unit for energy used in household electrical consumption. If you examine the unit, it is a product of kilowatt (a unit of power) and hour (a unit of time). This can be converted to kilojoules by multiplying by the conversion factor (3600s / 1 hr) and then by (1 kilojoule/ (1 kilowatt s) ).

   Example: On a particularly cool day, one household was able to limit their energy consumption to 3.5kWh. How many Joules is this?

   $3.5 \text{ kWh} =3.5 \text{ kWh} \frac{3600 \text{ s}}{1 \text{ h}} \frac{1 \text{ kJ}}{1 \text{ kW s}}= 12600 \text{ kJ}$
   Or $1.3 \times 10^6$ J

   The *Ampere-hour* is another common unit for energy which can be found on many batteries in mobile phones, tablets, laptops, etc. Standing alone, it is a meaningless unit for energy. It is implicitly assumed that the output voltage of the battery is known. To get the energy content, one must multiply the ampere-hour rating to the output voltage of the battery.

   Example: A phone has a battery rated at 1800mAh. The output voltage of the battery is 6.0 V. What is the usable energy stored in the battery, assuming it is fully charged?

   Answer: $\text{Energy}= (6.0 \text{ V}) (1800 \text{ mAh}) \frac{1 \text{ mW}}{1 \text{mV A}} \frac{3600 \text{ s}}{1 \text{ h}} \frac{1 \text{ W}}{1000 \text{ mW}} \frac{1 \text{ J}}{1 \text{ W s}} =3.9 \times 10^{4}$ J

6. *Emf* also known as electromotive force. Ask students to touch a battery while it is supplying power to a light bulb. After some time the battery should experience an increase in temperature; based on the lessons on specific heat, it should be possible to argue that a battery is also dissipating energy, and that it would be plausible to assume that it acts as both a supplier of energy as well as an agent for energy dissipation. It is therefore plausible that the battery must have an internal resistance r.

7. To introduce *emf* ask students to consider the quantity $IV+I^2r$, where *r* is the *internal resistance of the battery*. If we factor the current out we obtain

$$IV+I^2r = I(V+Ir) = I\,\varepsilon$$

where we have identified $(V+ir)= \varepsilon$ as some quantity with a unit of voltage.

The *emf* (with symbol $\varepsilon$ ) is now defined to be the rate at which energy is supplied to by a battery per unit current passing through the battery, whenever the battery is supplying power. This rate does not take into account the losses due to internal resistance.

An alternative way of writing down the relationship between emf $\varepsilon$ and terminal voltage V, and internal resistance r, is

$$V = \varepsilon - ir$$

## DISCUSSION

Provide sample questions and demonstrate the solution. See Appendix 1

## INDIVIDUAL WORK

1. Assign a short exercise for students to solve in class. In the sample problems, mainly parts exclude parts c).

2. Check student work.

## EVALUATION

Ask students to make a concept map for today's lesson.

## ENRICHMENT

A. Ask students to examine a mobile phone or tablet or laptop charger. Ask them to examine the output voltage and current. Tell them that these numbers should allow them to calculate the rate at which power is being supplied to their device.

As homework, complete the following table and then answer the following questions:

| | |
|---|---|
| Device | |
| Output Current of Charger | |
| Output Voltage of Charger | |
| Rating of Device battery in Ampere-hours | |
| Charging time from empty to full (t) | |

1. How long does it take for the battery to get fully charged from empty? (Call this value t.)
2. At what rate is the charger supplying power to the battery?
3. Based on your answers to 1 and 2, how much energy is stored in the battery?
4. Multiply the rating of the device battery (in Ampere h) to the output voltage. This result is not in standard SI units. Convert this number to Joules, and then compare this number to your answer in 3 (less than, greater than, or equal to). Explain why these two numbers are or are not equal to each other.

B. In class, we discussed that the four quantities P, V, I and R of a resistor are related so that any one of these can be expressed in terms of any two of the others. There are twelve such possible forms. Deduce all these possible forms from the relations P=IV and the definition of resistance R= \frac{V}{I}

**APPENDIX 1: Pre-Lesson Lab or Homework**

**Sample Questions:**

All questions from part c onwards involve concepts that should have been encountered before this lesson.

1. A light bulb has a 25 W rating, and it is plugged into a socket with terminals at a 220 V potential difference. Assuming that the current is steady at this voltage and power, find the following:
   a) the *current passing through the light bulb.*
   b) the *resistance of the light bulb.*
   c) the *length of the tungsten filament*, if the diameter of the tungsten filament of the light bulb is 0.037 mm. Assume that the filament is cylindrical with resistivity 111.1 \mu \omega cm, and that it is operating at 3500 K.

   **Ans.** 0.11 A; 1.9 x 10^3 Ohm ; 1.8 m

2. Incandescent lamp labels are usually rated in Volts and Amperes. One household lamp is labeled by the manufacturer as "3 Volts, 0.6 Watts".
   (i) Explain what information this labelling provides about the normal operation of the lamp.
   (ii) Calculate the current in the filament of the lamp when it is operating at normal brightness.

   **Ans.**
   (i) when connected to a 3 V supply, the lamp will be at normal brightness;
   and energy is produced in the filament at the rate of 0.60 W;
   Look for the idea that 3 V is the operating voltage and the idea of energy transformation.
   or
   when connected to a 3 V supply, the lamp will be at normal brightness;
   and the resistance of the filament is 15 Ω / the current in the filament is 0.20 A;
   (ii) $I = \frac{P}{V}$ ; to give I = 0.20 A;

3. A household water heater has a resistance of 50 Ohm. The operating voltage is 220 V. Find the following:
   a) the current passing through the resistive element in the water heater
   b) the rate at which water is being heated
   c) the time it takes to heat a litre of water at 25 C to the boiling point. The specific heat of water is 4190 J/(kg K)

   **Ans.** 4.4 A; 968 W; 325 s

4. A current of 800mA flows into the positive terminal of a battery, and leaves through the negative terminal of the battery. Is the battery charging or discharging? If the current is reversed, is the battery charging or discharging?

   **Ans.** Charging; Discharging.

5. A battery is connected to a charger plugged into a wall socket. A current of 800 mA is flowing (from the charger) into the positive terminal and out of the negative terminal of a battery rated at 6.0 V. (After the current leaves the negative terminal, it then proceeds back to the charger to make a complete circuit.)
   a) At what rate is the battery storing energy? (Ignore internal resistance of the battery)
   b) Assuming that you start charging from an empty state, and that the battery can store 1.7 x 10^5 J, how long must the charger be plugged in?
   c) A battery charger takes in an input voltage of 220 V and 0.2 A of current, and it outputs 6.0 V and 800mA of current. What is the efficiency of this charger? Efficiency here is defined as output power divided by input power, expressed as a percentage.
   d) A local electric utility, COLMERA, charges PhP 10 for every kWh consumed. How much does it cost to fully recharge this battery from an empty state?

   **Ans.** 4.6 W;  3.7 x 10^3 s or 10h;  11%;  PhP 4.40

6. The current passing through a resistor is 0.6 A, while the resistance is 20 Ohms. Find the following:
   a) the applied voltage across the resistor;
   b) the power dissipated.

**Ans.** 12 V; 7.2 W

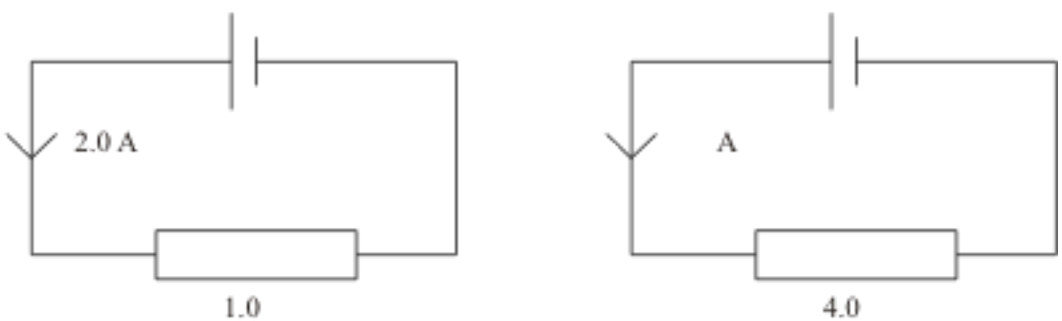
7. A battery is connected in series with a resistor R. The battery transfers 2 000 C of charge completely round the circuit. During this process, 2 500 J of energy is dissipated in the resistor R and 1 500 J is expended in the battery.
   What is the emf of the battery?

   **Ans.** 2.00 V

8. A conductor of constant resistance dissipates 6.0 W of power when the potential difference across it is 12 V. The potential difference across it is changed to 24 V. What will the power that will be dissipated in this conductor change to?

   **Ans.** 24W

9. A resistor of resistance 1.0 ohm is connected in series with a battery. The current in the circuit is 2.0 A.
   The resistor is now replaced by a resistor of resistance of 4.0 ohm. The current in this circuit is 1.0 A.




   What is the internal resistance of the battery?

   **Ans.** 2.0 ohm

**Additional Questions/Sample Assessments**

1. An LED bulb has a power rating of 3.5 Watts, and is meant to be plugged into a 220 V fixture.
   a. Find the following:
      a.i. the current passing through the LED bulb.
      a.ii. the resistance of the LED bulb.
   b. To produce the same amount of light, you will need a 25 W incandescent bulb. Explain why incandescent bulbs consume more power compared to LED's.

   **Ans.** 1.6 x 10^{-2} A; 1.4 x 10^{4} Ohm ; More energy is dissipated as heat in incandescent bulbs (radiation at non-visible wavelengths)

2. A household water heater has a resistance of 30 Ohm. The operating voltage is 220 V. Find the following:
   a. the current passing through the resistive element in the water heater
   b. the rate at which water is being heated
   c. the time it takes to heat a litre of water at 25 C to the boiling point. The specific heat of water is 4190 J/(kg K)

   **Ans.** 7.3 A; 1.6 x 10^3 W; 195 s or 3.2 minutes

3. A current of 0.4 A flows out of the positive terminal of a battery, and enters through the negative terminal of the battery. Is the battery charging or discharging? If the current is reversed, is the battery charging or discharging?

   **Ans.** Discharging; charging.

4. A battery is connected to a charger plugged into a wall socket. A current of 2.4 A is flowing (from the charger) into the positive terminal and out of the negative terminal of a battery rated at 5.2 V. (After the current leaves the negative terminal, it then proceeds back to the charger to make a complete circuit.)
   a. At what rate is the battery storing energy? (Ignore internal resistance of the battery)
   b. Assuming that you start charging from an empty state, and that the battery can store 42.5 Wh, how long must the charger be plugged in?

c. The battery charger takes in an input voltage of 220 V and 0.5 A of current, and it outputs 5.2 V and 2.4 A of current. What is the efficiency of this charger? Efficiency here is defined as output power divided by input power, expressed as a percentage.

d. A local electric utility, COLMERA, charges PhP 10 for every kWh consumed. How much does it cost to fully recharge this battery from an empty state?

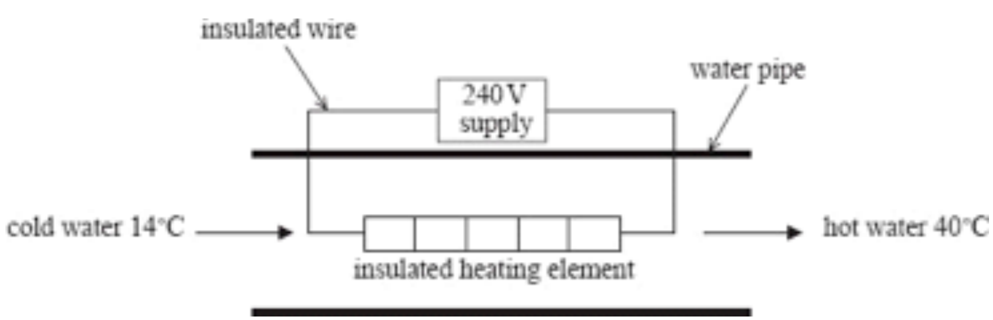
**Ans.** 12.5 W; 3.5 h; 11% ; PhP 3.85

5. Copper at American Wire Gauge 10 has a diameter of 5.26 mm^2, and its resistance per length is 3.277 mOhm /m. Assume that 220 V is applied to 8.0 m of this copper wire. (This can happen, for example, due to a short-circuit).
   a. What is the resistance of the wire?
   b. What is the rate at which energy is supplied to the copper wire?
   c. If this power were used to heat 10 kg of water, how long will it take for the temperature to go from 25 C to the boiling point? (Specific heat of water is 4190 J/(kg K) )

**Ans.** 2.6x 10^{-2} ; 1.8 x 10^6 W; 1.74 sec

6. Specific heat and a domestic shower

In places with cold water, such as Baguio City, people install shower heaters. The diagram below shows part of the heating circuit of a domestic shower.



Cold water enters the shower unit and flows over an insulated heating element. The heating element is rated at 7.2 kW, 240 V. The water enters at a temperature of 14 °C and leaves at a temperature of 40°C. The specific heat capacity of water is 4.2 x 103 J kg–1 K–1.

i. What is the flow rate of the water.

ii. Suggest one reason why your answer to (i) is only an estimate.

**Ans.**

i. energy supplied by heater in 1s = 7.2 x 103 J;
energy per second = (mass per second) ( sp ht) (rise in temperature);
7.2 x 103 = mass per second ( 4.2 x 103 )( 26);
to give mass per second = 0.066kg;

ii. energy is lost to the surroundings; flow rate is not uniform;

## Appendix

Resources:

(1) Arons, Teaching Introductory Physics
(2) (2) McDermott et al, Physics by Inquiry
(3) (3) Giancoli, Physics, 6th ed.

60 MINS

# Context-rich problems involving current, resistivity, resistance, and Ohm's Law

**Content Standards**

The learners demonstrate an understanding of

1. current, resistivity, and resistance
2. Ohm's Law

**Performance Standards**

The learners shall be able to use theoretical and experimental approaches to solve multi-concept and rich-context problems involving electricity and magnetism.

**Learning Competencies**

At the end of the session, the students should be able to solve problems involving current, resistivity, resistance, and Ohm's law in contexts such as, but not limited to, batteries and bulbs, household wiring, selection of fuses, and accumulation of surface charge in the junction between wires made of different materials. **(STEM_GP12EM-III-e44)**

**Prerequisite Knowledge**

STEM_GP12EM-III-e32 up to STEM_GP12EM-III-e43

**Prerequisite Skills**

1. Solving one equation algebraically for one unknown in terms of other known variables.
2. Solving two equations with two unknowns.

## LESSON OUTLINE

| | |
|---|---|
| **Introduction and Motivation** | Reminder for the learners |
| **Instruction** | Problem questions |
| **Evaluation** | Concept map |

**Resources**

(1) Arons, Teaching Introductory Physics
(2) McDermott et al, Physics by Inquiry
(3) Giancoli, Physics, 6th ed.

## INTRODUCTION AND MOTIVATION

Remind students of the following:

A. Only by doing problems will they remember.
B. They should strive to make their solutions readable so that they can serve as supplementary lecture notes.
C. Make sure they write the names of each symbol used, the values, and the units.
D. Place their final answers in a box.

## INSTRUCTION

1. Distribute or project the questions to be done by the students.

2. Since the only available time is 60 minutes, choose two problems from Appendix A1.

3. For the first 15 minutes assign one problem. Walk around the class to check that students are doing the work assigned. At the end of the 15 minute period, have them switch papers to check final answers only and assign a score. Discuss the solution on the board so that students can annotate their work.

4. Assign the second problem and give them 15 minutes to obtain the final answer. Walk around the class to check that students are doing the work assigned. At the end of the 15 minute period, have them switch papers to check final answers only and assign a score. Discuss the solution on the board so that students can annotate their work.

## INDIVIDUAL WORK

1. Assign one problem from Appendix 1 for students to solve in class. Exclude parts c and onward.

2. Check student work 3 minutes before class ends.

## EVALUATION

Ask students to identify the problems they had difficulty with. Ask them to explain the thinking process that produced the difficulty.

## INDIVIDUAL WORK

1. Assign a short exercise for students to solve in class. In the sample problems, mainly parts exclude parts c).

2. Check student work.

## EVALUATION

Ask students to make a concept map for today's lesson.

## HOMEWORK

You may assign one context-rich problem for students to do at home. Solution will be posted at a bulletin board the day after.

**APPENDIX 1:**

**Sample Questions:** All questions from part c onwards involve concepts that should have been encountered before this lesson.

1. A light bulb has a 25 W rating, and it is plugged into a socket with terminals at a 220 V potential difference. Assuming that the current is steady at this voltage and power, find the following:
   a) the *current passing through the light bulb*.
   b) the *resistance of the light bulb*.
   c) the *length of the tungsten filament*, if the diameter of the tungsten filament of the light bulb is 0.037 mm. Assume that the filament is cylindrical with resistivity 111.1 \mu \omega cm, and that it is operating at 3500 K.

   **Ans.** 0.11 A; 1.9 x 10^3 Ohm ; 1.8 m

2. A household water heater has a resistance of 50 Ohm. The operating voltage is 220 V. Find the following:
   a) the current passing through the resistive element in the water heater
   b) the rate at which water is being heated
   c) the time it takes to heat a litre of water at 25 C to the boiling point. The specific heat of water is 4190 J/(kg K)

   **Ans.** 4.4 A; 968 W; 325 s

3. A current of 800mA flows into the positive terminal of a battery, and leaves through the negative terminal of the battery. Is the battery charging or discharging? If the current is reversed, is the battery charging or discharging?

   **Ans.** Charging; Discharging.

4. A battery is connected to a charger plugged into a wall socket. A current of 800 mA is flowing (from the charger) into the positive terminal and out of the negative terminal of a battery rated at 6.0 V. (After the current leaves the negative terminal, it then proceeds back to the charger to make a complete circuit.)
   a) At what rate is the battery storing energy? (Ignore internal resistance of the battery)
   b) Assuming that you start charging from an empty state, and that the battery can store 1.7 x 10^5 J, how long must the charger be plugged in?
   c) A battery charger takes in an input voltage of 220 V and 0.2 A of current, and it outputs 6.0 V and 800mA of current. What is the efficiency of this charger? Efficiency here is defined as output power divided by input power, expressed as a percentage.

d) A local electric utility, COLMERA, charges PhP 10 for every kWh consumed. How much does it cost to fully recharge this battery from an empty state?

**Ans.** 4.6 W; 3.7 x 10^3 s or 10h; 11%; PhP 4.40

5. The current passing through a resistor is 0.6 A, while the resistance is 20 Ohms. Find the following:
   a) the applied voltage across the resistor;
   b) the power dissipated.

   **Ans.** 12 V; 7.2 W

**Additional Questions/Sample Assessments**

1. An LED bulb has a power rating of 3.5 Watts, and is meant to be plugged into a 220 V fixture.
   a. Find the following:
      a.i. the current passing through the LED bulb.
      a.ii. the resistance of the LED bulb.
   b. To produce the same amount of light, you will need a 25 W incandescent bulb. Explain why incandescent bulbs consume more power compared to LED's.

   **Ans.** 1.6 x 10^{-2} A; 1.4 x 10^{4} Ohm ; More energy is dissipated as heat in incandescent bulbs (radiation at non-visible wavelengths)

2. A household water heater has a resistance of 30 Ohm. The operating voltage is 220 V. Find the following:
   a. the current passing through the resistive element in the water heater
   b. the rate at which water is being heated
   c. the time it takes to heat a litre of water at 25 C to the boiling point. The specific heat of water is 4190 J/(kg K)

   **Ans.** 7.3 A; 1.6 x 10^3 W; 195 s or 3.2 minutes

3. A current of 0.4 A flows out of the positive terminal of a battery, and enters through the negative terminal of the battery. Is the battery charging or discharging? If the current is reversed, is the battery charging or discharging?

   **Ans.** Discharging; charging.

4. A battery is connected to a charger plugged into a wall socket. A current of 2.4 A is flowing (from the charger) into the positive terminal and out of the negative terminal of a battery rated at 5.2 V. (After the current leaves the negative terminal, it then proceeds back to the charger to make a complete circuit.)
   a. At what rate is the battery storing energy? (Ignore internal resistance of the battery)
   b. Assuming that you start charging from an empty state, and that the battery can store 42.5 Wh, how long must the charger be plugged in?
   c. The battery charger takes in an input voltage of 220 V and 0.5 A of current, and it outputs 5.2 V and 2.4 A of current. What is the efficiency of this charger? Efficiency here is defined as output power divided by input power, expressed as a percentage.
   d. A local electric utility, COLMERA, charges PhP 10 for every kWh consumed. How much does it cost to fully recharge this battery from an empty state?

   **Ans.** 12.5 W; 3.5 h; 11% ; PhP 3.85

5. Copper at American Wire Gauge 10 has a diameter of 5.26 mm^2, and its resistance per length is 3.277 mOhm /m. Assume that 220 V is applied to 8.0 m of this copper wire. (This can happen, for example, due to a short-circuit).
   a. What is the resistance of the wire?
   b. What is the rate at which energy is supplied to the copper wire?
   c. If this power were used to heat 10 kg of water, how long will it take for the temperature to go from 25 C to the boiling point? (Specific heat of water is 4190 J/(kg K) )

   **Ans.** 2.6x 10^{-2} ; 1.8 x 10^6 W; 1.74 sec

60 MINS

# Electrical Safety, Operating of devices for measuring currents and voltages

**Content Standards**

The learners demonstrate an understanding of

1. electrical safety
2. operating of devices for measuring currents and voltages

**Performance Standards**

The learners shall be able to use theoretical and experimental approaches to solve multi-concept and rich-context problems involving electricity and magnetism.

**Learning Competencies**

At the end of the session, the students should be able to :

1. Operate devices for measuring currents and voltages **(STEM_GP12EM-IIIe-45)**
2. Describe the physiological effects of electrical shock; electrical hazards; safety devices and procedures **(STEM_GP12EM-IIIe-43)**

**Prerequisite Knowledge**

electric potential, potential difference

## LESSON OUTLINE

| | |
|---|---|
| **Introduction** | Presentation of the objectives of the lesson |
| **Motivation** | Observation activity |
| **Instruction** | Lecture proper |
| **Individual Work** | Circuit drawing activity |
| **Evaluation** | Short quiz |

**Resources**

(1) Arons, Teaching Introductory Physics
(2) Giancoli, Physics, 6th ed.
(3) "Publication No. 98-131: Worker Deaths by Electrocution" U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES, Public Health Service, Centers for Disease Control and Prevention National Institute for Occupational Safety and Health, May 1998 http://www.cdc.gov/niosh/docs/98-131/pdfs/98-131.pdf (last accessed on June 25, 2015)

## INTRODUCTION

**Teacher Tip:**

Before the class starts, it would be useful to assign homework or do a lab activity. See Appendix 2

1. A quote from Kelvin on measurement may be used as an introduction. State that our purpose is to learn the proper way of measuring voltages and currents. How the voltmeter and ammeter operates is to be discussed elsewhere.

2. The main goal is to be able to measure the current passing through a circuit element, as well as the voltage across the same circuit element. This should be doable by the student for the following circuits:

   A. Simple battery and bulb (or battery and resistor) circuit.

   B. Simple series and simple parallel circuits.

   C. Circuits that can be decomposed into simple series and parallel circuits.

   D. Circuits that cannot be decomposed into series and parallel circuits (for which the use of Kirchoff's rules are required.)

## MOTIVATION

1. Setup a simple battery and two light bulbs in series circuit. Show the students a voltmeter and then ask them "what is the proper way of measuring the voltage across one bulb?". Show drawings of possible arrangements. Demonstrate what happens when you try all possible arrangements.

2. Setup a simple battery and two light bulbs in series circuit. Show the students an ammeter and then ask them "what is the proper way of measuring the voltage across one bulb?". Show drawings of possible arrangements. Demonstrate what happens when you try all possible arrangements.

3. Use the results to identify the need for properly setting up the voltmeter and ammeter. In particular, for those instances where the light bulb or light bulbs turn off, ask students why these arrangements are not the correct way of measuring.

## INSTRUCTION

Each of these points should be made:

Ideal voltmeters have infinite resistance, while ideal ammeters have zero resistance. Connecting a voltmeter in parallel or an ammeter in series to a circuit element therefore does not change the current. An ideal measurement should not change the state of the circuit element.

1. *Voltage measurement.* In multimeters for use with dc circuits, the probes are usually color-coded. The red end is used for the terminal with higher potential, and the black end is used for the terminal at lower potential. Analog multimeters will swing in the opposite direction if the probes are misapplied; this can damage the multimeter. When measuring voltage there is usually no need to disconnect parts of the circuit; voltage measurements are done in parallel.

2. *Current measurement.* To measure the current passing through a circuit element, one must place the multimeter or ammeter in series with the circuit element. Unlike voltage measurements, this almost always involves disconnecting the circuit so that the ammeter or multitester can be properly placed.

   The water meter analogy can be used here. If the ammeter is connected in parallel, this is analogous to diverting some of the current that should have passed through the circuit element. Students should use a series circuit involving light bulbs and then be asked to place the ammeter in parallel to one of the bulbs.

3. AC circuits. Students should be cautioned that the multitester settings should be modified when measuring currents and voltages for AC circuit elements.

4. *Physiological effects of current.* Even if the potential difference is large, so long as there is very small current, no harm will occur. Dry skin has a high resistance compared to wet skin or open sores or if covered in conducting gel. It is the magnitude of the current that determines the physiological effects. The table below lists what happens when current passes through the human body.

**Teacher Tip:**

The main method of choice is by demonstration and then having students work in pairs. If possible, students should buy their own digital multimeters for use with their battery and bulb setups.

| current | physiological effects |
|---|---|
| less than 0.001 amperes | no perception |
| 0.001 amperes | tingling or sensation of heating |
| 0.001 to 010 amperes | involuntary muscular contraction, pain |
| 0.10 to 0.50 amperes | ventricular fibrillation |
| 0.50 to a few amperes | heart stops but can restart if current stops |
| More than a few amperes | heart stops, no breathing, burns |

5. *Safety measures.* All safety rules are aimed at not causing a current to pass through paths we do not intend, whether it is the human body, a wire, or another circuit element that's sensitive to current. The rules involve either increasing an effective electrical resistance or eliminating the likelihood of accumulating excess charge.

   The first class of safety rules involves *increasing the effective resistance* between a wire element at some potential greater than the ground, the human body, and the ground. Examples include wearing rubber shoes and other insulators. This increases the resistance and lowers the possible currents that can pass through the human body. Another example: standing on water reduces the effective electrical resistance of the human body.

   A second class of safety rules is used to *prevent the production of sparks* (current in air), which may cause combustion in nearby combustible agents. Examples involve preparation of hospital patients before surgery so that little methane is produced during surgery.

   A third class of safety rules involves *good grounding* of a person or an object. There are instances when a person or an object can accumulate excess charge, e.g. rubbing of rubber shoes on carpet during a dry day or while inside an air-conditioned room with low humidity. If a person suddenly approaches and reaches out for an object that is grounded (same potential as the ground), and if excess charge has accumulated on the person, then a sudden discharge can occur through the person's finger, the air, and then the grounded object. A spark may occur. Aside from being painful, this can also cause damage to electronics and may affect nearby combustible materials.

## DISCUSSION

1. Give a list of common electrical safety rules.

2. For each safety rule, ask students to trace how current will flow when the rule is violated.

## INDIVIDUAL WORK

1. Give a set of circuit drawings.

2. Ask students to draw how the circuits must be changed if they want to measure the voltage and currents of assigned circuit elements.

## EVALUATION

At around 15 minutes before the end of the class, have a multiple choice quiz. The quiz should involve the circuits assigned, and should only have questions about how the ammeter and voltmeter should be connected.

## ENRICHMENT

The Electricity and Magnetism Section of Jearl Walker's *The Flying Circus of Physics* has many examples that may be used to discuss safety rules.

60 MINS

# Experiments on Ohmic and Non-Ohmic Materials

**Content Standards**
The learners demonstrate an understanding of Ohmic and Non-Ohmic Materials

**Performance Standards**
The learners shall be able to use theoretical and experimental approaches to solve multi-concept and rich-context problems involving electricity and magnetism.

**Learning Competencies**
At the end of the session, the students should be able to :

1. Differentiate ohmic and non-ohmic materials in terms of their I-V curves. **(STEM_GP12EM-III-e38)**
2. Operate devices for measuring currents and voltages. **(STEM_GP12EM-III-e45)**
3. Plan and perform an experiment involving non-ohmic materials and analyze the data—identifying and analyzing discrepancies between experimental results and theoretical expectations when appropriate. **(STEM_GP12EM-III-e46)**

**Prerequisite Knowledge**
Voltage, current, and resistance. Simple battery and bulb circuit.

**Prerequisite Knowledge**

1. Use the relationship R=V/I to solve problems. **(STEM_GP12EM-III-e41)**
2. Estimate intercepts and slopes—and their uncertainties—in experimental data with linear dependence using the "eyeball method" and/or linear regression formulae. **(STEM_GP12EU-Ia-7)**

## LESSON OUTLINE

| | |
|---|---|
| **Introduction** | Pre-lecture and activity tasks |
| **Instruction** | Laboratory Activity |
| **Discussion** | After-lab discourse |
| **Enrichment** | Experiment design |

**Resources**

(1) Arons, Teaching Introductory Physics
(2) McDermott et al, Physics by Inquiry
(3) Giancoli, Physics, 6th ed.

# INTRODUCTION

Do the following one or two days before the experiment.

1. Sketch a simple circuit involving a battery and an ohmic resistor, a variable resistor, along with strategically placed voltmeters and ammeters. Call this Setup A. See Appendix 1.

2. Sketch a simple circuit involving a battery, a variable resistor, and a light bulb, along with strategically placed voltmeters and ammeters. Call this Setup B. See Appendix 1.

3. On the board, show the following prompt: "How is applied voltage across a resistive element related to the measured current passing through the resisitive element?"

4. To answer this question, students should write a prelab paper containing the following information:
   a. The hypothesized relationship between the applied voltage and current.
   b. Circuit diagrams for each setup.
   c. Step-by-step procedure.
   d. Blank data tables.
   e. Graphing paper for data analysis.

5. Remind students that the graphs of I versus V for each setup should be done ten minutes before the period ends. Students should be told to have the current I as the abscissa (x-axis), and the voltage V as the ordinate (y-axis). They can think of it in the following way: adjusting the variable resistor allows them to adjust the current (their independent variable) and they then measure the voltage (the dependent variable).

6. Note: Alternatively, the current is thought of as the dependent variable, while the voltage is the independent variable. The point of view taken depends on the experimenter. For uniformity of analysis, we arbitrarily choose voltage as the dependent variable. The main advantage in doing this lies in the interpretation of the trendline's slope. The slope is immediately recognized (for ohmic resistors) as the resistance.

7. For light bulbs, which are non-ohmic, the slope of the trendline has no meaningful interpretation.

## INSTRUCTION

On the lab day itself:

1. Distribute the materials to be used. Students should be asked to bring their own battery and bulbs. Voltmeters and ammeters are to be provided by the school.

2. Give students 40 minutes to setup the circuits and make measurements. Extra time available should be used by students to start the data analysis.

3. Remind students that the graphs of I versus V for each setup should be done ten minutes before the period ends. Students should be told to have the current I as the abscissa (x-axis), and the voltage V as the ordinate (y-axis). When appropriate, there should be a trend-line included.

4. Stamp the data sheets for proof of work done.

5. Data analysis and writing conclusions to be done at home. Submission is on next class meeting.

## DISCUSSION

Some points for discussion:

1. If the students hypothesized a linear relationship between voltage and current, it makes sense to include a linear trend-line. A quick look at the graphs should suggest, however, that for the light bulb, a linear trend-line will be out of fit with the data. This should suggest that the following hypotheses should be ruled out: i) "The voltage is proportional to the current." And ii) "The voltage has a linear dependence on the current."

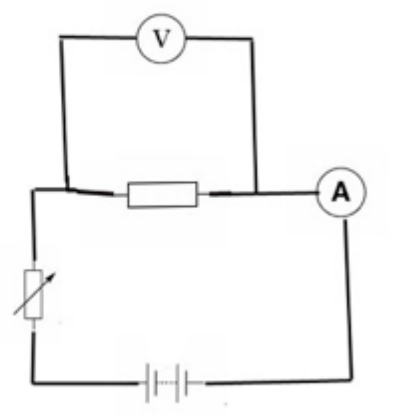
2. For an ordinary ohmic resistor, the resistance is indeed proportional. The graph for the ohmic resistor should reflect this. After fitting a trend-line, students should be asked to interpret the slope and give the units.

3. Students should be asked about whether fitting a trend-line to the I versus V graph of a light bulb is sensible. At the end, they should recognize that this is an example of a non-ohmic resistor.

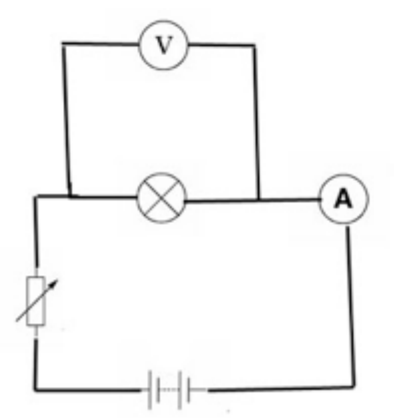
## ENRICHMENT

Ask students to design an experiment to measure the internal resistance of a battery.

**Appendix**




Setup A




Setup B

60 MINS

# Series and Parallel Circuits

**Content Standards**

The learners demonstrate an understanding of resistors in series and parallel

**Performance Standards**

The learners shall be able to use theoretical and experimental approaches to solve multi-concept and rich-context problems involving electricity and magnetism.

**Learning Competencies**

At the end of the session, the students should be able to :

1. Draw circuit diagrams with power sources (cell or battery), switches, lamps, resistors (fixed and variable)fuses, ammeters and voltmeters. **(STEM_GP12EM-IIIf-47)**
2. Evaluate the equivalent resistance,current, and voltage in a given network of resistors connected in series and/or parallel. **(STEM_GP12EM-IIIg-48)**

**Prerequisite Knowledge**

Ohm's law

## LESSON OUTLINE

| | |
|---|---|
| **Introduction** | Observation activity |
| **Motivation** | Connecting the phenomenon to real-life situations |
| **Instruction** | Lecture proper |
| **Individual Work** | Short exercise |
| **Evaluation** | Draw circuit diagrams |
| **Enrichment** | Problem questions |

**Resources**

(1) Arons, Teaching Introductory Physics
(2) McDermott et al, Physics by Inquiry
(3) Giancoli, Physics, 6th ed.

**Prerequisite Knowledge**

1. Use the relationship R=V/I to solve problems. **(STEM_GP12EM-III-e41)**
2. Estimate intercepts and slopes—and their uncertainties—in experimental data with linear dependence using the “eyeball method” and/or linear regression formulae. **(STEM_GP12EU-Ia-7)**

## INTRODUCTION

1. Setup the circuits (include a switch) that students were assigned to construct, and then ask students which circuit makes the bulbs light up brighter. This should be given as a quiz to verify that students actually performed the experiment.

2. Add more bulbs in series to the series circuit. Add more bulbs in parallel to the original circuit with bulbs in parallel. Ask students to predict what happens to the brightness of the bulbs.

3. Ask students to predict what happens when one of the bulbs is removed from the socket. Ask students to explain why in terms of current.

4. Using the circuits constructed, define the phrases: "circuit elements in parallel", and "circuit elements in series."

## MOTIVATION

Ask students which kinds of connections (series or parallel) are used for home electrical connections.

## INSTRUCTION

Each of these points should be made:

1. If we place a box around the light bulbs for each circuit produced, the light bulbs as a whole can be thought of as a single circuit element or single resistor. This means we can define an equivalent resistance for circuit elements in series and circuit elements in parallel.

2. In a circuit diagram, if we draw a box around a set of resistive circuit elements in such a way that only two wires pass through the boundary of the box, the system of resistive elements will act like a single resistor. That is, if we replace the system with a single resistor with the appropriate resistance, it will not change the behaviour of the rest of the circuit. We can therefore speak of an effective or

**Teacher Tip:**

Assign the following homework

1. Ask students to draw or sketch two different circuits involving wires, a battery, and two light bulbs so that both bulbs will light up.

2. Using their materials (students should each have batteries, light bulbs with sockets, and wires), students should construct these circuits, and as evidence take photos using their phones or tablets of their constructed circuits.

3. Students should take note of which circuit causes the light bulbs to glow brighter.

4. Ask students to submit the photos via email or other alternative means.

equivalent resistance for this more general case.

3. Students should take note of the following:

   A. For circuit elements in parallel
      A.1. Two or more circuit elements are in parallel when they have the same potential difference, and are connected to the same two junctions.
      A.2. When two or more circuit elements are in parallel, the current passing through divides into currents that pass through each circuit element. The currents are not equal; for Ohmic resistors, Ohm's law will give the current passing through each element.

   B. For circuit elements in series
      B.1.Two or more circuit elements are connected in series when there is no possible place for current to split as one goes through the circuit elements one by one. This means the current passing through must be identical or current is constant.
      B.2.BThe potential difference or voltage across each circuit element within a series will not be identical. For Ohmic resistors, the voltages will be given by applying Ohm's law for each resistor.

4. For circuit elements connected in simple series or simple parallel to a single battery, the direction of current flow is going out from the positive terminal of the battery and the current at the end should flow into the negative terminal of the battery. On the board, trace how current flows from the positive terminal, then through each of the circuit elements and then back to the negative terminal.

5. Without derivation, state the rules for getting equivalent resistances of resistors in series:

$$R_{eff} = R_1+R_2+R_3+\ldots +R_N$$

$$V_{eff}=V_1+V_2+V_3+\ldots+V_N$$

$$i_{eff}= i_1=i_2=\ldots=i_N$$

6. Without derivation, state the rules for getting equivalent resistances of resistors in parallel:

$$1/R_{eff} = 1/R_1+1/R_2+1/R_3+\ldots +1/R_N$$

$$V_{eff}=V_1=V_2=V_3=\ldots=V_N$$

$$i_{eff} = i_1 + i_2 + i_3 + ... + i_N$$

7. The derivations should probably be assigned after the discussion of Kirchoff's rules.

8. For circuits involving combinations of elements in series and parallel, the technique for getting the currents and voltages through each resistor involves a divide and conquer approach. Place a box around each set of resistors that can be regarded as either simple series or simple parallel.

   For each boxed set, get the equivalent resistance, and then redraw the circuit diagram with each boxed set replaced by their matching equivalent resistance.

   Keep on repeating the process until the circuit can be reduced to a single effective resistance. After doing this, reverse to process and use Ohm's law and the rules for currents to obtain the currents and voltages of each individual resistor.

9. The power consumption rate of each resistor is still given by P=IV, where I is the current passing through the resistor, and V is the voltage across the resistor. To get the total power consumption rate, add the power consumption rate of each individual resistor.

10. The power supplied by each battery when the current flows into the negative terminal and out of the positive terminal is given by P=IV. If the current is opposite in direction, the power is being consumed by the battery, and the sign becomes negative. The total power consumed by the resistors should be equal to the total power supplied by the batteries. This can be used to check for consistency.

## DISCUSSION

Provide sample questions and demonstrate the solution. See Appendix 2

## INDIVIDUAL WORK

1. Assign a short exercise for students to solve in class.

2. Check student work. (Have students exchange their work, and check answers.) After returning, discuss solution in class so that students can annotate their work.

3. If homework is to be assigned, include circuits that cannot be done without using Kirchoff's rules. In the instructions, state that if a problem cannot be done using decomposition into series and parallel, students must state “cannot be done using decomposition into series and parallel”.

## EVALUATION

Show or print sample circuits with labels for each element and then ask students to draw circuit diagrams. After drawing the circuit diagrams, ask students to identify the circuit elements in series and in parallel.

## ENRICHMENT

1. Assign the following problem: Find the equivalent resistance of an infinite number of resistors of resistance R connected in parallel.

2. Ask students what happens when you short a circuit consisting of resistors or light bulbs in parallel. Hint: A wire has very low but nonzero resistance. How is this relevant to household wiring?

60 MINS

# Kirchoff’s Rules

**Content Standards**
The learners demonstrate an understanding of Kirchoff’s Rules.

**Performance Standards**
The learners shall be able to use theoretical and experimental approaches to solve multi-concept and rich-context problems involving electricity and magnetism.

**Learning Competencies**
At the end of the session, the students should be able to :

1. Calculate the current and voltage through and across circuit elements using Kirchhoff’s loop and junction rules (at most 2 loops only) **(STEM_GP12EM-IIIg-49)**

**Prerequisite Knowledge**
Ohm's law

**Prerequisite Skills**
(STEM_GP12EM-IIIf-47) and (STEM_GP12EM-IIIg-48).

## LESSON OUTLINE

| | |
|---|---|
| **Introduction** | Circuit diagram |
| **Instruction** | Discussion proper |
| **Individual Work** | Short exercise |
| **Evaluation** | Assign a simple circuit |
| **Resources** | |

## INTRODUCTION

Draw a circuit diagram that cannot be decomposed into simple series or simple parallel, and set up for students to see.

## MOTIVATION

Use the circuit to explain the need for Kirchoff's rules.

## INSTRUCTION

Each of these points should be made:

1. Kirchoff's rules can be thought if as a sequence of steps. Assign a current (symbol and direction).

2. Use Kirchoff's junction rule to setup algebraic relationships between the currents. (Sum of all currents going into a junction = Sum of all currents going out of a junction)

3. Use Kirchoff's loop rule to obtained further relationships. The loop rule is as follows: Start at a point on the circuit diagram and mark out a loop along the circuit. As you go along the loop:
    I. whenever you pass through a battery from the negative to the positive terminal , add the voltage of the battery. If passing through the battery from the positive to the negative terminal, subtract the voltage of the battery.
    II. whenever you pass a resistor A in the same direction as the current, subtract (current through the resistor A)(resistance of A). If you pass through in the opposite direction as the current, add (current through resistor A)(resistance of A)
    III. The total of all these, once you get back to the starting point is zero.

4. In using Kirchoff's rules, the direction of the current assigned to each circuit element is arbitrary. If the actual direction is different from what was assumed while solving the problem, the value of current obtained will be negative.

5. If two or more circuit elements are in series, the current through these elements should all be the same in magnitude and direction.

6. The power consumption rate of each resistor is still given by P=IV, where I is the current passing through the resistor, and V is the voltage across the resistor. To get the total power consumption rate, add the power consumption rate of each individual resistor.

7. The power supplied by each battery when the current flows into the negative terminal and out of the positive terminal is given by P=IV. If the current is opposite in direction, the power is being consumed by the battery, and the sign becomes negative. The total power consumed by the resistors should be equal to the total power supplied by the batteries. This can be used to check for consistency.

## DISCUSSION

Provide sample questions and demonstrate the solution. See Appendix 1

## INDIVIDUAL WORK

1. Assign a short exercise for students to solve in class.

2. Check student work. (Have students exchange their work, and check answers.) After returning, discuss solution in class so that students can annotate their work.

## EVALUATION

Assign a simple circuit that requires only two loops and ask students to solve for the unknowns.

## ENRICHMENT

Ask students prepare a presentation on the following:

60 MINS

# Magnets, magnetic poles, magnetic fields, magnetic field lines

**Content Standards**

The learners demonstrate an understanding of:

1. Magnetic fields
2. Gauss' Law for Magnetism
3. Magnetic Flux

**Performance Standards**

The learners are able to:

Use theoretical and experimental approaches to solve multi-concept and context-rich problems involving electricity and magnetism.

**Learning Competencies**

At the end of the session, the students should be able to:

1. Describe the interaction between magnetic poles **(STEM_GP12EM-IIIh-53)**.
2. Differentiate interactions between gravitational, electric and magnetic interactions **(STEM_GP12EM-IIIh-54)**.
3. Evaluate the total magnetic flux through an open surface **(STEM_GP12EM-IIIh-55)**.
4. Explain why the magnetic flux on a closed surface is zero **(STEM_GP12EM-IIIh-56).**
5. Draw the magnetic field pattern around (1) a bar magnet, and (2) between the poles of two bar magnets **(STEM_GP12EM-IIIh-57)**.

**Prerequisite Knowledge**

Concept of field and its representation, Coulomb's law

## LESSON OUTLINE

| | | |
|---|---|---|
| **Motivation** | Discussion of the earth as a natural magnet | 10 |
| **Instruction/ Discussion** | Lecture proper | 40 |
| **Evaluation** | Practice examples | 10 |
| **Materials** | Slide presentation<br>RHR handout<br>big and small magnets<br>iron fillings | |

**Resources**

(1) H.D. Young, R.A. Freedman, A.L. Ford, University Physics, 12th Ed. (Addison-Wesley, 2011), (Sections 27.1-27.3).

(2) Paul Hewitt, Conceptual Physics, 11th Ed. Addison-Wesley, 2009.

## MOTIVATION (10 MINS)

Discuss that the earth is a natural magnet and explain that the magnetic field B serves as its "shield". Discuss that the aurora borealis/australis occur as a consequence of the presence of its magnetic field.

(*images from google)

Figure 1. (first) The earth as it is protected by its magnetic fields from the direct hit of solar flares; (second) aurora borealis/australis formed.

Sample questions from students:

a. Does the earth have magnetic north and south poles?
b. How do aurora borealis/australis form?

## INSTRUCTION AND/OR DISCUSSIONS (30 MINS)

1. Enumerate the two sources of magnetic fields covered in this guide: (a) magnet and (b) moving charge (current). State the unit of magnetic field, which is Tesla.

2. Show a picture of some pins attracted to magnets and/or a picture of light metals attracted to current-carrying wires.

**Teacher Tips**

The RHR handout should be given on the day of this lesson. Inform them that it is for advanced reading.

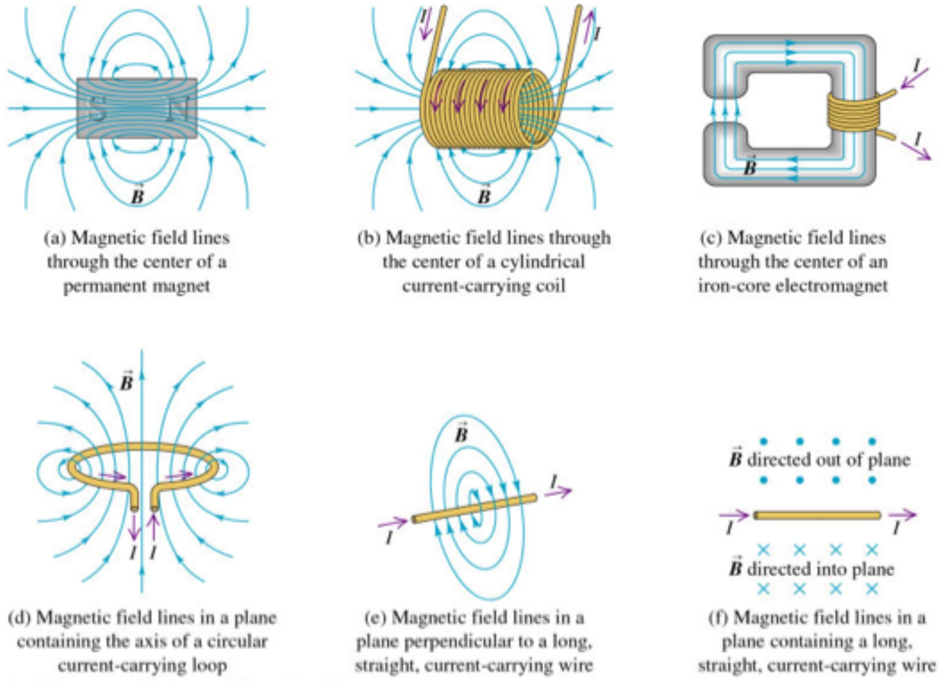



Figure 2. Sources of magnetic fields: (1) magnets and (2) moving charges or current.

**Teacher Tips**

You may opt to show only figure (a) together with a diagram of a moving charge as source of magnetic field.

3. Use the table of properties of matter as a reference in the discussion of the succeeding items. Instructions on how to use the table, follows after it.

| Points of comparison | Mass | Charge | Magnetic poles |
|---|---|---|---|
| Examples | rock | Charged balloon (by rubbing or by induction) | Magnets |
| Existence of Poles | Point masses | Monopole | No monopole |
| Interaction | Attract | Attract/repel | Attract/repel |
| Fields Produced | Gravitational field | Electric field | Magnetic field |
| Force | Gravitational force | Electric force | Magnetic force |

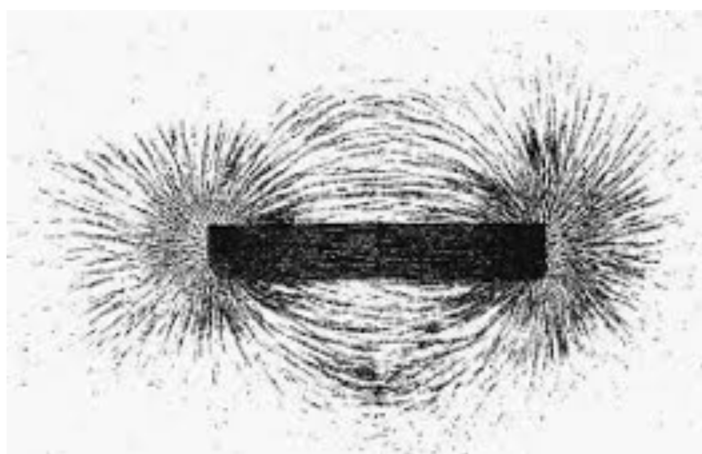
Instructions on how to use the table:

i. Discuss that the magnetic field is produced by a certain "unit" of quantity called magnet, by using an analogy with the gravitational and electric fields. That is, a unit **mass** produces a gravitational field that exerts a gravitational force on another mass; a **charge** produces its own electric field that exerts electric force on another charge; and so with a **magnet** producing magnetic fields that exerts magnetic force on charges or magnets.
ii. Emphasize that like the attraction between charges, the magnetic attraction is either attraction or repulsion.

4. *Magnetic Poles.* Compare the difference between a charge and magnetic poles (N and S). Ask what happens to the pole when the magnet is broken. Demonstrate the non-existence of magnetic monopoles by showing that the even if magnets are broken into small pieces, they still attract each other, indicating that they still have both south and north poles.

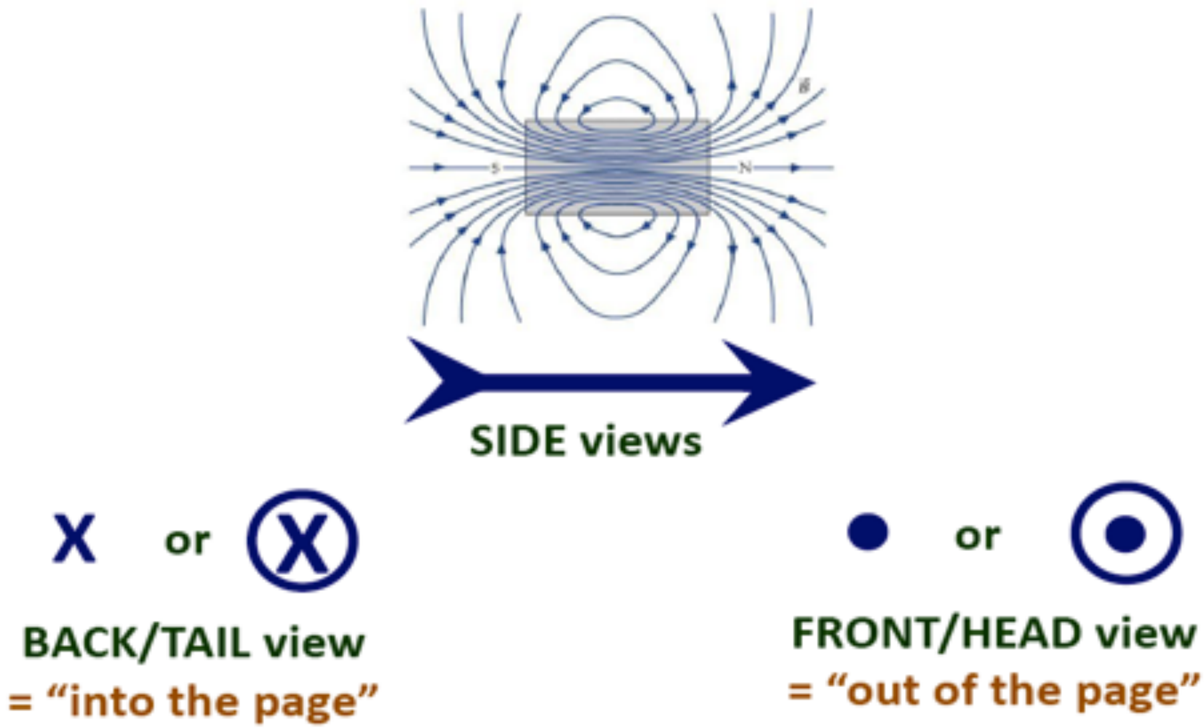
5. *Magnetic Attraction.* Compare the difference between electric and magnetic interaction, following the table above.
   Like charges repel, opposite charges attract.
   Ask: like poles _____________, opposite charges ___________.

6. **Practice:** Demonstrate the magnetic field lines with iron filings.
   a. *Magnetic Fields.* Place iron filings around a magnet to demonstrate the magnetic field lines.

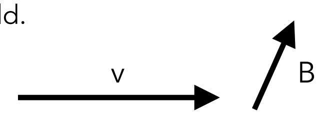


   b. *Magnetic Field Direction.* Next, place a compass anywhere at side of the magnet. Ask, what is the direction of magnetic field lines outside the magnet? Ans: N → S

7. Display the following representation of magnetic field lines:




8. Discussion on magnetic interaction:
   Refer to the following table. Emphasize that an electric charge can interact with both the electric and magnetic fields.
   But… Only moving charges are affected by a magnetic field.

| | **Electric Force** | **Magnetic Force** |
|---|---|---|
| Charge interaction | Stationary/moving charges are both affected | A moving charge whose velocity has a component that is perpendicular to the magnetic field vector interacts with magnetic field.   |

### Teacher Tips

Because of the presence of fields, even a distant charge may experience force, even if there is no direct contact by the source of magnetic field. This is not intuitive to students since our daily experiences may dictate that force needs to be in contact in order to feel it.

***Gauss' Law for Magnetism (10 mins)***

1. Review magnetic field patterns of several simple symmetric current configurations and permanent magnets. Ask the question: If you break a bar magnet, with its poles properly labeled "North" and "South," into two, what is the product? If there is magnet that you can break and iron filling available, you may perform a demonstration. You may also demonstrate using two solenoid electromagnets connected in series.

2. Let the students sketch the magnetic field lines of the original (whole) magnet and the new (fragmented) magnets. Emphasize that the magnetic field lines should be drawn completely such that a closed loop is clear.

3. Then, let the students draw a closed surface (in 2D, this appears as a loop) superimposed on the field lines. It can be of any shape as long as it is closed. Let them estimate the surface area.

4. Finally, let them count the total number of inward and outward field lines and multiply the surface, and compare their result with those of classmates. Let them state their result or observation about the magnetic field (flux) through a closed surface.

5. Introduce **Gauss Law, a geometric relation between magnetic poles and magnetic field**, in equation and statement form:

$$\Phi = \oint_{\text{closed surface}} \vec{B} \cdot dA = 0$$

*"Magnetic monopole does not exist. If you cut a permanent magnet into two, the product is not a magnet with only one pole but rather a weaker magnet that still has both North and South Pole. Accordingly, the magnetic flux through any close surface is zero."*

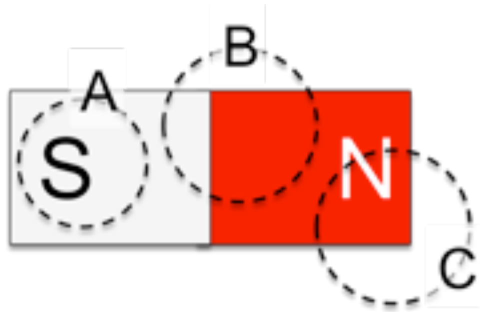
## EVALUATION (10 MINS)

1. Ask the students to enumerate some possible sources of magnetic fields are.

2. Ask the students to draw the magnetic field lines between two magnets that repel each other.

3. Ask what is the magnitude of the magnetic field exactly between the two magnets.

4. Ask which of the Gaussian surfaces (dotted lines) has the highest magnetic flux.




**Teacher Tips**

Note: Distribute the vector cross-product handout.

5. Ask what happens to the magnetic flux through a Gaussian surface when the area of the surface is doubled.

60 MINS

# Lorentz Force; Motion of charged particles in electric and magnetic fields

**Content Standards**

The learners demonstrate an understanding of:

1. Magnetic fields
2. Lorentz Force
3. Motion of charge particles in electric and magnetic fields

**Performance Standards**

The learners are able to use theoretical and experimental approaches to solve multi-concept and rich-context problems involving electricity and magnetism

**Learning Competencies**

At the end of the session, the students should be able to:

1. Calculate the magnetic force on a charge placed in a constant magnetic field and in an environment with both electric and magnetic field using the Lorentz Force.
2. Describe the motion of a charged particle in a magnetic field in terms of its speed, acceleration, cyclotron radius, cyclotron frequency **(STEM_GP12EM-IIIh-58).**

**Prerequisite Knowledge**

Magnetic fields and field lines, centripetal force, superposition principle

**Prerequisite Skills**

Cross-product

## LESSON OUTLINE

| | | |
|---|---|---|
| **Motivation** | Brief review | 10 |
| **Instruction/ Delivery/ Practice** | Lecture proper | 40 |
| **Evaluation** | Short activity | 10 |
| **Materials** | Slides<br>RHR handout<br>internet<br>youtube video (if no internet connection) | |

**Resources**

(1) H.D. Young, R.A. Freedman, A.L. Ford, University Physics, 12th Ed. (Addison-Wesley, 2011), (Sections 27.1-27.3).

(2) Paul Hewitt, Conceptual Physics, 11th Ed. Addison-Wesley, 2009.

## MOTIVATION (10 MINS)

1. State that there is a way to confine electrons and make them move in a circular motion without spatial restrictions of their paths (use the picture below).

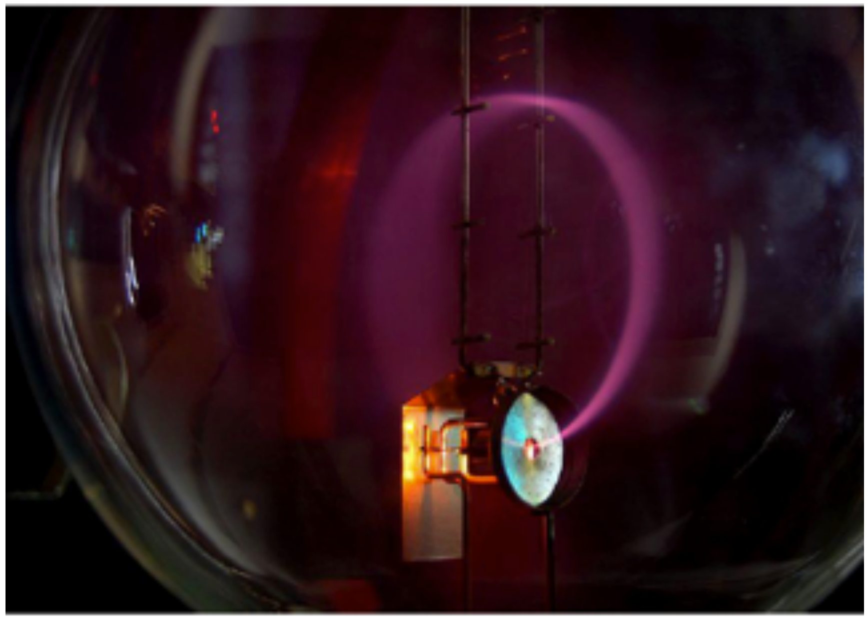


Figure 1. Electrons confined to move within a circular path.

2. Ask, what kind of force in classical physics is most closely related to the motion of electrons in the picture above, if the electrons are assumed as classical mass particles?
   *Answer: centripetal force.*

3. Recall that the equation for a centripetal force expressed in terms of mass  and centripetal acceleration , of the object is given as:

$$\vec{F}_c = m\vec{a}_c = m\frac{v}{r} \qquad \text{(Eqn 1)}$$

4. Ask as follow-up for question number 2, what is the property of the electrons that determines the radius of their circular motion (pink) based on Eqn 1?

*Answer: mass*

5. Check for a video link of mass spectrometer in youtube.

## DISCUSSIONS (40 MINS)

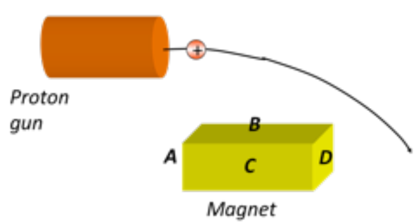
1. Recall the table comparing the interactions of a charge with electric field and magnetic fields (5 mins).

| | Electric Force | Magnetic Force |
|---|---|---|
| Charge interaction | Stationary/moving charges are both affected<br>$\vec{F}_E = q\vec{E}$ | A moving charge, whose velocity has a component that is perpendicular to the magnetic field vector, interacts with magnetic field.<br>$\vec{F}_B = q\vec{v} \times \vec{B}$ |

2. Use the handout that was provided and recall the cross-product from calculus and General Physics 1 (GP1), before introducing the magnetic force acting on a charge moving in a magnetic field. Answer the questions in the handout guided exercises.

   Practice 1 (5 mins)
   A proton gun fires protons moving to the right. When a magnet is placed near the gun (as shown below), it was observed that the protons are deflected downwards. Which of the labeled faces is the south pole of the magnet?

   *Answer: B: North, C:South*




**Teacher Tips**
The discussion should be done in 10 minutes if the handout was given as an advanced reading material. Students may not be able to master the RHR immediately, so the handout must be given in advance.

3. Introduce Lorentz Force:
   i. Using the following table, define Lorentz force as the force experienced by a charge due to electromagnetic fields, i.e. electric and magnetic fields. State that the unit of $F_B$ is still in Newtons (N). (5 mins)

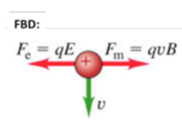
| | |
|---|---|
| Change interacting with magnetic field **B**<br>$\vec{F}_B = q\vec{v} \times \vec{B}$ | Lorentz Force: Charge in the presence of both electric and magnetic fields<br>$\vec{F} = q\,(\vec{E} + \vec{v} \times \vec{B})$ |

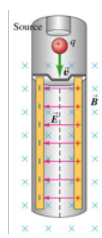
   ii. Using the principle of superposition, explain that in the presence of both **B and E**, a moving charge will experience both $F_B$ and $F_E$.

   <u>Practice 2 (10 mins)</u>
   A charge q is moving straight downwards with a velocity of 20,000 m/s through the electric (E) and magnetic (B) fields as shown. What are the possible values of E and B?

   *Answer/Teacher's solution:*

   $\vec{F}_E = \vec{F}_B$
   $qE = qvB$
   $E = vb$




**Teacher Tips**

Explain the meaning of the result: that given |v|, |E| can have values as a function of |B|.

4. Introduce Cyclotron Frequency. (5mins)
   Using Eqn 1, recall from GP1 (Classical Mechanics) that an object moving in a circular motion has an acceleration $\vec{a}_c$, velocity $\vec{v} = r\omega$, and $\omega = 2\pi f$.

   For a charged particle moving in a circular motion in a region of uniform magnetic field, it experiences the centripetal force that is perpendicular to its velocity such that one can easily derive the cyclotron radius r and angular speed, $\omega$:

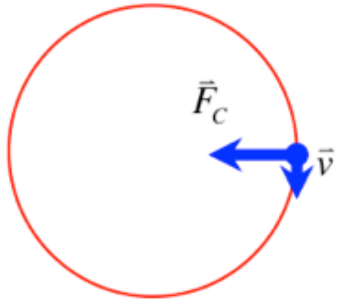
   $\vec{F}_B = \vec{F}_C$
   $= m\vec{a}_C$

$|q|\vec{v} \times \vec{B} = m$

$\frac{|q|B}{m} = \frac{v}{r}$

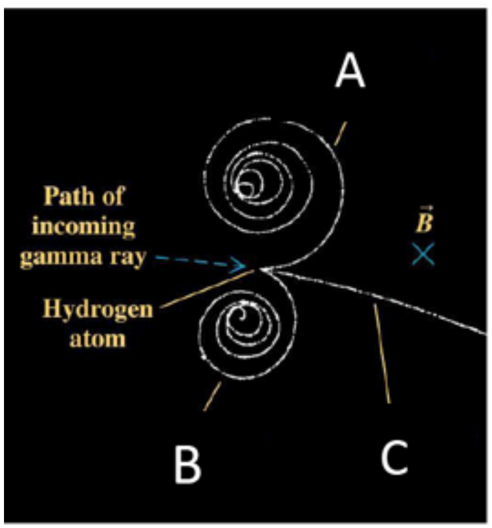
$r = \frac{mv}{|q|B}$;

$\omega = \frac{|q|B}{m}$




<u>Practice 3 (5 mins)</u>

Interpreting the chamber bubble:




Gamma ray ejects an electron from a (stationary) hydrogen atom. The collision broke the atom producing a slow moving electron, a fast moving electron and a slow moving positron (charge equal to that of proton but mass is equal to that of electron).

Identify the particles travelling on paths A, B, and C.

A:_______

B:_______

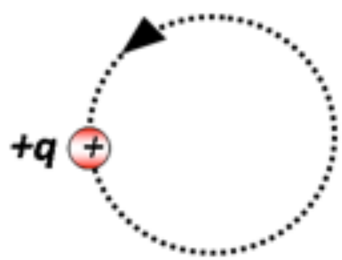
C: _______

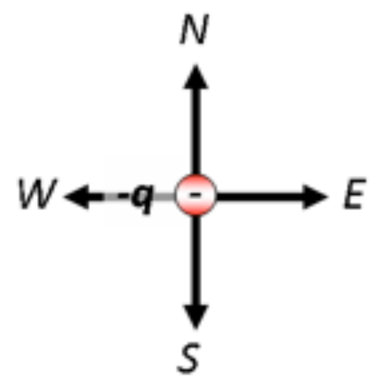
5. Rank the properties of the charged particle from 1 to 3, 3 being the highest, in terms of its speed, acceleration, cyclotron, radius, cyclotron frequency, and kinetic energy. (5mins)

*Answer:*

| | A | B | C |
|---|---|---|---|
| speed, v | 2 | 1 | 3 |
| mass, | 2 | 1 | 3 |
| magnitude of radius, r | 2 | 1 | 3 |
| cyclotron frequency, f | | | |
| kinetic energy | 2 | 3 | 1 |

## EVALUATION (10 MINS)




A positive charge q in a region with uniform magnetic field is found to be moving in a circular trajectory as shown in the figure. A negative charge, of the same mass as the positive charge, is then fired into the region where the positive charge q is located. Using the following figures, answer the following questions:

1. What is the direction of the magnetic field in the region where the positive charge is moving?
   *Answer: Into the page,* ⊗

2. Describe the trajectory of the negative charge q as it enters the region of uniform magnetic field.
   *Answer: opposite the trajectory of +q*

**60 MINS**

# Magnetic Force of a Current-Carrying Wire

**Content Standards**
The learners demonstrate an understanding of magnetic forces on current carrying wires that are immersed in uniform magnetic fields.

**Performance Standards**
The learners are able to:
Use theoretical and experimental approaches to solve multi-concept and rich-context problems involving electricity and magnetism

**Learning Competencies**
At the end of the session, the students should be able to evaluate the magnetic force on an arbitrary wire segment placed in a uniform magnetic field **(STEM_GP12EM-IIIh-59)**.

**Prerequisite Knowledge**
Lorentz force, Conventional Current direction

**Prerequisite Skills**
Cross-product, line integral

## LESSON OUTLINE

| | | |
|---|---|---|
| **Motivation** | Demo video showing | 10 |
| **Instruction** | Lecture proper | 30 |
| **Evaluation** | Sample brief exercises | 20 |
| **Materials** | Youtube video<br>2 strong magnets (can be ceramic magnet)<br>insulated copper wire (with bare portion)<br>9-V battery<br>RHR handout<br>Slides | |

**Resources**

(1) H.D. Young, R.A. Freedman, A.L. Ford, University Physics, 12th Ed. (Addison-Wesley, 2011)
(2) Paul Hewitt, Conceptual Physics, 11th Ed. Addison-Wesley, 2009.

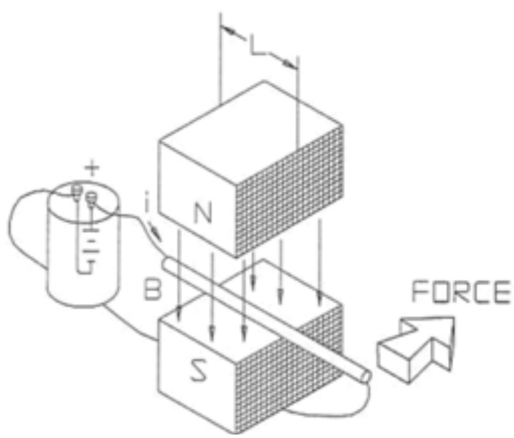
## MOTIVATION (10 MINS)

Show a demo or a video of a current-carrying wire that suddenly experiences a force.

Option 1: Play a video from Youtube (https://www.youtube.com/watch?v=tbCXaER0w-s)
Option 2: Demonstrate following the steps enumerated below.

How to demonstrate:

(i) Place an insulated circuit loop with a bare portion in between south and north poles as shown on the figure to the right. Note that at first, the circuit loop should still be open.
(ii) Close the circuit loop by connecting both ends of the circuit to the battery. Recall that current flows from the positive to the negative terminal of the battery.
(iii) Ask what made the conductor move.




http://rack1.ul.cs.cmu.edu/rotaryvoicecoil/

Sample questions from students: (Share the answers at the end of Discussions part.)

a. What will happen if the arrangement of the poles is interchanged?
b. If the circuit connection to the battery is reversed, what will be the direction of movement of the wire

**Teacher Tips**

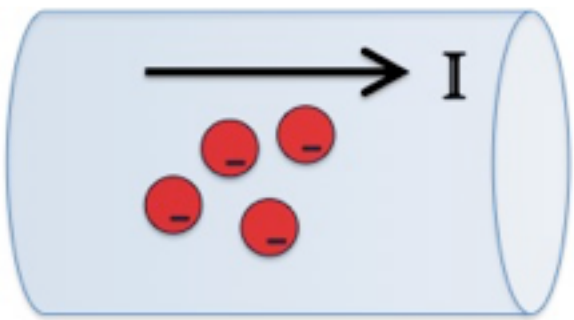
Always practice the experiment before actual demonstration in class.

## INTRODUCTION AND/OR DISCUSSIONS (30 MINS)

1. Recall that a moving charge in a uniform magnetic fields experiences a magnetic force, $\mathbf{F_B}$ due to the field, which is proportional to its velocity, **v**.

2. Recall that a moving charge experiences a force due to an external magnetic field described by the Lorentz Force.

   Discuss that current is defined as the total number of charges passing through a cross-sectional area of a wire. By convention, it follows the direction of the movement of electrons as shown in the figure below. Note that, in a circuit, current flows from the positive terminal to the negative terminal. The current of a conducting wire, ***I***, can be easily measured by an ammeter and is constant throughout the wire.




3. Discuss that **Fnet**, or the total force exerted on a current-carrying wire is equal to the sum of the cross products of the current ***I***, passing through infinitesimal lengths *dL*, with the magnetic field B. In other words, it is equivalent to the following equation:

$$\vec{F}net = \int I d\vec{L} \times \vec{B} \qquad (1)$$

For a straight wire, $\int d\vec{L} = \vec{L}$ (2)

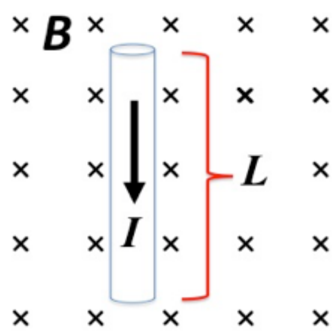
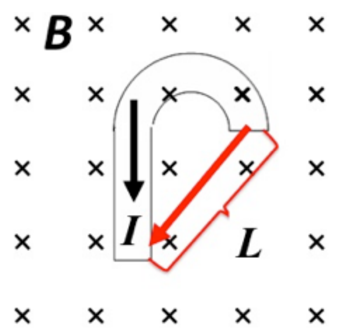
Where *L* is the vector length of the wire.

4. **Example 1:** Demonstrate how to get the vector length, L, of wires:

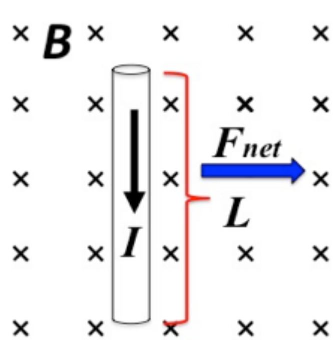
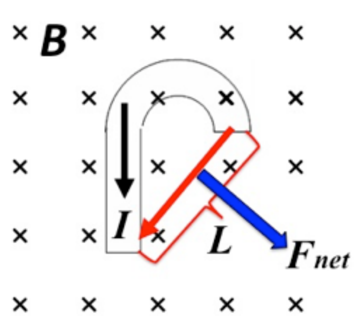
**Teacher Tips**

Line integral is done through the length of the wire, which is not necessarily straight.

Answers are in red.

<table>
<tr><th>i. Straight Wire</th><th>ii. Curved Wire</th></tr>
<tr><td>
</td><td>
</td></tr>
</table>

5. Example 2: After getting L, demonstrate how to get the direction of the net force acting on the wires in Example 1.
   Answers are in blue.

<table>
<tr><th>i. Straight Wire</th><th>ii. Curved Wire</th></tr>
<tr><td>
</td><td>
</td></tr>
</table>

6. **Example 3.** Using the same procedure for examples 1 and 2, show that the net force on a current-carrying square loop that is immersed in a uniform magnetic field is zero.

**Teacher Tips**

Make sure that they remember the right-hand-rule.

**Teacher Tips**

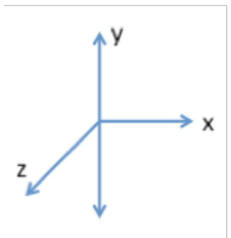
The current-carrying conducting wire will only move at the instantaneous time that the current flows through the wire, i.e., right after the switch is closed. After some time, the wire will no longer experience magnetic force as the system

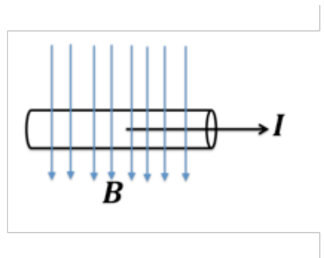
# EVALUATION (20 MINS)

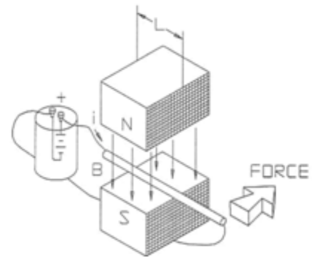
1. Recall the video or demonstration showed at the start of the class. While showing the same figure, make them draw a schematic diagram of the system of the wire and conductor with proper labels of current I and magnetic field B, step by step, just as how the Examples 1 and 2 were drawn. Have them use the formula in equation (1) and the RHR technique to solve for the magnitude and direction of the force experienced by the conductor, respectively.

   Answer:

   $\vec{F}_{net} = \int I d\vec{L} \times \vec{B}$
   $\vec{F}_{net} = I \int d\vec{L} \times \vec{B}$
   $\vec{F}_{net} = ILB(=\hat{z})$








   a. What will happen if the poles are interchanged?
   b. If the connection of the circuit to the battery is reversed, what will be the direction of movement of the wire as the switch is turned on?

2. Following equation (1), what will be the direction of the force experienced by the current-carrying conductor if the magnetic field B is parallel, instead of being perpendicular, to the conductor?

3. Using the same figures in Example 1, if I=2.0A, L is 0.2m, and B=1.0T, solve for the magnitude of the net force that acts on the wire.

4. Using the same figures in Example 1, what will be the direction of the force on the current-carrying conductor if the current direction is reversed?

5. A current I=1.0A flows through a conductor with a vector length given as L=(0.1i -0.5j)m. The conductor is immersed in a region with uniform magnetic field B= (1i + 1.2j + 2k)T. Find the force experienced by the conducting wire.

   Answer: F=(1i - 0.2j + 0.38k)N

60 MINS

# Biot-Savart Law

**Content Standards**

The learners demonstrate an understanding of:

1. Magnetic fields produced by moving charges, current carrying straight wires, and circular current-carrying loops or solenoids.
2. Biot-Savart Law

**Performance Standards**

The learners are able to:

Use theoretical and experimental approaches to solve multi-concept and rich-context problems involving electricity and magnetism

**Learning Competencies**

At the end of the session, the students should be able to:

1. Evaluate the magnetic field vector at a given point in space due to a moving point charge, an infinitesimal current element, or a straight current-carrying conductor **(STEM_GP12EM-IIIh-60)**.
2. Calculate the magnetic field due to one or more straight wire conductors using the superposition principle **(STEM_GP12EM-IIIi-62)**.
3. Calculate the force per unit length on a current-carrying wire due to the magnetic field produced by other current-carrying wires **(STEM_GP12EM-IIIi-63).**
4. Evaluate the magnetic field vector at any point along the axis of a circular current loop **(STEM_GP12EM-IIIi-64).**

**Prerequisite Knowledge**

Lorentz force, Coulomb's law, Superposition principle

**Prerequisite Skills**

Cross-product, integral calculus

## LESSON OUTLINE

| | | |
|---|---|---|
| **Motivation** | Demo video and picture-showing | 5 |
| **Instruction/ Delivery** | Lecture-proper | 40 |
| **Evaluation** | Sample brief exercise | 15 |
| **Materials** | Slides<br>Youtube Video | |

**Resources**

(1) H.D. Young, R.A. Freedman, A.L. Ford, University Physics, 12th Ed. (Addison-Wesley, 2011)

(2) Paul Hewitt, Conceptual Physics, 11th Ed. Addison-Wesley, 2009.

## MOTIVATION (5 MINS)

1. Choose one of the following options.
   Option 1: Play a video from Youtube (https://www.youtube.com/watch?v=dVS4Q4VgDxk)
   Option 2: Show pictures (dailymail.co.uk)

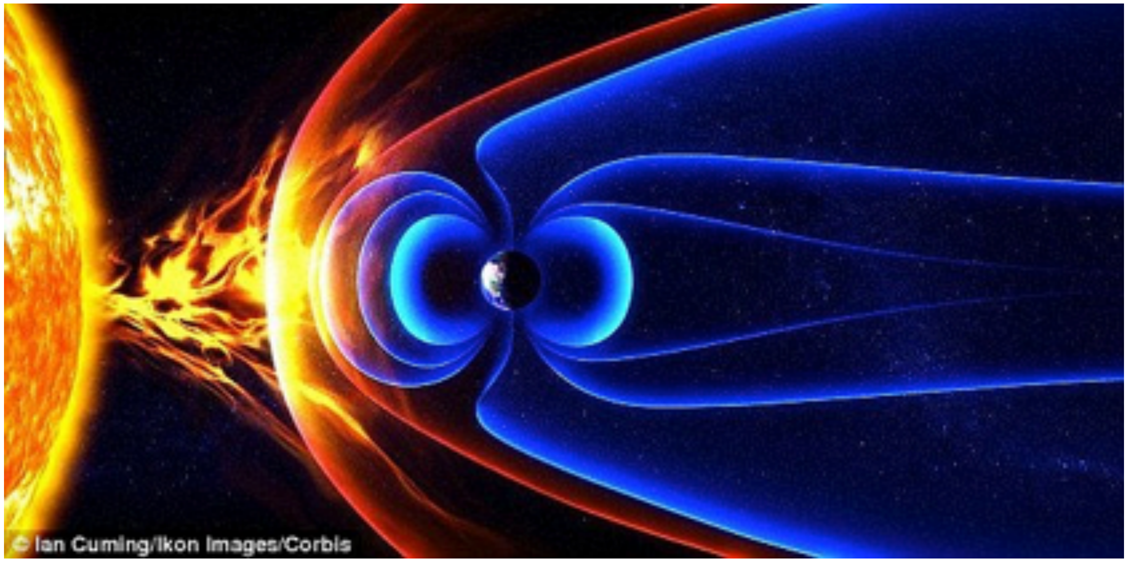



*Figure 1. Magnetic field shielding the earth from solar flares.*

2. Upon showing a video or picture, discuss why the field in Figure 1 distorted. Solar storms send ions and plasmas that create their own magnetic field such that during a solar storm, the magnetic field of the earth is distorted.

3. Sample question(s) from students: (Share the answers at the end of Discussions part.)
   a. Will the earth's magnetic field remain forever?
   b. If the magnetic field is produced by moving charges then does that mean that the earth has charges that are always moving?

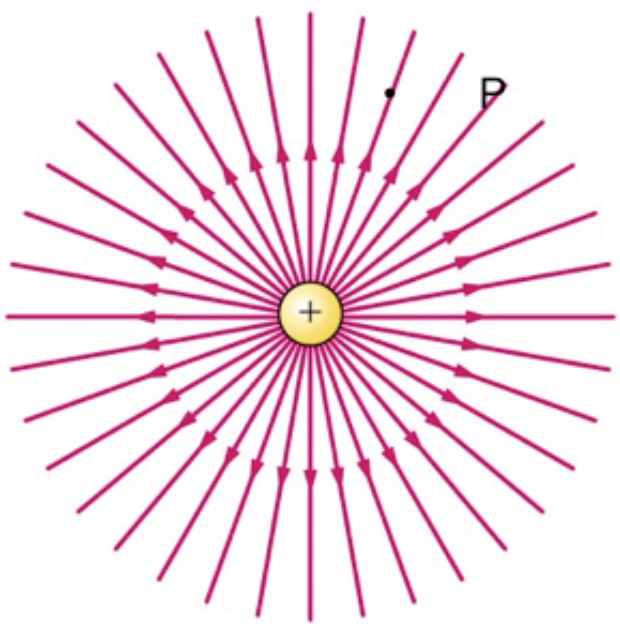
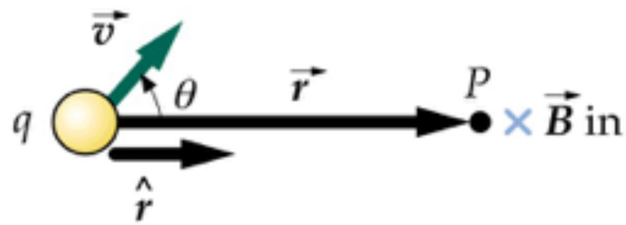
**Teacher Tips**

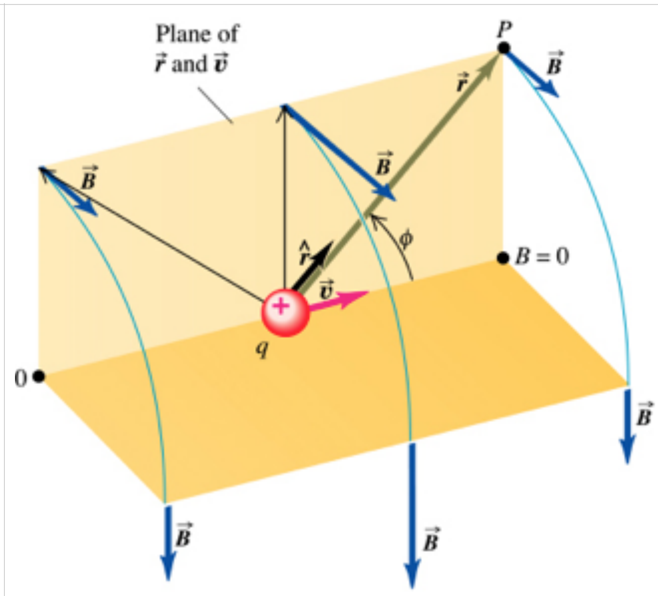
Discuss the meaning of all the symbols used in the equation.

## INTRODUCTION AND/OR DISCUSSIONS (40 MINS)

1. **B produced by a moving charge q:**
   Compare electric field with magnetic field using the table below. Emphasize that both electric and magnetic fields are proportional with *q* and inversely proportional with the square of the distance of the charge from the point where the field is being measured ($r^2$).

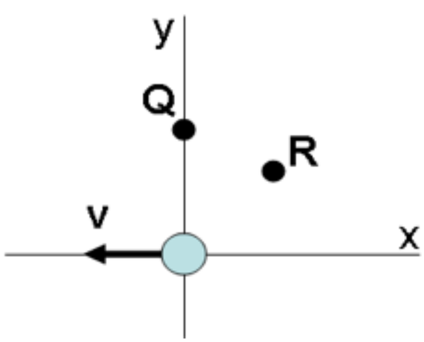
**Teacher Tips**
Both magnetic and electric field lines extend in three dimension (3D).

| | |
|---|---|
| $\vec{E} = \frac{1}{4\pi\varepsilon_0} \frac{\lvert q \rvert}{r^2} \hat{r}$ (Eqn 1)<br><br>Note:<br>• $\hat{r}$ (blue arrow in Figure 2) is a unit vector that points from the source charge to the observation point, P.<br><br><br><br>Image from University Physics, Young, 11th Edition. | $\vec{B} = \frac{\mu_0}{4\pi} \frac{q\vec{v} \times \hat{r}}{r^2}$ (Eqn 2)<br><br>Note:<br>• $\vec{v} \times \hat{r}$ is maximum when $\vec{v} \perp \hat{r}$ and minimum when $\vec{v} \parallel \hat{r}$.<br><br><br><br>Figure 3. Sample visualization in 2D |

| | |
|---|---|
| Figure 2. A point charge and its electric field at point P. Note that this visualization corresponds to only one plane of a 3D space, but in reality, the fields extend in all space. A 3D visualization is needed. | <br><br>Image from University Physics, Young, 11th edition.<br><br>Figure 3. Sample visualization in 3D of a moving point charge and its magnetic field at Point P. |

**Example 1:** What are the directions of the magnetic fields at observation points Q and P?
Answer: Into the page.

Figure 6. Illustration for Example 1.



## 2. B produced by an infinitesimal current element, dL:

Discuss that Eqn (2) can be generalized for current-carrying wires and current loops using the superposition principle. In other words, by summing over all the infinitesimal current elements of the wire or loop (integral form), we an integral form as follows:

$$\vec{B} = \int d\vec{B} = \frac{\mu_0}{4\pi} \int \frac{I d\vec{L} \times \hat{r}}{r^2} \qquad \text{(Eqn 3)}$$

## 3. B produced by a current-carrying wire:

$$B = \frac{\mu_0}{4\pi} \int \frac{I d\vec{L} \times \hat{r}}{r^2}$$

$$B = \frac{\mu_0 I}{4\pi} \int_{-a}^{a} \frac{\sin\theta}{(\sqrt{x^2 + y^2})^2}\, dy$$

$$B = \frac{\mu_0 I}{4\pi} \int_{-a}^{a} \frac{x}{(\sqrt{x^2 + y^2})^{3/2}}\, dy$$

$$B = \frac{\mu_0 I}{4\pi} \frac{2a}{x\sqrt{x^2 + a^2}} \qquad \text{(Eqn 4)}$$

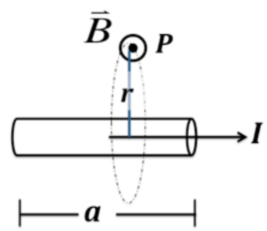



Figure 7. The magnetic field at point P produced by a current carrying wire. By RHR, the direction is out of the page.

**Teacher Tips**

The derivation above may be skipped and the teacher may directly proceed to Eqn 4 if there is not much time for the discussions.

If a>>x, i.e. when the wire is very long, then Eqn (4) reduces to

$$B = \frac{\mu_0 I}{2\pi x} \qquad \text{(Eqn 5)}$$

On the other hand, if a<<x, then Eqn (4) reduces to

$$B = \frac{\mu_0 I a}{2\pi x^2} \qquad \text{(Eqn 6)}$$

Equations (4-6) solve for the magnitude of **B**, while the direction can be found using the RHR, with the thumb pointing to the direction of current while the fingers curl following the direction of the magnetic field as shown in the next figure.

Figure 8. RHR for a current-carrying wire.

**Teacher Tips**

The x in the denominators of Eqns 4-6 serve as the radius of the magnetic field that encircles the wire and may be replaced by a more general symbol, r.

**Example 2 (Don't skip this part):** [The teacher must solve this problem step-by-step on the blackboard. This part satisfies the competencies stated in IIIi-63.] There will be a separate seatwork, which is similar to the following problem for evaluation.

Shown in the figure is a current-carrying wire with the direction of current indicated by the arrow.

a. Verify that the direction of **B** at point P is into the page, and
b. Compute for the magnitude of B. Assume that the wire is infinitely long.
   *Answer:*

   $$B = \frac{\mu_0 I}{2\pi x}$$

c. If another current-carrying wire with the same direction is placed to the right, what is the direction of force experienced by the second wire? What is the magnitude of the force per unit length experienced by wire 1?

   *Answer:* Discuss with the following steps as you draw on Figure 10.
   Step 1: Focus on wire 1 as the source of magnetic field B. Find the direction of magnetic field due to the first wire $B_1$, at the location of second wire (this is the same question in (a))
   Step 2: Focusing on wire 2, use the answer in (a) as the external magnetic field. Then recall that $\vec{F}$
   from the previous chapter.

   *<u>The magnetic force is to the left, thus the second wire will move towards the first wire. One can compute F/L for the force per unit length experienced by wire 1.</u>*

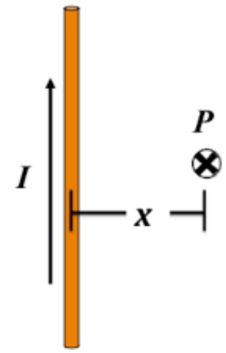



*Figure 9.*

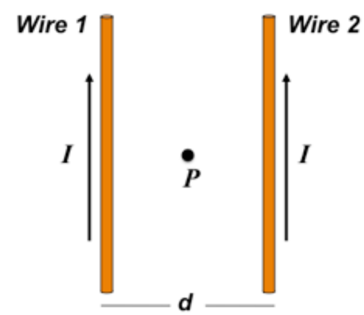



*Figure 10.*

**Teacher Tips**

The evaluation #1 can be used at this stage as a seatwork if there is time. You may end the discussion at this stage if there is no more time.

## 4. <u>B produced by a circular current loop:</u>

$$\vec{B} = \int d\vec{B} = \frac{\mu_0}{4\pi} \int \frac{Id\vec{L} \times \hat{r}}{r^2} \qquad \text{(Eqn 7)}$$

While showing Figure 12, discuss that B lies along the x-y plane and by symmetry, all the y-components of B will cancel, resulting to a net B along the axis of the loop (see figure). The net B is given as:

$$B_x = \frac{1}{2} \frac{\mu_0 I a^2}{(x^2 + a^2)^{3/2}} \qquad \text{(Eqn 8)}$$

When x<<a, or when point P is at the center of the loop, Eqn (8) reduces to

$$B_x = \frac{\mu_0 I}{2a} \qquad \text{(Eqn 9)}$$

When x>> a, or when P is very far from the loop, Eqn (8) reduces to

$$B_x = \frac{\mu_0 I a^2}{2x^3} \qquad \text{(Eqn 10)}$$

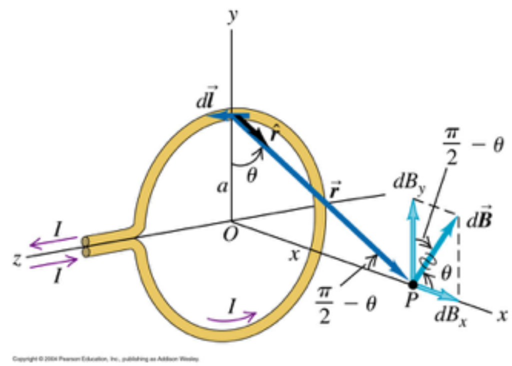



*Figure 12. Magnetic field due to a circular current loop*

**5. <u>B produced by a circular current loop:</u>**

Give the formula for B of a solenoid, which is:

$$B_x = N * \frac{1}{2} \frac{\mu_0 I a^2}{(x^2 + a^2)^{3/2}} \qquad \text{(Eqn 11)}$$

Emphasize that the method of getting the direction of Eqn (11) is similar to the method of finding the direction of B for a current-carrying wire.

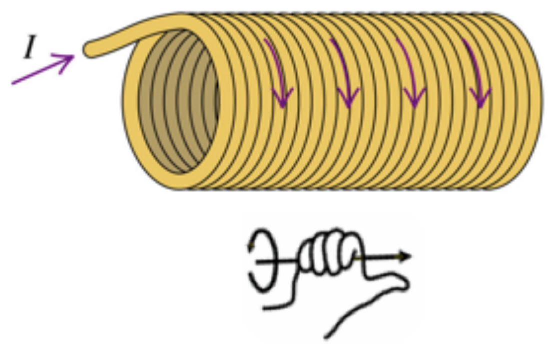



*Figure 13. B of a solenoid*

**Teacher Tips**

The evaluation #1 can be used at this stage as a seatwork if there is time. You may end the discussion at this stage if there is no more time.

**Teacher Tips**

Emphasize that Eqns 4 and 8 are general equations where once can derive the equations for various conditions such as for the cases of infinitely long wires, which corresponds to Eqns 5.

## EVALUATION (15 MINS)

1. **B** between two long conductors:

a. Given two current-carrying wires, each with current direction as shown in Figure 14. What is the magnetic field at d/2 between the two wires?
Answer: zero.

b. What is the force experienced by wire 1 due to the magnetic field produced by wire 2? (Hint: Follow the discussion in Example 2. Find the direction of magnetic field due to wire 2 at the location of wire 1, $B_2$, and use that as the external magnetic field for wire 1. Then recall that F=1LxB from the previous chapter and previous example, such that in this case, $F_{2on1} = I_1L_1 \times B_2$.)

c. Answers:
B experienced by wire 1 due to wire 2: out of the page
F experienced by wire 1 due to wire 2: to the right

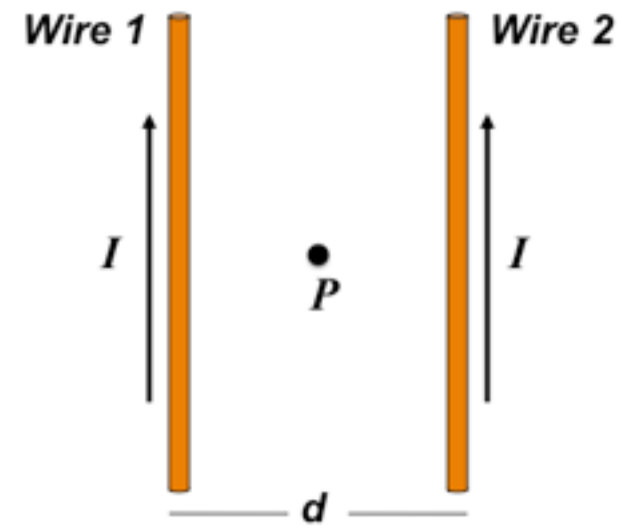



Figure 14

2. Solenoid and magnet. What will happen to the magnet, will it be attracted towards the solenoid or will it be repelled. Refer to Figure 15.

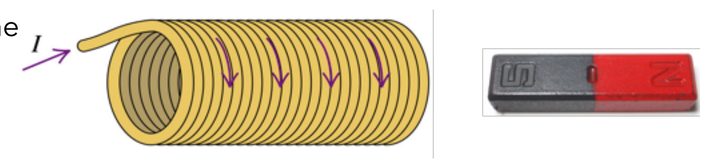



Figure 15

*(Answer: $B_{SOLENOID}$ along the solenoid's axis is directed to the right, which makes the solenoid behave as if it is a magnet with its north pole in front the south pole of the magnet as in the figure on the right. Thus the two will be attracted to each other.)*

60 MINS

# Ampere's Law

**Content Standards**
The learners demonstrate an understanding of Ampere's Law

**Performance Standards**
The learners are able to use theoretical and experimental approaches to solve multi-concept and rich-context problems involving electricity and magnetism

**Learning Competencies**
1. Evaluate the magnetic field vector at any point along the axis of a circular current loop (**STEM_GP12EM-IIIi-63**)
2. Calculate magnetic fields for symmetric current configurations using Ampere's law (**STEM_GP12EM-IIIi-64**)

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction** | Present Ampere's Law as a geometric relation between current and magnetic field | 3 |
| **Motivation** | Comparison of the calculation of electric field using Biot-Savart's Law and Ampere's Law | 7 |
| **Instruction/ Delivery** | a. Preliminaries.<br>b. "Proving" the Ampere's Law<br>c. Applying Ampere's Law<br>d. Sample discussions on the issues and application of Ampere's Law.<br>e. Comments on the common misconceptions, mistakes, or difficulties | 30-35 |
| **Enrichment** | Determining the magnetic field of a current-carrying toroid and a solenoid | |
| **Evaluation** | Individual or by-pair quiz | 6 |
| **Materials** | chalk and board, pen and paper | |

**Resources**


(1) R.W. Chabay, B.A. Sherwood. Matter and Interaction II: Electric and Magnetic Interactions, 3rd Ed. (J. Wiley & Sons, Inc. 2010).

(2) C.A. Manogue, K. Browne, T. Dray, B. Edwards. Why is Ampere's law so hard? A look at middle-division physics. Am. J. Phys. 74(4), 344-350 (2006).

(3) H.D. Young, R.A. Freedman, A.L. Ford, University Physics, 11th Ed. (Addison-Wesley, 2011).

(4) D. Halliday, R. Resnick, J. Walker. Fundamentals of Physics Extended, 10th Ed. (J. Wiley & Sons, Inc., 2013.)

## INTRODUCTION (3 MINS)

1. Introduce **Ampere's Law, a geometric relation between current and magnetic field** , in equation and statement form:

$$\oint B \bullet dl = \mu_0 \sum_i^N I_{i,enclosed} \qquad (1)$$

   "The sum of the components of the magnetic field that are parallel to the infinitesimal segments of any close loop (Amperian loop) is equal to the total current enclosed (i.e., inside) by that same loop."

2. Emphasize that the Amperian loop as an imaginary object, who specification is determined by necessity in solving a given problem. (In fact, it can be arbitrarily chosen, as will be shown later, except that some choices not be useful for the purpose of manually calculating the magnetic field of a given current configuration.)

## MOTIVATION (7 MINS)

1. Show a sample calculation, performed in the previous meeting, of magnetic field using Biot-Savart's Law and asking students for difficulties they encounter. Ensure that this current configuration is of the kind where where Ampere' Law is also appropriate to use. (Suggestion: Give a one-minute concept quiz/ game asking students to determine magnetic field of an infinite wire carrying a current, I. See Appendix A.)

2. Show the solution of the same problem but using Ampere's Law this time. Ask the students to compare the two approaches, such as the length or number of lines of solution, and the final answer. (See Appendix B.)

3. Remind the student about the parallelism with the Gauss Law for Electric Field. Relate Biot-Savart Law to Ampere's Law using dimensional analysis, pointing out the similarity in the main quantities, and emphasizing the inverse square nature of Biot-Savart Law as the crucial basis of the equivalence.

## INSTRUCTION (30-35 MINS)

***Preliminaries***

1. To build intuition, review the pattern and equation of the magnetic field of a single very long (infinite) wire carrying a current I, as calculated using Biot-Savart Law. Note that that this is in cylindrical coordinates, where $\hat{\Phi}$ here is a unit vector.

$$\vec{B} = \frac{\mu_0 I}{2\pi r}\,\hat{\Phi} \qquad (2)$$

2. Calculate $\oint \vec{B} \bullet d\vec{l}$ of this configuration to show that it is equal to $\mu_0 I$.

$$\oint \vec{B} \bullet d\vec{l} = \int_0^{2\pi}\left(\frac{\mu_0 I}{2\pi r}\hat{\Phi}\right) \bullet r d\vec{\Phi} = \int_0^{2\pi}\left(\frac{\mu_0 I}{2\pi r}\hat{\Phi}\right) \bullet r d\Phi\hat{\Phi}$$

$$= \int_0^{2\pi}\left(\frac{\mu_0 I}{2\pi r}\right)(\hat{\Phi} \bullet \hat{\Phi}) r d\Phi = \left(\frac{\mu_0 I}{2\pi r}\right) r \int_0^{2\pi} d\Phi = \left(\frac{\mu_0 I}{2\pi r}\right) r 2\pi = \mu_0 I$$

***"Proving the Ampere's Law"***

3. Explain that Ampere's Law is a theorem showing the geometrical relation between a field quantity, which has a source-point – to – field-point distance that follows an inverse inverse square law, and current.

4. Show that previous result holds for an Amperian loop of any size by repeating the preceding calculation (Item 2) for two cases, i.e., $r = R_1$ and $r = R_2$ ($R_2 > R_1$).

5. Show that previous result holds for an Amperian loop of any shape by repeating the calculation in Item 2 for square loop. Since the calculation for square loop is tedious, the demonstration can be graphical by appealing to symmetry.

6. Show that wires outside the Amperian loop will have no contribution. This can be demonstrated by considering an infinite straight current-carrying wire situated outside a square loop or a circle loop. Demonstrate graphically, by appealing to symmetry, that $\vec{B} \bullet d\vec{l}$ ($\approx \vec{B} \bullet \Delta\vec{l}$) in one segment of the loop will be cancelled by the $\vec{B} \bullet d\vec{l}$ in another segment.

***Applying Ampere's Law***

7. Explain that the practical use of Ampere's Law is for manually solving the magnetic field of symmetric current configurations, or, in conjunction with the Principle of Superposition, asymmetric current configurations that are decomposable into several symmetric configurations.

8. Briefly demonstrate that if the closed surface and the charge enclosed form a symmetric configuration, one can obtain a simple formula for electric field magnitude:

   *If there is symmetry…*

   $\oint B \bullet dl = B \oint dl = B \ast$ (circumference of the closed loop) $= \mu_0 \sum_i^N I_{i,enclosed}$

   $$\rightarrow B = \frac{\mu_0 \sum_i^N I_{i,enclosed}}{\textit{circumference of the closed loop}} \qquad (3)$$

   *The sign of the magnetic field is determined from the direction of its arrow relative to the coordinate system.*

9. Introduce the basic steps in solving magnetostatic problems using Ampere's Law for manual calculation. (Discuss this protocol using three infinite wire carrying current I.)
   a. Draw the situation, i.e., current, and coordinate system.
   b. Imagine decomposing the asymmetric configuration into symmetric portions then dealing with each portion individually until Step (g) (as needed).
   c. Draw the Amperian loop enclosing the current. Position the Amperian loop such it is concentric or co-axial with that the charge distribution and the field point is in the loop.
   d. Note the direction/sense of the trace, i.e., clockwise or counterclockwise. Right-hand Rule: Curl the right hand following the direction/ sense of the trace. The thumb points the positive direction, i.e., the sign of the current, $I_{enclosed}$, flowing in the same direction is positive and negative if opposite.
   e. Apply Equation 3.
   f. The direction of the magnetic field is tangent to the curve.
   g. Apply superposition principle to obtain the final answer (as needed).

## DISCUSSION (10 MINS, MAY BE INTERWOVEN INTO THE INSTRUCTION)

1. In what situation is it better better to use Biot-Savart's Law or Ampere's Law? (Depends on the situation. On one hand, some problems are easier/ more straightforward to solve using Biot-Savart's Law. On the other hand, more complex configuration, but can be redefined to have symmetry, are better approached using Ampere's Law.)

2. When is Ampere's Law true and useful? (It is true all the time but useful for manual calculation if the problem can be set up to have symmetry.)

3. What is an Amperian/Ampere's loop? (It is an imaginary surface one defines depending on a problem. It is at this surface where one measures the magnitude and direction of the electric field.)

4. How is Ampere's Law related to Biot-Savart's Law? (They both relate the magnetic field to the current. Ampere's Law rest on the fact that Biot-Savart's Law is an inverse square law.)

5. How do we use Ampere's Law to manually solve asymmetric cases? (Decompose configuration into several symmetric configuration, then apply Ampere's Law, then apply superposition principle to obtain final answer. Emphasize that Ampere's law is always true but not always useful. Ampere's Law is useful for manual calculation if the problem has symmetry.)

## COMMON MISCONCEPTIONS, MISTAKES, OR DIFFICULTIES

The following are some of the misconceptions, mistakes and difficulties of the students that the teacher should look out for. It might also be helpful to discuss these things with the student for emphasis, awareness, and/or benchmarking:

1. Most Ampere's Law problems are simpler to solve in the spherical or cylindrical coordinates, but students are less familiar with these coordinates. Before this lesson, assign a task encouraging study of different coordinates.

2. Magnetic field is more difficult to visualize than electric field because it is perpendicular to distance and to the current. Encourage sketching as part of the problem-solving strategy and use props like three sticks or pens to illustrate the relationship of these quantities.

3. The idea of projecting (via dot product) the magnetic field against the Amperian loop, which is an abstract object to begin with, require imagination. Review lessons on dot product and integration, and encourage sketching in problem-solving.

4. Students often exclusively associate Integration with area. Clarify that that it can also be sums of quantities along a contour.

5. The Amperian loop, magnetic field arrow/ pattern, and the wire are often mixed up. Emphasize that these are three different things. The signs (polarities) of the current and the direction of the magnetic field often get mixed up. Encourage the habit of including the coordinate system in the sketch of the problem. Particularly in applying the principle of superposition, i.e., adding of vectors, the sign of the magnetic field is determined from the direction of its arrow relative to the coordinate system.

## ENRICHMENT (15 MINS)

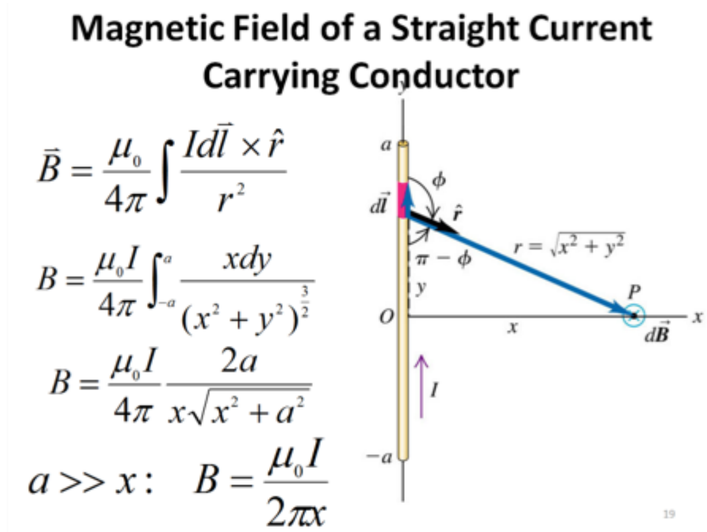
As homework, ask the students to solve the magnetic field due to a toroid and a solenoid (if not done in the Evaluation). The use of Ampere's Law is clearly more advantageous than Biot-Savart Law in these situations.

## EVALUATION (5 TO 10 MINS)

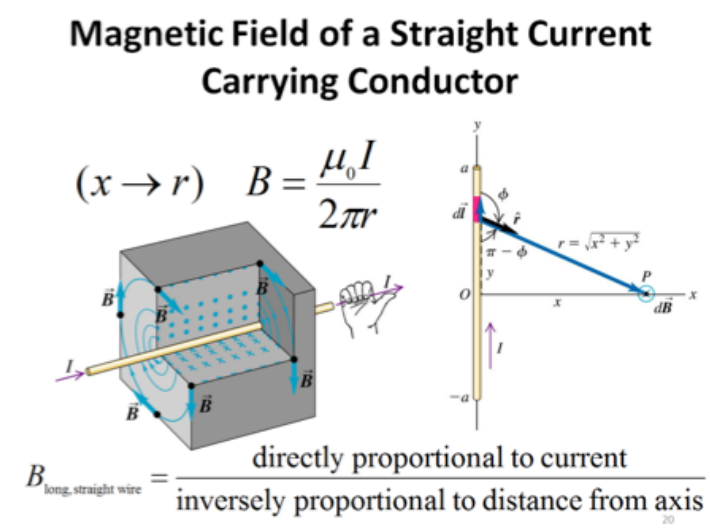
Individual or by-pair quiz: Determine the magnetic field three of different current configurations. Suggestions: 1) at a point co-planar to two parallel straight infinite wire with current in the opposite direction and different magnitude; 2) at points inside and outside a thick long current-carrying wire; and (3) at points inside and outside a long solenoid.

(Please redraw all the figures/ slide snapshots in the appendices.)

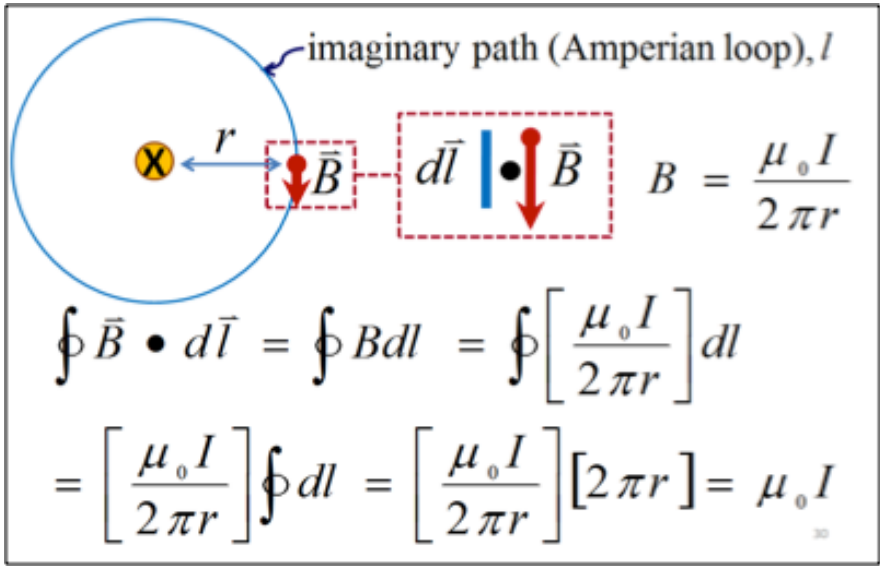
**Appendix A:  Sample calculation using Biot-Savart's Law**




**Appendix B:  Sample calculation using Ampere's Law**



## Appendix C: Amperian Loop



60 MINS

# Context-Rich Problems Involving Magnetic Fields and Forces, and Motion of Charges and Current Carrying Wires

**Content Standards**

The learners demonstrate an understanding of

1. Biot-Savart Law
2. Ampere's Law

**Performance Standards**

The learners are able to use theoretical and experimental approaches to solve multi-concept and rich-context problems involving electricity and magnetism

**Learning Competencies**

At the end of the session, the students should be able to solve problems involving magnetic fields, forces due to magnetic fields and the motion of charges and current-carrying wires in contexts such as, but not limited to, determining the strength of Earth's magnetic field, cyclotrons, mass spectrometers, and solenoids. (**STEM_GP12EM-IIIi-66**)

**Prerequisite Knowledge**

Coulomb's Law, Lorentz Force, Magnetic Flux, Biot-savart Law, Circuits

**Prerequisite Skills**

Cross-product, integral calculus

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction** | Background of context-rich problems | |
| **Logistics and Instructions** | Rationale and context of Context-rich problems | 30 |
| **Context-rich Problems** | Sample problems | |
| **Materials** | Writing materials and other materials to be determined by the students depending on the problem | |

**Resources**

(1) H.D. Young, R.A. Freedman, A.L. Ford, University Physics, 12th Ed. (Addison-Wesley, 2011).

## INTRODUCTION (3 MINS)

Solving context rich problems provide students opportunity to practice implementing concepts and procedures in realistic scenarios. This learning experience is consistent with the fact that charge, electric field and forces, and other related concepts are descriptions of our world. In other words, physics is relevant to many aspects of our daily lives.

The context rich problems are presented such that the students are part of the story and are often required to interact with other people in making and reporting their solutions. The problems are different from the typical end-of-chapter problems such that students usually need to specify the unknowns, design a problem-solving strategy, use several concepts, make assumptions, recall or invoke prior knowledge or "common-sense", research additional information, perform experiment, and interact with experts and non-experts.

## LOGISTICS AND INSTRUCTIONS (30 MINS)

1. Discuss the rationale of solving context-rich problems in physics as articulated in the Introduction.

2. Discuss the steps or framework for problem-solving and specify the template or distribute the problem-solving sheet.

3. Discuss the grading system for this particular activity. The recommended system is to grade each step, either in equal weights in the scale of 1 to 5 or 1 to 10 or unequal weights, usually giving premium to analysis than on the final answer. Inclusion of peer- and self-evaluation in the final grade is also recommended.

4. Group the students (the recommended number is three to five students per group) and arrange their seats (the arrangement should be conducive for long discussions). Due effort should be exerted to achieve heterogeneous distribution in terms of gender and performance. Encourage the students to device a system that would allow every member of the group to contribute to the discussion for every step and to rotate the roles among themselves, especially the role of secretary

**Teacher Tips**

You may adopt the problem solving sheet designed by Kenneth Heller and Patricia M. Heller of University of Minnesota (see Chapter 2 of their book "Cooperative Group Problem Solving in Physics," which is publicly available). The steps advocated by Heller & Heller, which is consistent or similar with those of the famous mathematician G. Polya, are as follows: focus on the problem; describe the physics; plan a solution; execute the plan; and evaluate the solution. Heller & Heller has a discussion and recommendation for the grading system, role assignment, and student distribution.]

or scribe.

5. Arrange the schedule for problem solving and reporting to class. It is recommended that each group should solve at least one problem for each topic in this chapter. Reporting to class will allow students be familiar with problems that they are not assigned to solve.

## CONTEXT-RICH PROBLEMS:

1. In a physics laboratory, you were given a set of charges, which is a mixture of both positive and negative charges. Let say that your adviser told you that you can use a machine that moves the particles at a constant speed. Design an apparatus that can segregate the charges.

2. In a geology class, you were ask to determine miniscule pieces of rocks are magnetic or not. The problem is you don't have available magnets in the laboratory but few copper wires and a power supply. How will you identify the magnetic property of rocks?

3. Say you want to build a painting apparatus that draws a perfect circle. Let's say a very light magnetic point brush and a uniform magnetic field generator are readily available. Design the apparatus in way that a user may opt to draw small perfect circles, or big circles.

4. Imagine that Batman wants to train his body using a pair of wires that opens or closes. The wires are not insulated such that if he is hit, he will be electrocuted. Also Batman wants the speed of opening and closing of the wires to be varied. Discuss with each other how to design this training machine.

120 MINS

# Magnetic Induction, Induced EMF, Induced Current; Faraday's Law; Lenz's Law

**Content Standards**

The learners demonstrate an understanding of Magnetic induction and Faraday's Law

**Performance Standards**

The learners are able to:

1. Use theoretical and, when feasible, experimental approaches to solve multiconcept, rich-context problems using concepts from electromagnetic waves, optics, relativity, and atomic and nuclear theory
2. Apply ideas from atomic and nuclear physics in contexts such as, but not limited to, radiation shielding and inferring the composition of stars

**Learning Competencies**

1. Identify the factors that affect the magnitude of the induced emf and the magnitude and direction of the induced current (Faraday's Law) (**STEM_GP12EM-IVa-1**)
2. Compare and contrast electrostatic electric field and nonelectrostatic/ induced electric field (**STEM_GP12EM-IVa-3**)
3. Calculate the induced emf in a closed loop due to a time-varying magnetic flux using Faraday's Law (**STEM_GP12EM-IVa-4**)
4. Describe the direction of the induced electric field, magnetic field, and current on a conducting/non-conducting loop using Lenz's Law (**STEM_GP12EM-IVa-5**)

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction** | Discussion about the possibility of the converse of Oersted's discovery | 5 |
| **Motivation** | Discussion about the technological advancement, especially in energy and information transmission brought about by the discovery of Faraday's Laws | 10 |
| **Instruction/ Delivery/ Discussion** | a. Introduction of $\vec{E}_{induced}$<br>b. Discussion of Faraday's Law<br>c. Presentation of Lenz's Law<br>d. Sample Discussions on the issues and application of Faraday's Law<br>e. Comments on the common misconceptions, mistakes, or difficulties | 90 |
| **Enrichment** | Connection of Faraday's Law to other major physical laws, etc. | |
| **Evaluation** | Quizzes | 45 |
| **Materials** | 1. Writing and drawing instruments<br>2. (optional) circuit to be designated as the "original" circuit consisting of solenoid, ammeter, and power supply with mechanism to vary current<br>3. (optional) circuit to be designated as the "induced" circuit consisting of wire, resistor, and ammeter | |

**Resources**

See Appendix

## INTRODUCTION (3 MINS)

1. Discuss the historical observation that people, especially philosophers and scientists (natural philosophers), have been interested on symmetry. And so when Hans Christian Oersted discovered that *electric field* (*manifested through its effect on charge, i.e., current*) *generate magnetic field*, these people also entertained the idea that the converse might also be true: *magnetic field can also generate electric field*.

2. Explain that the converse is true but with important additional condition: *the magnetic field has to change with time*. In other words, *time-varying magnetic field generates electric field*. (However, James Clerk Maxwell will later show that the more symmetric pairings are "*time-varying magnetic field is to electric field*" and "*time-varying electric field is to magnetic field*".

## MOTIVATION (10 MINS)

Discuss that nowadays, we can live comfortably even if our sources (or destination) of energy and information are from afar. For example: 1) geothermal, coal, and nuclear power plants are usually several kilometers away from our house; and 2) we exchange information wirelessly even with other people living in another island. This was made possible by the discovery of Michael Faraday and Joseph Henry of the relationship between time-varying magnetic field and electric field.

## INSTRUCTION (90 MINS INCLUSIVE OF 45 MINS OF EVALUATION)

***Introduction of $\vec{E}_{induced}$*** *(10 minutes + 10 minutes Evaluation)*

1. Review Biot-Savart's Law and Ampere's Law, particularly as it is applied to a current-carrying solenoid. The choice of solenoid is pedagogically strategic because its magnetic field $\vec{B}_{original}$ is simple, i.e., inside the solenoid constant magnitude and is parallel to the axis, and outside, it is zero.

2. Introduce the curly non-conservative non-Coulombic electric field, $\vec{E}_{induced}$, using the (very long) solenoid that has a **time-varying** current, $I_{original}$, i.e., the solenoid is part of a circuit in which the current is variable. The characteristics of $\vec{E}_{induced}$ is simple: inside the solenoid, the magnitude of $\vec{E}_{induced}$ is proportional to distance, r, from the axis, while outside, it is inversely proportional to r, i.e., 1/r.

3. Emphasize that the phenomenon just presented was first studied by Michael Faraday and Joseph Henry and is known as the electromagnetic induction (EMI):

*"A time-varying magnetic field is accompanied by a circulating electric field."*

4. Present the rule for determining the direction of the $-\frac{d\vec{B}_{original}}{dt}$ and $\vec{E}_{induced}$ as follows: Determine the $-d\vec{B}_{original} \approx -\Delta\vec{B}_{original}$ (negative of the final minus the initial magnetic field). Point the thumb anti-parallel (because of the negative sign) to the (infinitesimal) change in the magnetic field $-\frac{d\vec{B}_{original}}{dt}$. Then curl the rest of the finger. The curled finger is the general direction of $\vec{E}_{induced}$. (See Appendix A.)

5. Explain that the curly electric field, $\vec{E}_{induced}$, has different pattern as the electric field due to a charged object, $\vec{E}_{Coulomb}$. The former is a closed "curly" loop while the latter radiates to or from a source charge. However, both have the same effect on other charges. In fact, if a circuit without a battery or voltage source is placed in a region with $\vec{E}_{induced}$, the charges in the wire will also move, i.e., current, $I_{induced}$, is induced. (A demonstration using a circuit, made only of a wire and a bulb, encircling concentrically and coaxially the solenoid may be performed.) In other words, $I_{induced}$, if present, indicates the presence of $\vec{E}_{induced}$. Emphasize that $\vec{E}_{induced}$ exist in a region even without the conductor to carry the $\vec{E}_{induced}$.

6. Perform evaluation described in Evaluation Item 1.

***Faraday's Law: A More Quantitative Description of EMI*** *(15 minutes + 15 minutes Evaluation)*

7. Since electric field is not directly measureable, EMI is better understood if $\vec{E}_{induced}$ is related to a directly measurable quantity. Review the concept that electric field is related to electric potential ($V_b - V_a = \int_a^b \vec{E} \bullet d\vec{l}$). Similar to $\vec{E}_{Coulomb}$, this concept also holds for $\vec{E}_{induced}$, i.e., $\int_a^b \vec{E}_{induced} \bullet d\vec{l} = V_b - V_a = EMF$. (Brief discussion clarifying the definition and unit of EMF may be necessary.) However, due to its "curly" pattern, $\oint \vec{E}_{induced} \bullet d\vec{l} = \int_a^a \vec{E}_{induced} \bullet d\vec{l} = V_b - V_a = EMF \neq 0$ unlike $\vec{E}_{Coulomb}$, where $\oint \vec{E}_{Coulomb} \bullet dl = 0$.

8. For simplicity, consider the case that the wire carrying the $I_{induced}$ is an Ohmic material (review Ohm's Law if necessary). Then one can determine EMF by multiplying $I_{induced}$ with the resistance of the circuit.

9. After establishing the description or definition of the quantities ($\vec{E}_{induced}$, $I_{induced}$, and EMF) of the induced circuit, we relate these quantities to that of the solenoid ("original circuit").

10. Explain (or demonstrate) that $\vec{E}_{induced}$, $I_{induced}$, and EMF and  are directly related to the variation with time of the $\Phi_{original}$ ($=\vec{B}_{original} \bullet \vec{A}_{original}$): increasing (decreasing) the original current $I_{original}$ to increase (decrease) $\vec{B}_{original}$ increases (decreases) the EMF; increasing (decreasing) the cross-sectional area of the solenoid $\vec{A}_{original}$ increases (decreases) the EMF; varying the angle between the $\vec{B}_{original}$ and $\vec{A}_{original}$ varies the EMF. Note that any one or a combination of these variations will cause EMF.

$$- \frac{d\Phi_{original}}{dt} = - \frac{d(\vec{B}_{original} \bullet \vec{A}_{original})}{dt} = - \frac{d(\vec{B}_{original}\vec{A}_{original}\cos\Theta)}{dt}$$

$$= - [\vec{A}_{original}\cos\Theta \frac{d(\vec{B}_{original})}{dt} + \vec{B}_{original}\cos\Theta \frac{d(\vec{A}_{original})}{dt} - \vec{B}_{original}\vec{A}_{original}\sin\Theta \frac{d(\Theta)}{dt}]$$

11. Introduce Faraday's Law to summarize the results of the experiment demonstrated or described in the preceding item, which is actually just a more precise version of the statement in Item 3:

$$- \frac{d(\vec{B}_{original} \bullet \vec{A}_{original})}{dt} = - \frac{d\Phi_{original}}{dt} = - \oint \vec{E}_{induced} \bullet dl = EMF_{induced}$$

*"A time-varying magnetic flux is accompanied by a circulating electric field."*

12. Perform evaluation described in Evaluation Item 2.

***Presentation of Lenz's Law (20 minutes + 20 minutes Evaluation)***

13. Focus the attention on the negative sign in Faraday's Law. Discuss that this aspect of the phenomenon was systematically studied by Heinrich Lenz. Faraday already observed that $I_{induced}$ is induced whenever a circuit, without its own power source, encloses a region with time-varying $\vec{B}_{original}$. But it was Lenz who focused on the direction of $I_{induced}$ and $\vec{B}_{induced}$.

14. Using the same solenoid set up, present several scenarios where the solenoid generates different changes in the $\vec{B}_{original}$, and as a result, different corresponding changes in the $\vec{E}_{induced}$. For example, consider the cases of increasing and decreasing magnitude of  for different directions. Perform this until the students are quite comfortable relating $\vec{B}_{original}$ and $\vec{E}_{induced}$.

15. Next, let the student focus on the case in which a wire loop or circuit, without a battery or other power source, is placed in the region where there is $\vec{E}_{induced}$, such that the loop encloses the magnetic flux (but not necessarily immersed in the magnetic flux) of the original solenoid.

16. Remind them of the concept, first presented in Coulomb's Law and then Ohm's Law, on the effect of $\vec{E}_{induced}$ on charges, i.e., causes current or movement of charge. This is $I_{induced}$, which flows in the same direction as the $\vec{E}_{induced}$.

17. Let the students recall Biot-Savart's Law, i.e., current carrying wire generates magnetic field, and emphasize that this law holds for any current. In other words, $I_{induced}$ will also have its corresponding $\vec{B}_{induced}$. Preferably by pair, let the students apply Biot-Savart's Law (and it's right-hand-rule) to the cases considered in Item 14. Ask the students to compare the direction of the $\vec{B}_{original}$ and $\vec{B}_{induced}$. (At first glance, they will find no regular pattern, i.e., sometime both point in the same direction, sometimes opposite.)

18. Next, ask the students to include this time the information about the magnetic flux, $\Phi_{original}$, of the solenoid. (They will find $B_{original}$ and $\vec{B}_{induced}$ point in the same direction if $\Phi_{original}$ is decreasing, while opposite if $\Phi_{original}$ is increasing. Moreover, $\vec{B}_{induced}$ is zero if $\Phi_{original}$ is constant. In other words, $\Phi_{induced} = \vec{B}_{original} \bullet A$ opposes change in $\Phi_{original}$.)

19. Present Lenz Law, which summarizes the observation about the relationship between the original and induced quantities:

"If there is a closed loop enclosing a region of time-varying magnetic flux $\Phi_{original}$, $I_{induced}$ will flow in the said loop. The direction of $I_{induced}$ is such that corresponding $\vec{B}_{induced}$ and $\Phi_{induced}$ opposes the change (increase or decrease) of $\Phi_{original}$."

20. Perform evaluation described in Evaluation Item 3.

## DISCUSSION (10 MINS, MAY BE INTERWOVEN INTO THE INSTRUCTION)

1. Can we distinguish between $\vec{E}_{coulomb}$ and $\vec{E}_{induced}$? In terms of pattern, yes because $\vec{E}_{induced}$ is "curly" while $\vec{E}_{coulomb}$ radiates toward or away from source. However, the effect on charge is the same, i.e., charges will accelerate if in a region with $\vec{E}_{induced}$.

2. Is it necessary that there is time-varying magnetic field or flux in a particular point for $\vec{E}_{induced}$ to exist in that exact same point? No. $\vec{E}_{induced}$ exists as long as there is time-varying magnetic field or flux in near that point.

3. Does $I_{induced}$ or $\vec{E}_{induced}$ succeed in completely opposing the change in magnetic flux? No. The resistance of the wire loop (unless it is a superconductor) dissipates some of the energy.

4. Why is EMI mostly attributed to Michael Faraday, and not to Joseph Henry? Faraday not only studied the phenomenon more thoroughly, he is also the first to publish his research about it.

## COMMON MISCONCEPTIONS, MISTAKES, OR DIFFICULTIES

The following are some of the misconceptions, mistakes and difficulties of the students that the teacher should look out for. It might also be helpful to discuss these things with the student for emphasis, awareness, and/or benchmarking:

1. Review the distinction between magnetic field and magnetic flux as the students may still be confused.

2. When the loop or circuit is in place, the students may be confused as to what area to dot multiply to $\vec{B}_{original}$ to determine $\Phi_{original}$. It is only the area co-planar to the area bounded by the loop and where $\vec{B}_{original}$ is non-zero (the students may have to be reminded about dot product).

3. In determining $\oint \vec{E}_{induced} \bullet dl$ for the loop, the path of the line integral is the loop.

4. The students may think that the loop or circuit is necessary for $\vec{E}_{induced}$ to exist. In fact, they may not recognize some situations as EMI if only the source of time-varying $\Phi_{original}$ exists. $\vec{E}_{induced}$ exists due to the time-varying $\Phi_{original}$, regardless whether or not it has charge to act upon and move. This is why we started the Instruction considering the solenoid only, i.e., no loop or circuit yet, to emphasize the essential conditions for $\vec{E}_{induced}$, which is simply a time-varying $\Phi_{original}$.

5. The students may find it weird that the loop or circuit has $I_{induced}$ even if it is not directly immersed in $\vec{B}_{original}$ or $\Phi_{original}$. Remind the student that it is $\vec{E}_{induced}$ which moves the charge to produce $I_{induced}$, not $\vec{B}_{original}$. Note that $\vec{E}_{induced}$ could be non-zero in the region where $\vec{B}_{original}$ is zero, as shown for the case of the solenoid electromagnet (see Instruction).

6. EMI is an integration of several concepts and the set ups or devices usually consist of several parts. Encourage the students to sketch the problem and write a flowchart of the process so as not to lose track in applying Faraday's Law and Lenz Law. Relevant to this issue, van Weeren, et al. have suggestions in forming good habits in problem solving.

7. Perceptive students may correctly observe that Faraday's Law does not "explain why", but rather simply describes the observation that electric field accompanies time-varying magnetic field. Indeed, strictly speaking, an empirical law, like Faraday's Law, simply answers a question "how?" and states a consistent observation. We then use this empirical law to predict events in similar situations.

## ENRICHMENT (15 MINS)

1. Using the concept of work, discuss again the fact that, unlike, $\oint \vec{E}_{induced} \bullet d\vec{l} = EMF = -\frac{d\Phi_B}{dt}$ , $\oint \vec{E}_{Coulomb} \bullet d\vec{l} = 0$.

2. Explore the relationship of Lenz Law to Newton's 3rd Law of Motion, Energy Conservation, and 2nd Law of Thermodynamics (impossibility of a perpetual motion machine).

3. Compare and contrast Induced EMF and Motional EMF. (This topic may be discuss again in the lessons on Relativity.)

## EVALUATION (45 MINS, INCLUDED IN THE INSTRUCTION)

1. Quiz on determining the direction of $\vec{E}_{induced}$. (See Appendix B.)

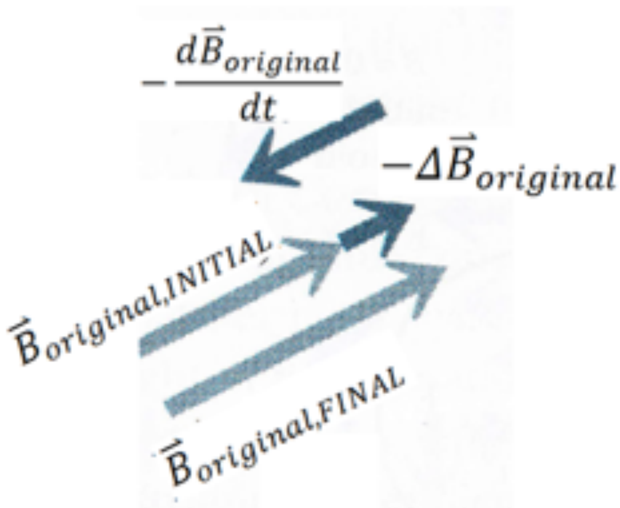
2. Quiz on the dependence of $EMF_{induced}$ on various parameters of $\Phi_{original}$. (See Appendix C.)

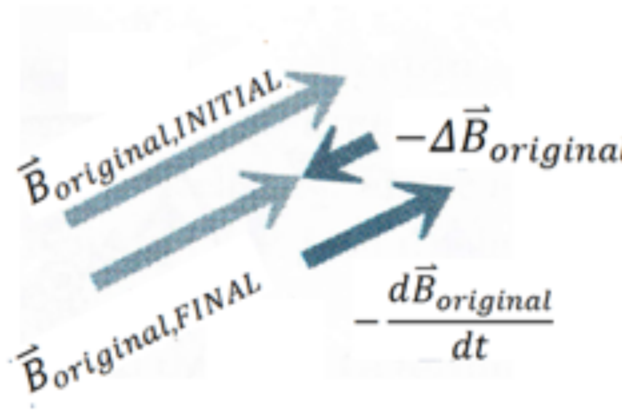
3. Quiz on applying Lenz's Law, i.e., relating the signs of $I_{original}$, $\vec{B}_{original}$, $I_{induced}$ and $\vec{B}_{induced}$. (See Appendix D.)

(Please redraw all the figures/ slide snapshots in the appendices.)

**Appendix A: Scheme for determining the direction of $-\frac{d\vec{B}_{original}}{dt}$ (and $\vec{E}_{induced}$) [Adapted from Chabay and Sherwood.]**

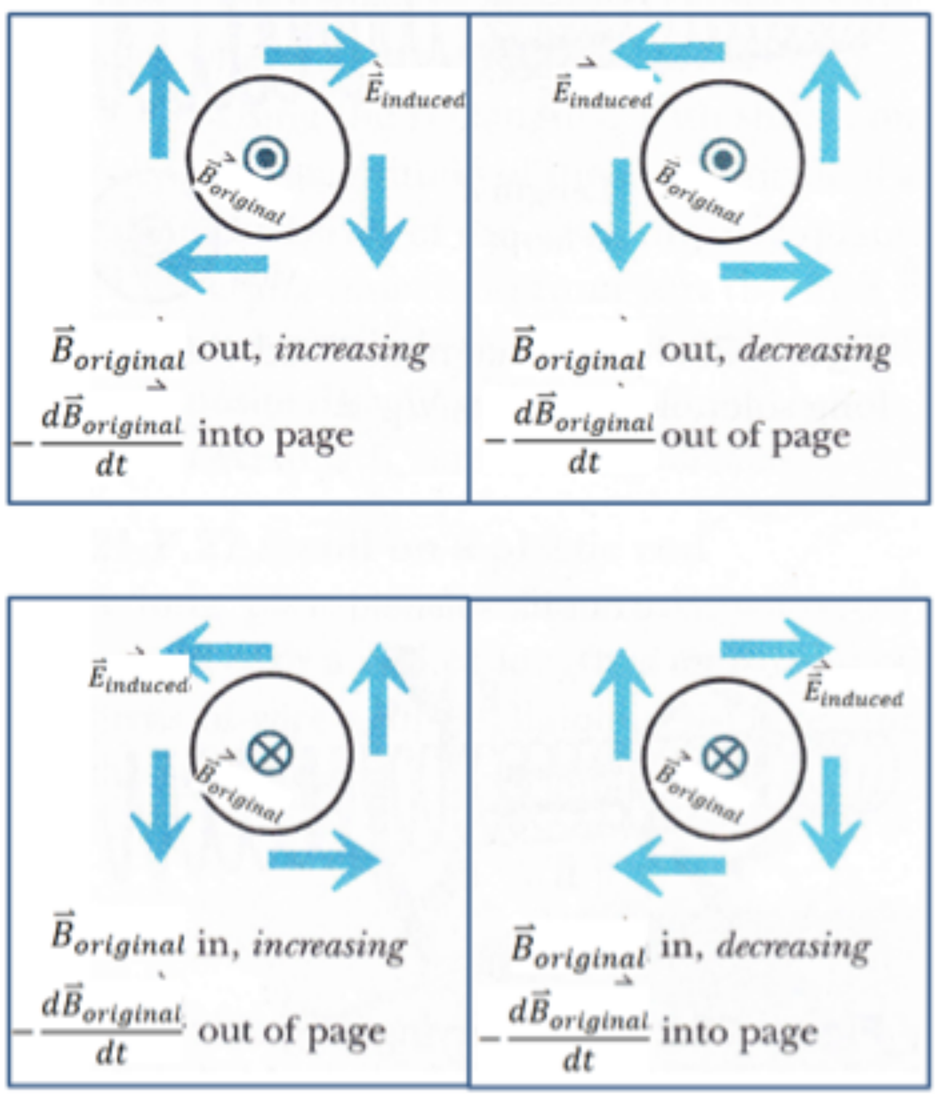
$$-d\vec{B}_{original} \approx -\Delta\vec{B}_{original}$$
$$= -\left(\vec{B}_{original,FINAL} - \vec{B}_{original,INITIAL}\right)$$



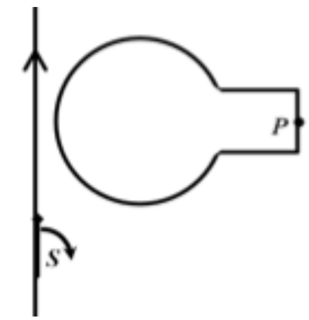
**Appendix B: Sample Quiz (& Answer) on determining the direction of $\vec{E}_{induced}$**

Given the direction and change (increasing/decreasing) of the magnetic field, $\vec{B}_{original}$, Determine the direction of $\vec{E}_{induced}$. [Adapted from Chabay and Sherwood.]



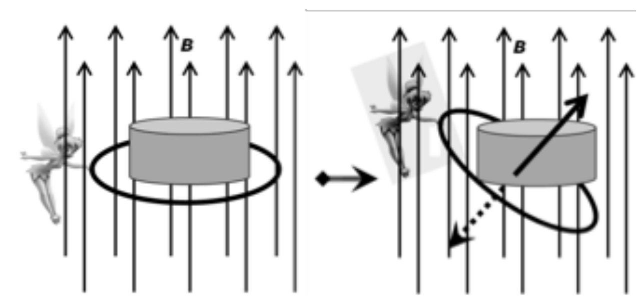
## Appendix C: Sample Quiz Questions about the dependence of $EMF_{induced}$ on various parameters of $\Phi_{original}$

1. A **very long** wire is part of a circuit with a switch. Beside it is conducting loop. The switch was opened (turned off) causing a current I to stop. During the switching, what is the direction of the induced magnetic field $\mathbf{B_{ind}}$ inside the coil and of the induced current $\mathbf{I_{ind}}$ through Point P.



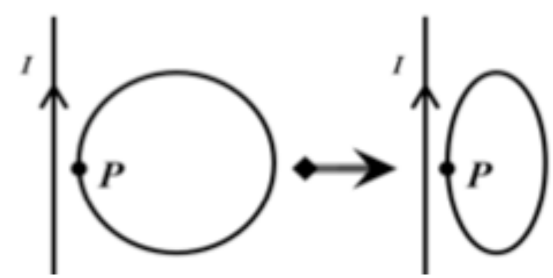

   A. $B_{ind}$ into the page; $I_{ind}$ upward
   B. $B_{ind}$ into the page; $I_{ind}$ downward
   C. $B_{ind}$ out of the page; $I_{ind}$ upward
   D. $B_{ind}$ out of the page; $I_{ind}$ downward
   E. $B_{ind}$ is zero; $I_R$ is zero

2. Consider a conducting loop immersed in uniform magnetic field B. Suddenly it was tilted as shown. What is direction of the induced current, I, at the point indicated by Tinker Bell and the induced magnetic field, Bind, in the middle of the loop while it is being tilted?




   A. $I_R$ into the page; $B_{ind}$ broken arrow (-->)
   B. $I_R$ into the page; $B_{ind}$ solid arrow (➔)
   C. $I_R$ out of the page; $B_{ind}$ broken arrow (-->)
   D. $I_R$ out of the page; $B_{ind}$ solid arrow (➔)
   E. $I_R$ is zero; $B_{ind}$ is zero

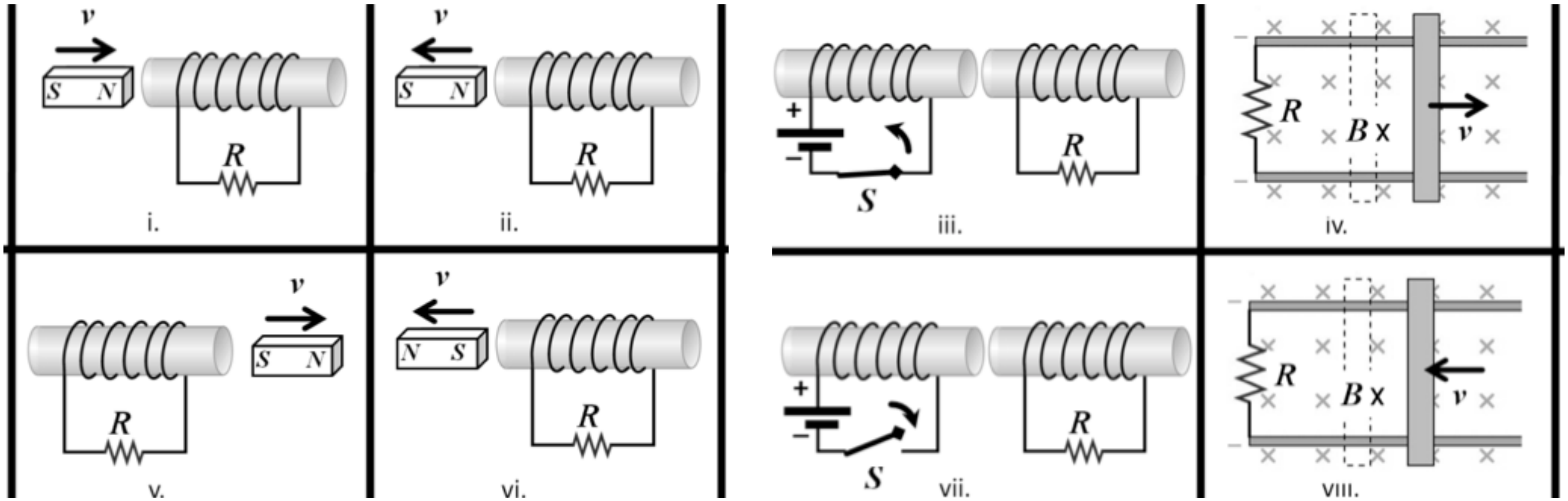
3. Consider a very long wire with current I and an elliptical conducting loop. Suddenly, the loop was deformed as shown. During the deformation, what is the direction of the induced magnetic field Bind inside the coil and of the induced current Iind through Point P.




   A. $B_{ind}$ is zero; $I_R$ is zero
   B. $B_{ind}$ into the page; $I_{ind}$ downward
   C. $B_{ind}$ out of the page; $I_{ind}$ upward
   D. $B_{ind}$ out of the page; $I_{ind}$ downward
   E. $B_{ind}$ into the page; $I_{ind}$ upward

**Appendix D: Sample Quiz Questions on applying Lenz's Law**

First, draw / superimpose on the coil/circuit (the coil/circuit connected to the resistor R) an imaginary magnet (or a magnetic field symbol) to represent the **induced magnetic field** __inside__ the coil. Then, Find the **direction** (draw the arrow) of the **induced current** through the resistors R in the figures shown.




**Resources**


(1) R.W. Chabay, B.A. Sherwood. Matter and Interaction II: Electric and Magnetic Interactions, 3rd Ed. (J. Wiley & Sons, Inc., 2010).

(2) S. Eric Hill. Rephrasing Faraday's Law. The Physics Teacher, Vol. 48, 410-412 (2010).

(3) K. Zuza, J.-M. Almudí, A. Leniz, and J. Guisasola. Addressing students' difficulties with Faraday's law: A guided problem solving approach. Phys. Rev. ST Phys. Educ. Res. 10, 010122 (2014).

(4) H.D. Young, R.A. Freedman, A.L. Ford, University Physics, 11th Ed. Addison-Wesley, 2011).

(5) Paul Hewitt, Conceptual Physics, 11th Ed. Addison-Wesley, 2009).

(6) D. Halliday, R. Resnick, J. Walker. Fundamentals of Physics Extended, 10th Ed. (J. Wiley & Sons, Inc., 2013).

(7) J. H. P. van Weeren, F. F. M. de Mul, M. J. Peters, H. Kramers-Pals, H.J. Roossink. Teaching problem solving in Phyics: a course in eletromagnetism. American Journal of Physics 50 (8), 725-732 (1982).

60 MINS

# Applications of Faraday's Law

**Content Standards**

The learners demonstrate an understanding of Alternating current, LC circuits, and other applications of magnetic induction

**Performance Standards**

The learners are able to:

1. Use theoretical and, when feasible, experimental approaches to solve multiconcept, rich-context problems using concepts from electromagnetic waves, optics, relativity, and atomic and nuclear theory
2. Apply ideas from atomic and nuclear physics in contexts such as, but not limited to, radiation shielding and inferring the composition of stars

**Learning Competencies**

Relate Faraday's experiments and Maxwell's evaluation to a given experiment (**STEM_GP12EM-IVa-2**)

## LESSON OUTLINE

| | | |
|---|---|---|
| **Logistics and Instructions for Teachers** | Grouping, assignment, grading system | 30 |
| **Presentation of Applications** | Outlines of the sample applications of magnetic induction; eight (8) sample applications | 50 |
| **Evaluation** | Peer evaluation and notes | 50 |
| **Materials** | 1. Writing and drawing materials<br>2. Video camera if applicable<br>3. Actual devices or equipment if available | |

**Resources**

(1) R.D. Knight, Physics for Scientists and Engineers: A Strategic Approach with Modern Physics and Mastering Physics, 2nd Ed. (Benjamin Cummings, 2007).
(2) H.D. Young, R.A. Freedman, A.L. Ford, University Physics, 11th Ed. (Addison-Wesley, 2011).
(3) Paul Hewitt, Conceptual Physics, 11th Ed. Addison-Wesley, 2009).
(4) D. Halliday, R. Resnick, J. Walker. Fundamentals of Physics Extended, 10th Ed. (J. Wiley & Sons, Inc., 2013).
(5) R.W. Chabay, B.A. Sherwood. Matter and Interaction II: Electric and Magnetic Interactions, 3rd Ed. (J. Wiley & Sons, Inc., 2010).
(6) T.C. Erren and P.E. Bourne. Ten Simple Rules for a Good Poster Presentation. PLoS Computational Biology 3(5) e102 (2007).

## PRESENTATION OF APPLICATIONS (50 MINS)

The following are outlines of the sample of applications of magnetic induction. The students are free to present other applications.

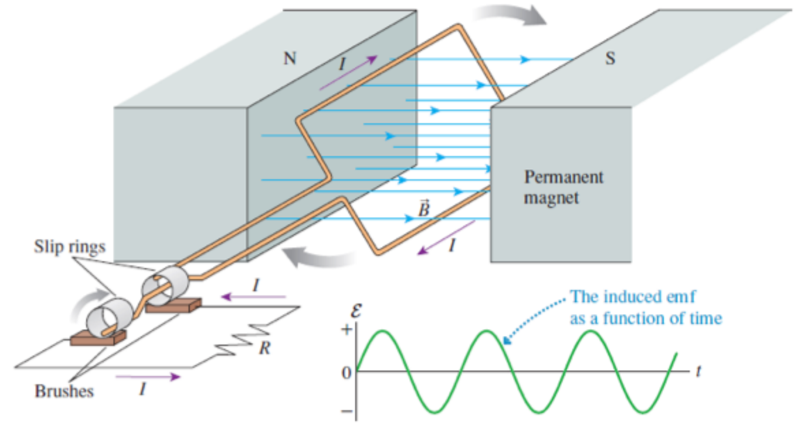
(Please redraw all the figures.)

1. **Alternating Current Generato**r

   **Function/ Purpose**: to transform mechanical energy to electrical energy

   **Diagram:**

   **Specific Parts and/or Trigger applying EMI:** "origin/ original circuit" = magnet; "induced circuit" = generator coil; "trigger" = water pushing the paddle

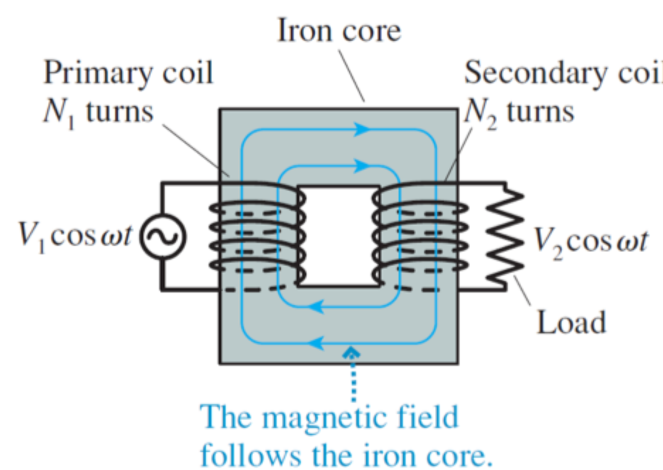



2. **Transformer**

   **Function/ Purpose:** to reduce the energy dissipation in the distribution of electricity

   **Diagram:**

   **Specific Parts and/or Trigger applying EMI:** "origin/ original circuit" = primary coil; "induced circuit" = secondary coil; "trigger" = alternating current



3. **Spark Plug**

**Function/ Purpose:** to produce, using small voltage source, a voltage high enough to cause dielectric breakdown of air ("spark") and ignite the mixture of fuel and oxygen

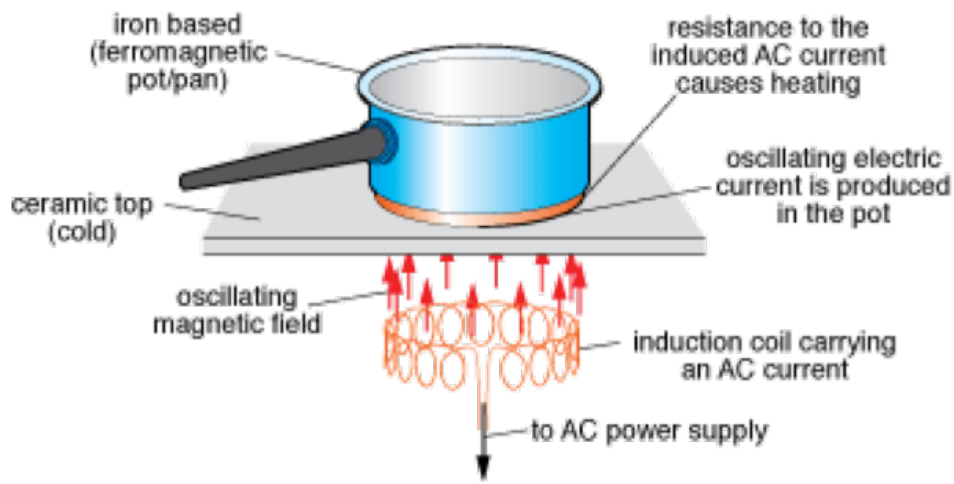
**Diagram:**


**Specific Parts and/or Trigger applying EMI:** "origin/ original circuit" = circuit connected to car key; "induced circuit" = circuit directly connected to spark plug; "trigger" = opening/ breaking of switch by the car key

4. **Induction Cooker**

**Function/ Purpose:** to produce heat by inducing current in a magnetizable metal with very high electrical resistance

**Diagram:**

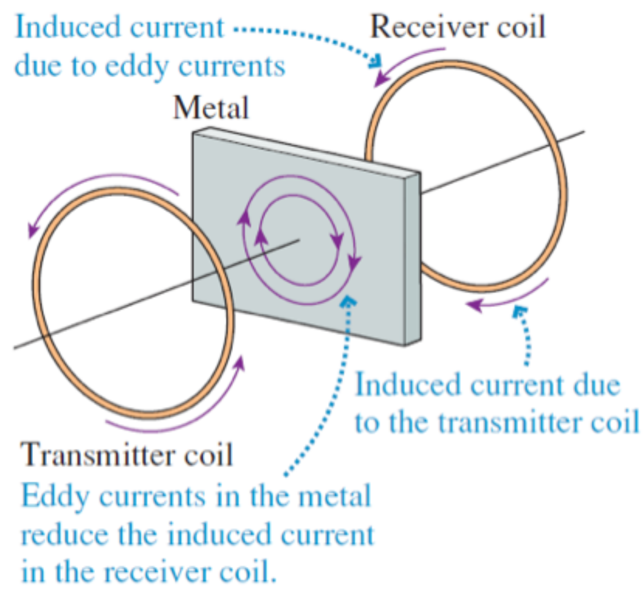



**Specific Parts and/or Trigger applying EMI:** "origin/ original circuit" = circuit made of good conductor connected to AC source; "induced circuit" = food container made of poorly conductor but magnetizable metal; "trigger" = alternating current

5. **Metal Detector**

**Function/ Purpose:** to detect metallic object through the reduction it causes on the induced current

**Diagram:**

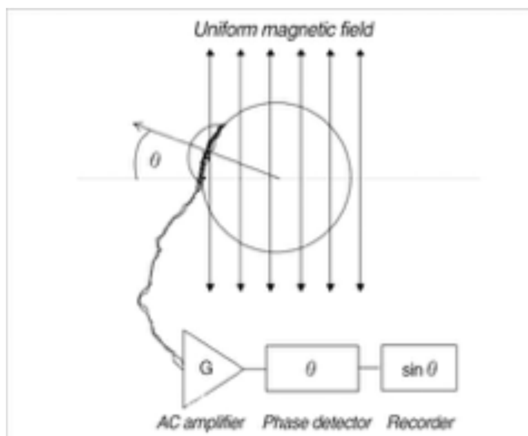


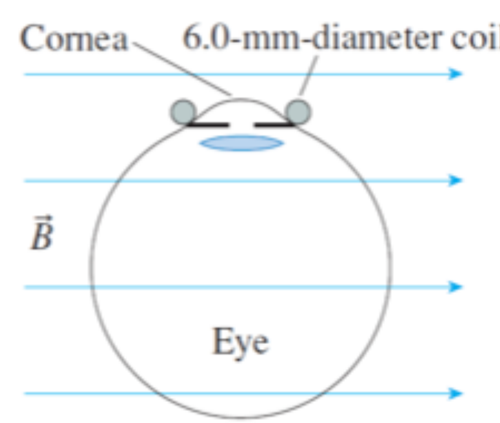

**Specific Parts and/or Trigger applying EMI:** "origin/ original circuit" = transmitter coil; first "induced circuit" = metallic object; second "induced circuit" = receiver coil; "trigger" = alternating current

6. **Eye Movement Tracker**

**Function/ Purpose:** to monitor or measure eye movement through induced current

**Diagram:**



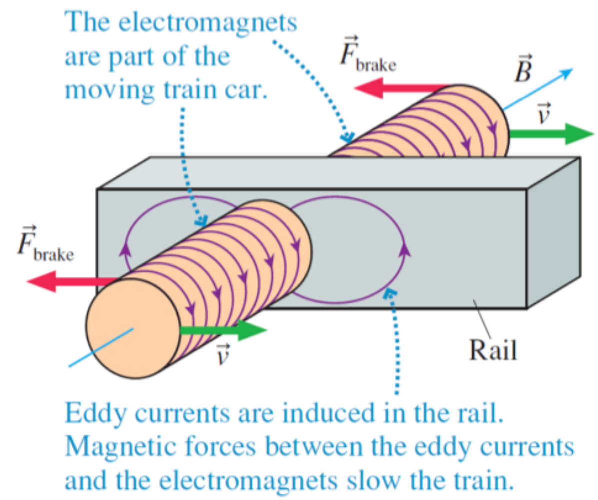




**Specific Parts and/or Trigger applying EMI:** "origin/ original circuit" = magnet or electromagnet; "induced circuit" = coil embedded in contact lens; "trigger" = eye movement

7. **Magnetic Braking System**

   **Function/ Purpose:** to stop the movement of the train without wearing or heating the train car parts

   **Diagram:**

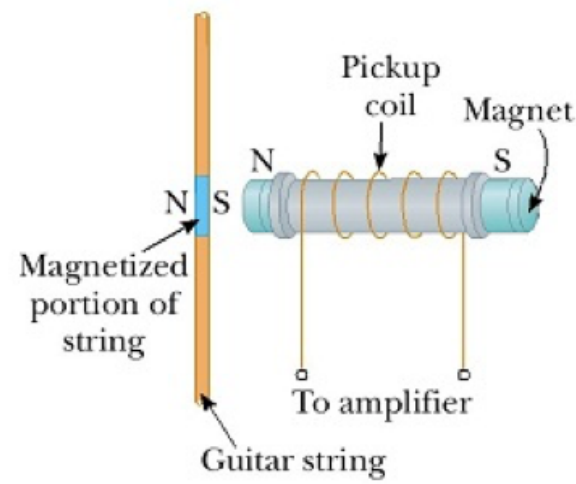



   **Specific Parts and/or Trigger applying EMI:** "origin/ original circuit" = electromagnet straddling the rail; "induced circuit" = rail which produces the eddy current; "trigger" = motion of the train

8. **Electric Guitar**

   **Function/ Purpose:** to produce sound like in a guitar but with more variety

   **Diagram:**




   **Specific Parts and/or Trigger applying EMI:** "origin/ original circuit" = bar magnet; first "induced circuit" = guitar string; second "induced circuit" = wire detecting the change in magnetic field due to guitar string; "trigger" = strumming of the guitar

## EVALUATION (50 MINS, SIMULTANEOUS WITH THE PRESENTATION)

1. Peer-evaluation
2. Notes summarizing the presentations (prepared individually by the students)

60 MINS

# AC circuits vs DC circuits

**Content Standards**
The learners demonstrate an understanding of Alternating current, LC circuits, and other applications of magnetic induction

**Performance Standards**
The learners are able to:
1. Use theoretical and, when feasible, experimental approaches to solve multiconcept, rich-context problems using concepts from electromagnetic waves, optics, relativity, and atomic and nuclear theory
2. Apply ideas from atomic and nuclear physics in contexts such as, but not limited to, radiation shielding and inferring the composition of stars

**Learning Competencies**
Compare and contrast alternating current (AC) and direct current (DC) (**STEM_GP12EM-IVb-6**)

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction** | Common indications of AC in circuits and electric distribution systems | 5 |
| **Motivation** | Some difficulties in using steady current | 5 |
| **Instruction/ Delivery/ Discussion** | a. Discussion on the behavior and properties of DC circuit<br>b. Discussion of the generation and distribution system of electricity and the challenges<br>c. Discussion on the behavior and properties of AC circuit<br>d. Introduction to Phasor Diagram<br>e. Discussion of the resistor AC circuit | 40 |
| **Entrichment** | Homework assignment and essay | |
| **Evaluation** | Individual or by-pair quiz | 10 |
| **Materials** | 1. Phasor diagram (with two movable hands) made of cardboard; graphing paper<br>2. Ball pen (chalk) and paper (board) | |

**Resources**
See Appendix E

## INTRODUCTION/MOTIVATION (5 MINS)

1. Ask the students why there are “60 Hz” (or “50 Hz”) marks in appliances that need to be connected to electric socket and why these are absent in battery-operated devices.

2. Present an overview of electric energy distribution, particularly giving attention to the ubiquitous large cylinders housing the distribution transformers. (See Appendix A.)

## MOTIVATION (5 MINS)

1. Recall lesson on circuits and Ohm’s Law where the resistance causes the dissipation of electric energy to heat is discussed. The solution would have been to make the wires thicker (larger cross-sections), but this would be entail the use of lots of copper and make the wires heavy.

2. Discuss also that relying on battery is not a good option because it is still difficult to make long lasting and long-storing batteries.

## INSTRUCTION (40 MINS)

1. Discuss the properties and behavior of the DC circuit. It is a circuit whose voltage across and current through its components are steady in value and direction. Historically, it is the first type of circuit because the first electric energy source is a battery. It is still a common type of circuit found in many devices, especially mobile devices. Emphasize that the scale of this type of distribution are usually in small scale (i.e., in a small device only).

2. Point out to the students that the problems aforementioned in the Motivation arise if the current being use is direct current (DC). The use of alternating current (AC) as the solution is hinted by the fact that electricity sources (e.g., generators, water and wind turbines) are rotational in nature.

3. Discuss the mechanism for large scale generation and distribution of electricity. The important quantity is the electric energy, which is transmitted at a rate of $P_{total}$ = IV, where power $P_{total}$ is the energy transmitted per unit time, R is res the resistance, and V is the voltage. The electricity is generated by machines with rotating parts (generators) driven by wind, water flow, or steam. The location of these power generators stations are usually very far from the users of the power i.e., would require long transmission lines.

4. Analyze the challenges posed by the long distance between the source and users of electricity. First, review the relationship among common quantities in circuit such as resistance, current, voltage and power. Then, discuss the fact that the power (or rate of energy) loss, $P_{loss}$, due to conversion to heat is proportional to resistance R and the square of current I, i.e., $P_{loss} = RI^2$, such that the actual power transmitted is only

   $$P_{trans} = P_{total} - P_{loss} = IV - RI^2$$

5. The discussion in the Introduction already explains there is not much to be done to reduce the resistance R of the wire. Fortunately, the current I can be made smaller. However, this means that voltage must be increased so as to maintain the same value of $P_{total}$. The required values of voltage are usually higher than what are originally produced by the generator.

6. The large voltage requirement can be fulfilled by applying Faraday's Law, particularly the transformer, which may step-up (increase) or step-down (decrease) the voltage by varying the ratio of the number of turns of the primary (original) and secondary (induced) coil. For transformer to work, the magnetic field (accordingly, the voltage and the current) has to vary with time, i.e., alternating current (AC). (See Appendix B.)

7. Discuss the properties and behavior of the AC circuit. It is a circuit whose voltage across and current through its components alternate or oscillates in magnitude and polarity (positive and negative values). In other words, there is backward and forward current flow.

8. To complete the story about the electric distribution system, discuss that electric power companies in the Philippines usually distribute voltage (and therefore, current) oscillating at 60 Hz. Furthermore, the maximum value of the voltage required for appliances in the homes and offices is only 240V. Thus, a step-down transformer is again used to decrease the voltage.

9. Discuss phasor diagram, which is the visual representation of the quantities in the AC circuit. Phasor is a vector of length equal to the maximum current $I_{max}$ through (or the maximum voltage $V_{max}$ across) the devices connected to oscillating voltage source rotating counter-clockwise around the origin at angular frequency, $\omega$, or frequency f (e.g., 60 Hz). The instantaneous value of the current i(t) (or voltage v(t)) is

the projection of the phasor against the x-axis. When this projection of i(t) or v(t) is plotted versus time, one obtains a periodic function such as the sinusoidal function. (See Appendix C.)

10. To show a concrete example of an AC circuit, discuss the case of a resistor circuit driven by oscillating voltage. Analyze the properties and behavior of the current through the resistor, the voltage source and the voltage across the resistor using the phasor diagram. (See Appendix D.)

## ENRICHMENT

1. Compare the cost of electric energy in AC circuits and electric energy in DC circuits? Express the answers in terms of price per kilowatt-hour. Note that watt is unit for power= (energy transmitted or transformed) per unit time.

2. If the voltage from the electric socket is oscillating, why is it labeled as "220V," which is a fixed number?

3. Describe the mechanism of AC to DC conversion.

4. Describe the mechanism of the step-up and step-down distribution transformer.

5. Analyze the behavior and properties of capacitor AC circuit, inductor AC circuit, resistor-inductor-capacitor (RLC) AC circuit.

## EVALUATION (10 MINS)

1. Recall the difference between AC and DC.

2. Recall the disadvantages of DC in terms of power distribution.

3. Given a diagram of a phasor of voltage (or current) in a resistor circuit at a particular instant, determine the instantaneous value of voltage (or current)

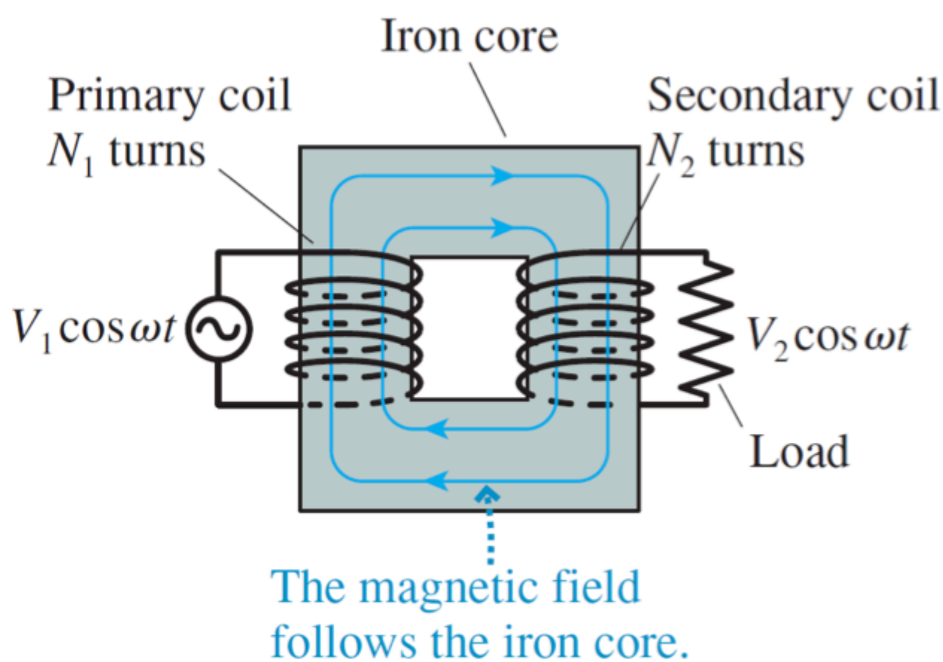
4. Given the expression for AC or oscillating voltage, draw the phasor diagram.

Please redraw all the figures/slide snapshots in the appendices

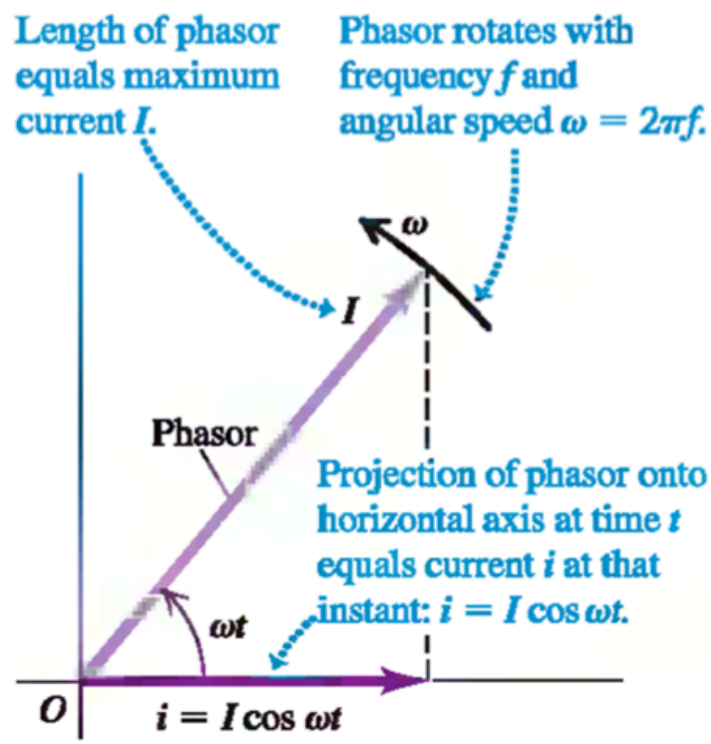
## Appendices

### Appendix A: Electricity Distribution System

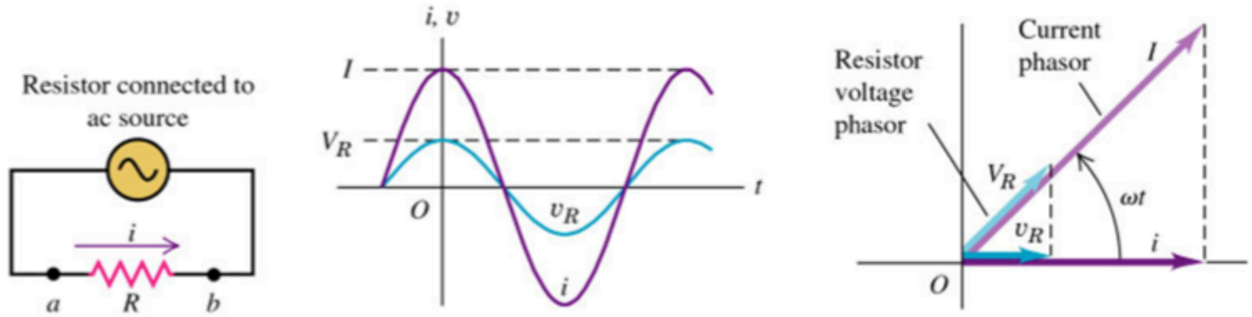

**Appendix B: Transformer**




**Appendix C: Phasor Diagram**



**Appendix D: Resistor circuit driven by an oscillating voltage**




$$v_{SOURCE} = V_{\max} \cos(\omega t)$$

$$i = I_{\max} \cos(\omega t)$$

$$v_R = iR = I_{\max} R \cos(\omega t) = V_R \cos(\omega t)$$

**Appendix E: Resources**


(1) D.C. Cassidy, G. Holton, F.J. Rutherford, Understanding Physics, 2nd Ed. (Springer, 2002).

(2) R.D. Knight, Physics for Scientists and Engineers: A Strategic Approach with Modern Physics and Mastering Physics (Benjamin Cummings, 2007).

(3) H.D. Young, R.A. Freedman, A.L. Ford, University Physics, 11th Ed. (Addison-Wesley, 2011).

(4) Paul Hewitt, Conceptual Physics, 11th Ed. Addison-Wesley, 2009).

(5) D. Halliday, R. Resnick, J. Walker. Fundamentals of Physics Extended, 10th Ed. (J. Wiley & Sons, Inc., 2013)

# LC Circuits

60 MINS

**Content Standards**

The learners demonstrate an understanding of Alternating current, LC circuits, and other applications of magnetic induction

**Performance Standards**

The learners are able to:

1. Use theoretical and, when feasible, experimental approaches to solve multiconcept, rich-context problems using concepts from electromagnetic waves, optics, relativity, and atomic and nuclear theory
2. Apply ideas from atomic and nuclear physics in contexts such as, but not limited to, radiation shielding and inferring the composition of stars

**Learning Competencies**

1. Use analogies with the spring-mass system to draw conclusions about the properties of LC circuits (**STEM_GP12EM-IVb-7**)
2. Characterize the properties (stored energy and time-dependence of charges, currents, and voltages) of an LC circuit (**STEM_GP12EM-IVb-8**)

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction/ Motivation** | Introduction of LC circuit, a generator and detector of electromagnetic waes, is an important component of electronic communication devices | 5 |
| **Instruction/ Delivery/ Discussion** | a. Introduction of inductance and inductor.<br>b. Review of capacitance and capacitor.<br>c. Qualitative discussion of LC circuit<br>d. Quantitative discussion of LC circuit.<br>e. Discussion of energy in LC circuit.<br>f. Comments on the common misconceptions, mistakes, or difficulties | 40 |
| **Entrichment** | Homework assignment and essay | |
| **Evaluation** | Individual or by-pair quiz | 10 |
| **Materials** | 1. Ball pen (chalk) and paper (board) | |

**Resources**

(1) R.D. Knight, Physics for Scientists and Engineers: A Strategic Approach with Modern Physics and Mastering Physics (Benjamin Cummings, 2007).

(2) R.W. Chabay, B.A. Sherwood. Matter and Interaction II: Electric and Magnetic Interactions, 3rd Ed. (J. Wiley & Sons, Inc., 2010).

(3) H.D. Young, R.A. Freedman, A.L. Ford, University Physics, 11th Ed. (Addison-Wesley, 2009).

(4) D. Halliday, R. Resnick, J. Walker. Fundamentals of Physics Extended, 10th Ed. (J. Wiley and Sons, Inc., 2013).

## INTRODUCTION/MOTIVATION (5 MINS)

1. Discuss with students the fact that there are lots and lots of electromagnetic wave signals, such as those of radio, television, and cellular phones, being broadcasted simultaneously in our surroundings. We need means or devices that would allow us to regulate or choose only a particular set of signals at a time because otherwise, we will be overwhelmed and not get sensible information. What circuit in these devices enables this choice? (Inductor-capacitor (LC) circuit. The design and sophistication may vary but the essential parts are the same.)

2. Inform the students that the later lessons will discuss nature and propagation of electromagnetic waves, such as light. This lesson will discuss LC circuit, which is an important example of generator and detector of electromagnetic waves. This circuit is a component of radio transmitters and receivers, televisions, and mobile phones

## INSTRUCTION (40 MINS)

1. Introduce the concept of inductance and inductor. The previous lessons focused on the solenoid, which consist of many coils, inducing EMF on the coils of another solenoid, such that the induced EMF opposes the changes (e.g., time-varying current, voltage, magnetic field, or other factors that changes the magnetic flux) that caused it. This phenomenon is called "mutual-inductance." Faraday's law states that it is also possible for each coil of the solenoid to induced EMF in the other coils of the same solenoid, i.e., the solenoid will induce an EMF on itself. Furthermore, similar to the case of two solenoids, the "self-induced" EMF also opposes the changes that caused it. This phenomenon is known as "self-inductance." (See Appendix A.)

2. 2Discuss the idea that the geometry and the material making up the core of the solenoid determine the extent that the change in magnetic flux results (specifically, change in current) to induced EMF. (This is similar to the fact that the geometry and the material making up the resistor determine the extent that the voltage results to current through that resistor.) The collective measure of geometry and the material making up the core of the solenoid is called "inductance," with "henry" as the unit (in honor of Joseph Henry). Accordingly, the solenoid is known as "inductor."

$$EMF = \Delta V_{inductor} = -\mu \frac{N^2}{d} \pi R^2 \frac{di}{dt} = -L\frac{di}{dt} \qquad (1)$$

$$L = \pi\mu_0 \frac{N^2R^2}{d} \qquad (2)$$

3. Discuss that whenever there is change in current, the inductor becomes a voltage source (like a battery) and, as will be shown below, stores energy in the magnetic field. In other words, the inductor, a seemingly plain coiled wire, becomes a battery whenever current changes with time. However, unlike batteries, its polarities oscillate. Introduce the sign convention as shown in the figure in Appendix B.

4. Review the lesson on capacitance and capacitor. (If voltage difference is applied across capacitors, like charges are accumulated in the capacitor plates and energy is stored in the electric field. Capacitance, which is the property of the capacitor, is a function of geometry and the dielectric between the plates, and has a unit of farad.)

**Qualitative discussion of LC Circuit**

5. With those information on the mechanism of the inductor and the capacitor, sketch (or let the student sketch) a cartoon strip of the LC circuit, the charge (polarity), current direction, and polarity of the voltage across the inductor over one oscillation cycle (supply figure). The "story plot" is as follows: *If subjected to (increasing) voltage, like charges, which tend to repel each other, are forced to accumulate in capacitor plate (the opposite charges accumulate on the other plate). The more the capacitor plates reaching its full capacity (as determined by the value of the capacitance), the less there is change in current, and in turn, the voltage induced in the inductor decreases. However, as the induced voltage decreases, the charges in capacitor succeed in repelling each other and move. The change in motion of the charges is a change in current, which again increases the voltage in the inductor (but this time in opposite polarity). Like charges are again forced to accumulate in the other capacitor plate (exchanging places with the opposite charges). The cycle is complete and the next one begins. (See Appendix C for example.)*

**Quantitative discussion of LC Circuit**

6. After building intuition from the previous steps, the students are supposed to get the sense that there are oscillating quantities. Start the discussion by setting up the sum of the voltages using the Kirchhoff's Loop Rule. Then express voltage of capacitors and inductors in terms of charge to derive an equation that resembles the equation of a spring-mass simple harmonic oscillator. The derived equation describes the total charge of a particular polarity in the capacitor plate as a function of time.

$$\Delta V_{inductor} + \Delta V_{capacitor} = L\frac{di}{dt}[i(t)] + \frac{q(t)}{c} = L\frac{d^2}{dt^2}[q(t)] + \frac{q(t)}{c} = 0 \qquad (3)$$

7. Demonstrate the use of Equation 3 in determining the charge, current, and angular frequency in LC circuit using its analogy with the simple harmonic oscillator (SHM). Emphasize that the time varying current induces the voltage across the inductor as discussed above.

| Table 1. Simple Harmonic Oscillator (SHM) vs. LC Circuit | |
|---|---|
| SHM | LC Circuit |
| $m \frac{d^2}{dt^2}[x(t)] + kx(t) = 0$ | $L \frac{d^2}{dt^2}[q(t)] + \frac{q(t)}{C} = 0$ |
| $x(t) = X_{max}\sin(\omega t)$ | $q(t) = Q_{max}\sin(\omega t)$ |
| $\omega = \sqrt{k/m}$ | $\omega = 1/\sqrt{LC}$ |
| $v(t) = \frac{d}{dt}[x(t)] = X_{max}\omega\cos(\omega t) = X_{max}\omega\sin(\omega t - \frac{\pi}{2})$ | $i(t) = \frac{d}{dt}[q(t)] = Q_{max}\omega\cos(\omega t) = Q_{max}\omega\sin(\omega t - \frac{\pi}{2})$ |

8. Discuss the behavior of energy, which is another important quantity in the LC Circuit. As the charge accumulation and current flow oscillate, energy also oscillates between the capacitor and the inductor. Recall that the (ideal) capacitor and inductor are non-dissipative devices, and so energy is conserved in LC circuits, which is equal to the maximum energy in the inductor or in the capacitor:

$$U_{total} = \frac{1}{2}\frac{Q^2_{max}}{C} = \frac{1}{2}LI^2_{max} = U_{capacitor\ (electric)} + U_{inductor\ (magnetic)} = \frac{1}{2}\frac{Q(t)^2}{C} + \frac{1}{2}L\,[i(t)]^2 \qquad (4)$$

9. Emphasize, by recalling Table 1, that the charge  and current  are out of phase by π/2 radians, and thus, the energy oscillates between the capacitor and inductor, i.e., transforms alternately from being an electric energy and magnetic energy.

**Common Misconceptions, Mistakes or Difficulties**

The following are some of the misconceptions, mistakes and difficulties of the students that the teacher should look out for. It might also be helpful to discuss these things with the student for emphasis, awareness, and/or benchmarking:

1. Similar to misconceptions and difficulties in the lessons on resistors (where students think that resistance depend on current or voltage), students may find difficulty understanding that inductance, which is a measure of geometry and material property, is not dependent on change in current or the resulting induced EMF. One way to explain this misconception is to use the analogy of a street: The material and geometry of the street is not dependent on the traffic situation and the cause of the traffic situation.

2. It is difficult to imagine the (original) current and induced current “existing” simultaneously in the same segment of wire making up the conductor. This confusion arises when the students focus on the charge, which is “material” aspect of the current. It should be kept in mind that current, or moving charge, consist of two concepts: charges, which are the material, and motion. The motion can cancel, which leads to the accumulation of the charges at the ends of the solenoid (inductor). These accumulated charges repel the charges in the capacitor.

3. Unlike in older (analog) models of device using LC circuits, it is difficult for students to associate the inductors and capacitors commonly found in laboratory to the more sophisticated models of radio, phones, and televisions. Students may benefit from reading assignment on the basic operations of these latter models.

## ENRICHMENT

1. In reality, the LC circuit has a resistance R. Let the student determine and analyze the properties of the RLC circuit, especially the resonance, using the damped harmonic oscillator as analogy.

2. Considering the parallel plate capacitor and the solenoid inductor, let the student determine the electric and magnetic energy densities. The result will show that the energy densities are proportional to the square of the electric or magnetic field. This is profound because this shows explicitly that the energy is stored in the field.

## EVALUATION (10-15 MINS)

1. Sketch a cartoon strip of the LC circuit, the charge (polarity), current direction, and polarity of the voltage across the inductor over one oscillation cycle.

2. Given an LC circuit made of an inductor of fixed inductance and a capacitor of variable capacitance (range is specified), determine the circuit’s range of frequency of electric oscillation.

3. Consider an FM radio station broadcasting at a particular frequency. What inductor should be paired with a given capacitor to build a receiver for this station? (Alternative: What capacitor should be paired with a given inductor to build a receiver for this station?)

4. Consider an LC circuit made of an inductor of a given inductance and a capacitor of a given capacitance. If the capacitor is initially charged to a given voltage, what is the maximum current through the inductor as the current oscillates? (Alternative: If the inductor is initially induced to a given voltage, what is the maximum charge of the capacitor as the charge oscillates?)

Please redraw all the figures/slide snapshots in the appendices

## Appendices

### Appendix A: Derivation of the Inductance

Recall that the magnetic field of the solenoid of length d, radius R, made of N number of coils, and carrying a current I is $B = \mu \frac{N}{d} I$. Accordingly, the magnetic flux, $\Phi = \mu \frac{N}{d} I \pi R^2$. If the current varies with time, each coil of the solenoid will have an induced $EMF_1$

$$EMF_1 = -\frac{d\Phi}{dt} = \mu \frac{N}{d} \pi R^2 \frac{di}{dt}$$

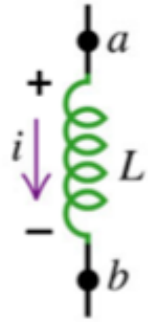
Since there are N coils, the total EMF is

$$EMF = N(EMF1) = -N\frac{d\Phi}{dt} = -\mu \frac{N^2}{d} \pi R^2 \frac{di}{dt}$$

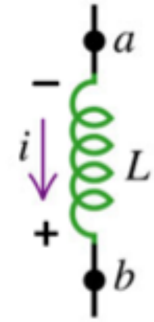
The proportionality constant lumped together is called inductance $L = \frac{\mu_0 N^2 \pi R^2}{d}$ and its unit is *henry* (H). Note that L is a quantity describing the geometry of the solenoid and the material in which the solenoid is immersed in (in vacuum, $\mu = \mu_0$). Note that we have change the variable for current, from capital letters "I" to small letter "i", to follow the naming convention for time dependent quantities in electric circuits.

### Appendix B: Voltage sign convention in an inductor

If the original current is increasing ($di/dt > 0$), the induced current carries positive charges to ***a*** (and negative charges to ***b***) creating a voltage/ potential across the inductor that decreases/drops from ***a*** to ***b***.

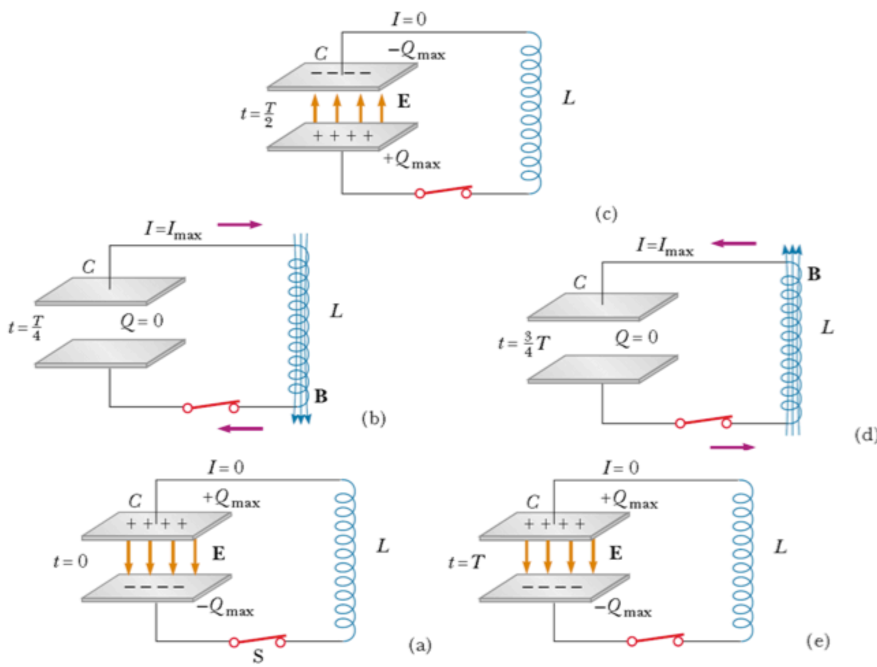



If the original current is decreasing ($di/dt < 0$), the induced current carries positive charges to ***b*** (and negative charges to ***a***) creating a voltage/ potential across the inductor that decreases/drops from ***b*** to ***a***.




If the current is constant ($di/dt = 0$), the voltage/ potential is zero.

### Appendix C: Sample cartoon of the charge and current in an LC circuit over one cycle



60 MINS

# Demonstrations Involving Magnetic Induction

**Content Standards**

The learners demonstrate an understanding of Magnetic induction; Faraday's Law

**Performance Standards**

The learners are able to:

1. Use theoretical and, when feasible, experimental approaches to solve multiconcept, rich-context problems using concepts from electromagnetic waves, optics, relativity, and atomic and nuclear theory
2. Apply ideas from atomic and nuclear physics in contexts such as, but not limited to, radiation shielding and inferring the composition of stars

**Learning Competencies**

Perform demonstrations involving magnetic induction in contexts such as, but not limited to, power generation, transformers, radio tuning, magnet falling in a copper pipe, and jumping rings (**STEM_GP12EM-IVb-9**)

## LESSON OUTLINE

| | | |
|---|---|---|
| **Logistics and Instructions for Teachers** | | |
| **Introduction/ Motivation** | Review of historical background of Faraday's experiments | 10 |
| **Demonstration** | a. Faraday's Experiments - Permanent Magnet<br>b. Faraday's Experiments - Electromagnet<br>c. Related demonstrations of electromagnetic induction | 50 |
| **Evaluation** | Notes (summary of observations) taken during demonstration | 40 |
| **Materials** | 1. bar magnets, electromagnet with switch and power supply, wire or solenoid, galvanometer or ammeter, core materials (e.g. aluminum, iron, and copper rods)<br>2. (if available) magnet and pipe; jumping ring set-up; bulb<br>3. (alternative) video of the demonstrations of electromagnetic induction | |

**Resources**

See Appendix C

## LOGISTICS AND INSTRUCTION TO TEACHERS

(These may be performed before Lesson 30 by the teacher. If performed after Lesson 30, the demonstrations may be performed by the students in groups. Furthermore, if materials are difficult to obtained, video clips or cartoon strips may be presented instead.)

1. Prepare materials and demonstration set-up (or video presentation).

2. Explain the rationale and historical background of the demonstration (Introduction/ Motivation).

3. Introduce the Evaluation. The intent of the Evaluation is simply to make the students pay attention and should not be a grading burden. Thus, it is recommended that you simply check the output for compliance.

4. You or the students perform the Demonstrations.

5. Collect or inspect cursorily the outputs notes of the students.

6. Summarize the key concepts of the demonstrations, emphasizing the importance of quantities having to "change with time."

## INTRODUCTION/MOTIVATION (10 MINS)

1. Tell the story of Michael Faraday conceiving the idea of "field," a mental picture of the agent of interaction among electric and magnetic objects not in contact. He visualized them as lines that has defined spatial relation to the objects or mechanism that generated them. So he knows that if he moves (or varies) the object (or mechanism), the field will also move (or vary). With this in mind, he performed experiments that shows the effect permanent magnets or electromagnets on a circuit not connected to a power supply.

2. Explain that this lesson will repeat the electromagnetic induction experiments of Faraday, which is not only crucial in Maxwell's conceptual synthesis of electricity and magnetism, but also to the pre-cursor to many modern technologies. Emphasize that Faraday's Law of Magnetic Induction is an empirical law (i.e., law deduced from observation). As such, performing or seeing first-hand the experiments of Faraday and other related demonstrations will enhance their appreciation and understanding.

## DEMONSTRATIONS (50 MINS)

### *A. Faraday's Experiments - Permanent Magnet*

The demonstration set up (Appendix A) consists of permanent magnet, wire loop/solenoid, which is attached to a galvanometer or ammeter. Let the students observe the direction and magnitude of the deflection of the galvanometer dial as the following tasks are performed or demonstrated:

1. Move the permanent magnet in and/or out of the coiled wire/solenoid. Vary the speed (fast, moderate, and slow) of the bar magnet's approach.
2. Repeating the demonstrations in Items 1 of this section, but this time vary the speed (fast, moderate, and slow) of the bar magnet's approach with the polarity of the bar magnet opposite of that in the previous.

### *B. Faraday's Experiments - Electromagnet*

The demonstration set up (Appendix B) consists of electromagnet with varying current, and a wire loop or solenoid, which is attached to a galvanometer or ammeter. Let the students observe the direction and magnitude of the deflection of the galvanometer dial as the following tasks are performed or demonstrated:

1. Turn ***on*** the electromagnet using a knob or a switch at different pace (fast, moderate, and slow).
2. Turn ***off*** the electromagnet using a knob or a switch at different pace (fast, moderate, and slow).
3. Repeat the demonstrations in Items 1 and 2 of this section, but this time vary geometry (angle, cross-sectional area, number of turns or length) of the solenoid or the electromagnet.
4. Repeat the demonstrations in Items 1 and 2 of this section, but this time vary magnetic permeability of the core material of the solenoid or the electromagnet by inserting different materials (e.g., air, aluminum, iron, and copper).

### *C. Related demonstrations of electromagnetic induction*

The following are related demonstrations of electromagnetic induction:

1. **Light from an electromagnet.** The demonstration set up consists of a solenoid, a bar magnet, and an LED or a light bulb (preferably with low pwer rating). Emphasize that the LED or light bulb is connected neither to the battery nor to the electric socket. Move the permanent magnet in and/or out of the solenoid. Observe the bulb. [*The LED or bulb should light up. This demonstrates electromagnetic induction. The magnet induces a current in the solenoid. In turn, the current powers the LED or bulb.*]

2. **Magnet through a pipe.** The demonstration set up consists of a bar magnet, a copper pipe, an aluminum pipe, a plastic pipe and a cushion (to catch the bar magnet). The pipes should have the same dimensions. Other pipes may be used as long as these have different conductivity. Place the copper pipe in the upright position and drop the bar magnet (with the North Pole up) into it and note the time elapsed between entry and exit. Repeat the same demonstration on other pipes. Compare the elapsed time. [*The magnet falls fastest in the plastic tube and slowest in the copper tube. This demonstrates particularly Lenz's Law. The motion of the magnet creates a varying magnetic field, which induces a current in the copper pipe (or aluminum pipe), which in turn produces a magnetic field (hence, called induced magnetic field). The induced magnetic field opposes magnet's magnetic field. With this repulsion, the magnet falls more slowly. However, this effect is more pronounced in copper because copper is a better conductor of current than aluminum. This effect is absent in a plastic pipe, which is an insulator.*]

3. **Jumping Ring.** The demonstration set up consists of a metallic ring and an electromagnet. The ring is placed on top of the electromagnet (may be aligned using a rod). The ring "jumps" when the electromagnet is switched on. [*The switching of the electromagnet creates a varying magnetic field, which induces a current in the ring, which in turn produces a magnetic field (hence, called induced magnetic field). The induced magnetic field opposes electric magnet's magnetic field. The repulsion causes the ring to jumping.*]

## ENRICHMENT

1. In reality, the LC circuit has a resistance R. Let the student determine and analyze the properties of the RLC circuit, especially the resonance, using the damped harmonic oscillator as analogy.

2. Considering the parallel plate capacitor and the solenoid inductor, let the student determine the electric and magnetic energy densities. The result will show that the energy densities are proportional to the square of the electric or magnetic field. This is profound because this shows explicitly that the energy is stored in the field.

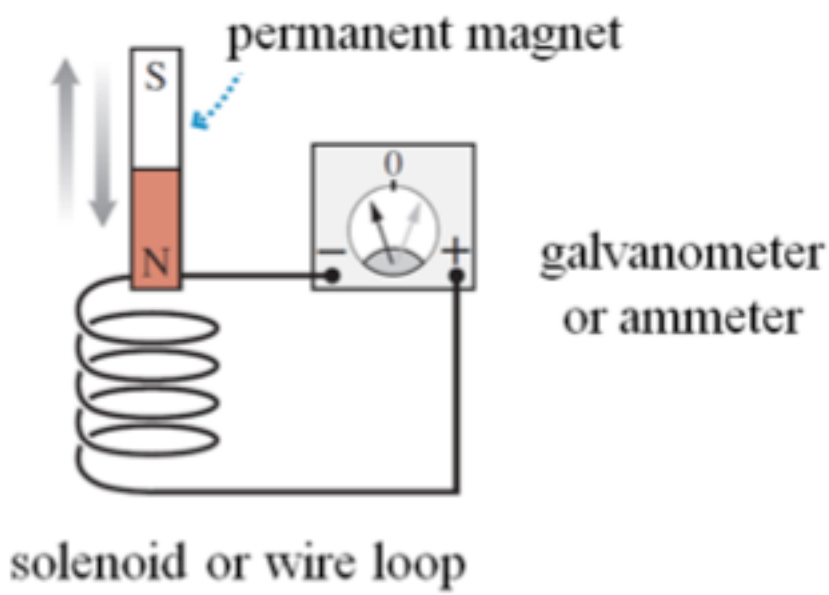
## EVALUATION (40 MINS, SIMULTANEOUS WITH DEMONSTRATION)

Let the students, first, list the summary of observations for all the demonstrations and, second, write the observations common to all demonstrations.

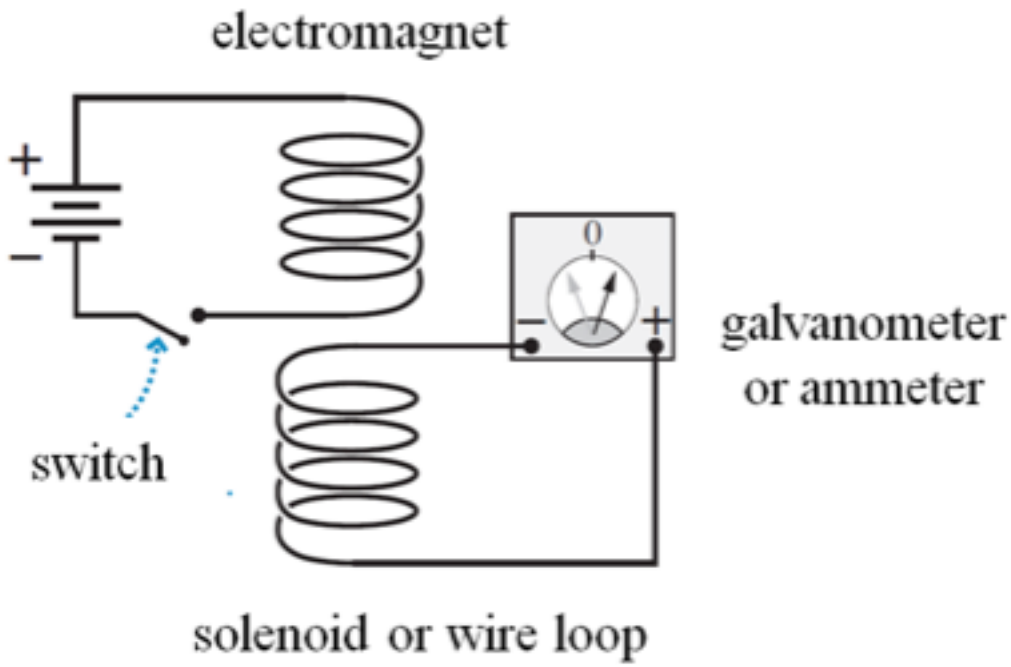
Please redraw all the figures/slide snapshots in the appendices

**Appendices**

**Appendix A: Faraday's Experiments - Permanent Magnet**



**Appendix B: Faraday's Experiments - Electromagnet**




**Appendix C: Resources**

(1) D.C. Cassidy, G. Holton, F.J. Rutherford, Understanding Physics, 2nd Ed. (Springer, 2002).

(2) R.D. Knight, Physics for Scientists and Engineers: A Strategic Approach with Modern Physics and Mastering Physics (Benjamin Cummings, 2007).

(3) H.D. Young, R.A. Freedman, A.L. Ford, University Physics, 11th Ed. (Addison-Wesley, 2011).

(4) P. Hewitt, Conceptual Physics, 11th Ed. Addison-Wesley, 2009).

(5) D. Halliday, R. Resnick, J. Walker. Fundamentals of Physics Extended, 10th Ed. (J. Wiley & Sons, Inc., 2013).

60 MINS

# Maxwell and light as an Electromagnetic Wave; Reflection, Refraction, and Dispersion

**Content Standards**

The learners demonstrate an understanding of:

1. Maxwell's synthesis of electricity, magnetism, and optics
2. EM waves and light

**Performance Standards**

The learners are able to:

1. Use theoretical and, when feasible, experimental approaches to solve multiconcept, rich-context problems using concepts from electromagnetic waves, optics, relativity, and atomic and nuclear theory
2. Apply ideas from atomic and nuclear physics in contexts such as, but not limited to, radiation shielding and inferring the composition of stars

**Learning Competencies**

1. Narrate Maxwell's line of reasoning in linking EM to light (**STEM_GP12EM-IVb-10**)
2. Narrate the story behind Hertz's experiments (**STEM_GP12EM-IVb-11**)
3. Relate the properties of EM wave (wavelength, frequency, speed) and the properties of vacuum and optical medium (permittivity, permeability, and index of refraction) (**STEM_GP12EM-IVb-12**)

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction/ Review** | Discussion about the possibility of the converse of Oersted's discovery | 4 |
| **Motivation** | Discussion about the prevalent interest on patterns, beauty, and symmetry, and on connections among disparate phenomena | 6 |
| **Instruction/ Delivery/ Discussion** | a. Analysis of Gauss's Law, Gauss's Law for magnetism, Ampere's Law, and Faraday's Law juxtaposed and written in mathematical and statement form.<br>b. Discussion of Maxwell's modification of Ampere's Law<br>c. Discussion of Maxwell's synthesis of the electricity, magnetism and light.<br>d. Examination of the solution of the EM wave equation.<br>e. Discussion of Hertz's experiment confirming Maxwell's ideas<br>f. Placing Maxwell's Equations and classical electromagnetism in contemporary context<br>g. Comments on the common misconceptions, mistakes or difficulties | 30 |
| **Enrichment** | Homework Assignments on some derivations and proofs | |
| **Evaluation** | Quiz | 10 |
| **Materials** | Chalk and board, pen and paper | |

**Resources**

See Appendix F

## INTRODUCTION (4 MINS)

Quickly review that the past lessons developed the mathematical description of seemingly unrelated electric and magnetic phenomena, particularly Gauss's Law, Gauss's Law for magnetism, Ampere's Law, and Faraday's Law. In this lesson, we study how James Clerk Maxwell summarized and integrated these different concepts into a concise and coherent body of knowledge. However, before this was achieved, he had to modify Ampere's Law. This modification made the connections and symmetry of those aforementioned laws more evident (even seen from the juxtaposition of their equations) and brought along a happy dividend, which is the realization that light is an electromagnetic wave. Maxwell's contribution is so significant such that the equations of those aforementioned laws are known as the Maxwell's Equations.

## MOTIVATION (6 MINS)

1. Discuss the historical observation that people, or at least philosophers and scientists (known before as natural philosophers), have been interested about patterns, beauty, and symmetry. This interest pervades even the physical sciences such that soon the search for symmetries was not only imbedded in the methods but also symmetries (and asymmetries) were recognized as properties of nature.

2. Discuss also the desire to see connections among many disparate phenomena in order to unify them in a compact scheme. In physics, this means reducing elaborate explanations to few concepts and equations.

## INSTRUCTION (30 MINS)

1. Analyze Gauss's Law, Gauss's Law for magnetism, Ampere's Law, and Faraday's Law in statement and mathematical form. Include also Lorentz' Force Laws and Continuity Equation. It is important that these concepts are written or flash side by side. Emphasize that these six laws describe all the electric and magnetic aspects of the universe on length scales greater than the size of the atom. (See Appendix A.)

2. Discuss the synthesis of the electricity, magnetism and light by Maxwell. Show the mathematical derivation but the emphasis should be on Maxwell's line of reasoning. Maxwell's crucial inputs are the analysis of those four aforementioned laws juxtaposed together and the addition of displacement current to Ampere's Law to achieve symmetry. Emphasize that the equations are not independent, i.e., they have common quantities. The four equations are reduced two wave equations, one for electric field and another for magnetic field, when substituted into one another. (See Appendix Band C. See also the section for "**Common Misconceptions, Mistakes or Difficulties.**")

3. Discuss that in Maxwell's time, the mechanical wave equation is already a well established concept. Thus, the formal similarity between the electric field and magnetic field wave equations, and the mechanical wave equation easily caught his attention. When he pushed further the logical consequences of the similarity by calculating the constants, the value that he obtained for the speed matched the value of the speed of light. He cannot help from inferring that light is an electromagnetic wave. Note that Maxwell himself was aware of the significance and novelty of his work, i.e., the discovery was a stereotypical "Eureka!" or "Aha!" moment. (See Appendix B and C.)

4. Examine the solution of wave equation: first, the general form of the solutions, $\vec{E} = \vec{E}\,(\vec{k} \bullet \vec{r} - \omega t)$ and $B = \vec{B}\,(\vec{k} \bullet \vec{r} - \omega t)$, and then, the sinusoidal functions. Furthermore, discuss the meaning of the quantities of the sinusoidal functions, i.e., amplitude, wavelength, wave number, frequency, angular frequency, speed and index of refraction.

5. Present an overview of the nature and propagation of light (the more detailed discussion will be in the succeeding lessons). The electric field and the magnetic field are the "waves"; the waves are transverse, i.e., electric field, magnetic field, and the direction of propagation of the wave are mutually perpendicular; there is a definite ratio between the electric field and the magnetic field, which is the speed of their propagation; the waves require no medium, and can travel in vacuum with a definite and unchanging speed; the waves transfer energy and momentum, exert pressure, and obey the superposition principle. Furthermore, the waves reflect, refract, are disperse and polarized. (See Appendix D.)

6. Discuss that after Maxwell died, Heinrich Hertz performed experiments to verify Maxwell's ideas. The experiment set up were essentially LC circuits, in which Hertz varied the geometries of the capacitor or inductor to generate sparks and standing electromagnetic waves. He found that these waves behaved just like light, i.e., he observed the reflection, refraction, polarization, etc. of these waves. (See Appendix E.)

7. Emphasize that Maxwell's synthesis of the concept of electricity and magnetism is a culmination of the works of many scientist and the second (the first is Newton's systematic description of motion) crowning achievement of classical physics. Particularly, it celebrated Faraday's genius in conceiving the field and it became the template for modern physics, where the unification of theories remains a major theme. These achievements not only have abstract and aesthetic implication but also technological (and social) implications such as the advancement in the generation and transmission of energy and information.

***Common Misconceptions, Mistakes or Difficulties***

The following are some of the misconceptions, mistakes and difficulties of the students that the teacher should look out for. It might also be helpful to discuss these things with the student for emphasis, awareness, and/or benchmarking:

1. Although based mostly on experimental results, the line of reasoning of Maxwell may not follow the typical scientific method. In fact, his predictions had no experimental proof even by the time of his death. Perceptive students may observe that Maxwell reversed the scientific method by starting from the conclusion. In some ways, expert practitioners, especially some theoretical physicists, reasoned the same way as Maxwell. Nonetheless, explain to the students that it is advisable for beginners to master first the scientific method taught in the usual order.

2. While the finish product is popularly known as Maxwell's Equations, it is advisable to remind students of the proper apportioning of credits. Maxwell's Equations is a culmination of the brave and brilliant efforts of many people living in different places and time. Maxwell had the broad view and the benefit of hindsight that enabled him to see and articulate the unity in the seemingly disconnected experiment results. He also had the critical eye for logic and beauty that enabled him to see the incompleteness of Ampere's Law and the confidence to offer a closure to the gap in knowledge. However, it must also be emphasized that the work was started by many people before him (e.g., Coulomb, Biot, Savart, Ampere, Faraday, etc.). Without them, Maxwell's synthesis would have been impossible or difficult to achieve.

## ENRICHMENT

This lesson is intended to simply familiarize the student with the brilliant insights of Maxwell. As such, the typical high school students are expected to have only a qualitative grasp of the story (even then, they may still find the logic strange). The more advanced students may solve the more involved or quantitative aspect of the story. The following are few sample problems:

1. Retrace the reasoning of Maxwell in introducing the displacement current in the Ampere's Law.
2. Prove that a sinusoidal function is one possible solution of the wave equation.
3. Starting from the differential form of Maxwell's Equations, derive the electric and magnetic wave equations.

## EVALUATION (10 MINS)

The following are sample quiz or exercise questions:

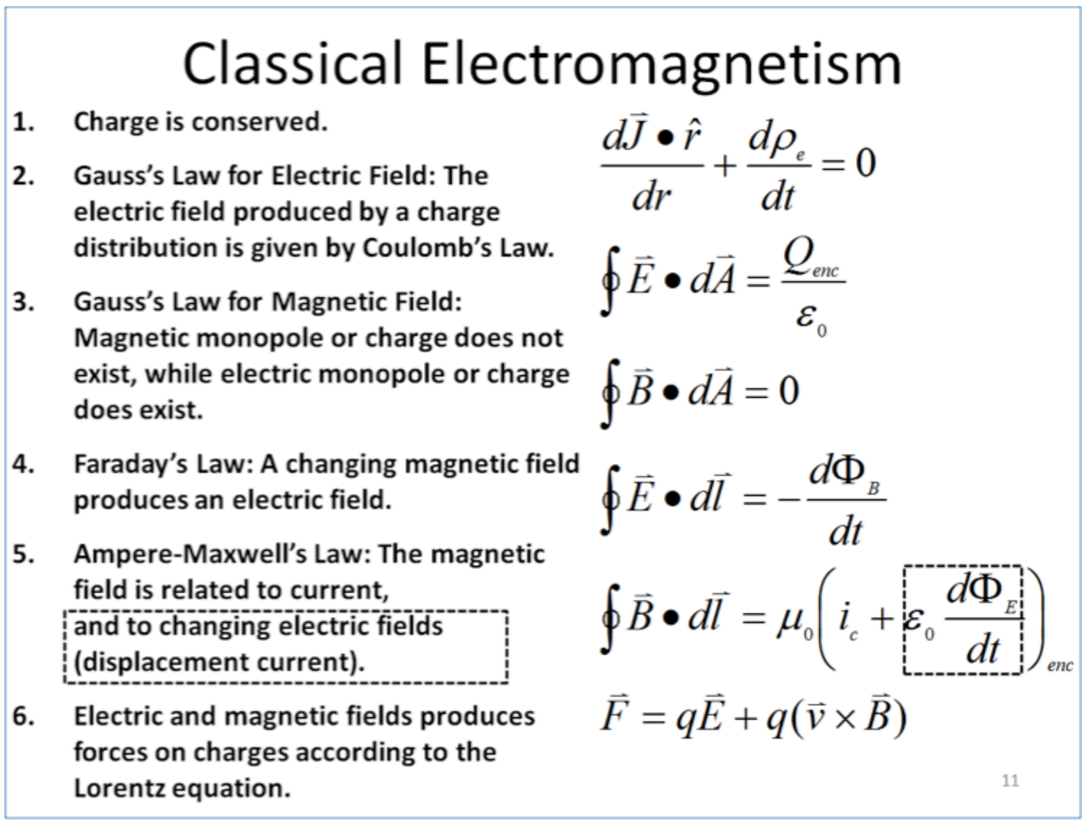
1. Draw a flowchart or a concept map of Maxwell's synthesis of electricity, magnetism, and light.
2. Sketch and label the parts of the experiment set up of Heinrich Hertz proving Maxwell's proposal that light is an electromagnetic wave.
3. Compare and contrast sound waves and electromagnetic waves.
4. Compute the speed of light in vacuum from the electric permittivity 0 and magnetic permeability 0.
5. Given the index of refraction, determine the speed of light in a medium.

6. Given a value of the magnetic field of an electromagnetic wave, determine its electric field. (Alternate: Given a value of the electric field of an electromagnetic wave, determine its magnetic field.)
7. Determine the wavelength and speed, determine the frequency of an electromagnetic wave. (Alternates: Other permutations of this question.)

Please redraw all the figures/slide snapshots in the appendices

**Appendices**

**Appendix A: Maxwell's Equations (Gauss's Law; Gauss's Law for magnetism; Ampere's Law; Faraday's Law) and the continuity equation and Lorentz Force Law in statement and mathematical form. Maxwell's modification of Ampere's Law is denoted by the dash-line box.**



**Appendix B: Sample slides for discussion of Maxwell's modification of Ampere's Law.**
**Discussion of Maxwell's synthesis of the electricity, magnetism and light.**

Ampere's Law is incomplete…
There should be displacement current…

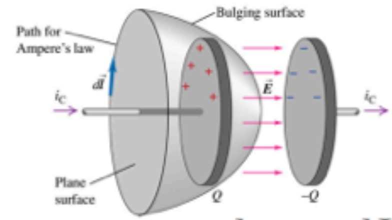
$$\oint \vec{E}_{induced} \bullet d\vec{A} = \frac{Q_{enc}}{\varepsilon_0}$$

$$\oint \vec{B} \bullet d\vec{A} = 0$$

$$\oint \vec{B} \bullet d\vec{l} = \mu_0 \left( i_c + \varepsilon_0 \frac{d\Phi_E}{dt} \right)_{enc}$$

$$\oint \vec{E}_{induced} \bullet d\vec{l} = -\frac{d\Phi_B}{dt}$$

## Displacement Current




$$i \to I(t); \quad v \to V(t)$$

$$\oint \vec{B} \bullet d\vec{l} = \mu_0 i_{enc}$$

$$q = Cv = \left[\frac{\varepsilon A}{d}\right][Ed] = \varepsilon EA = \varepsilon \Phi_E \to i_C = \frac{dq}{dt} = \varepsilon \frac{d\Phi_E}{dt}$$

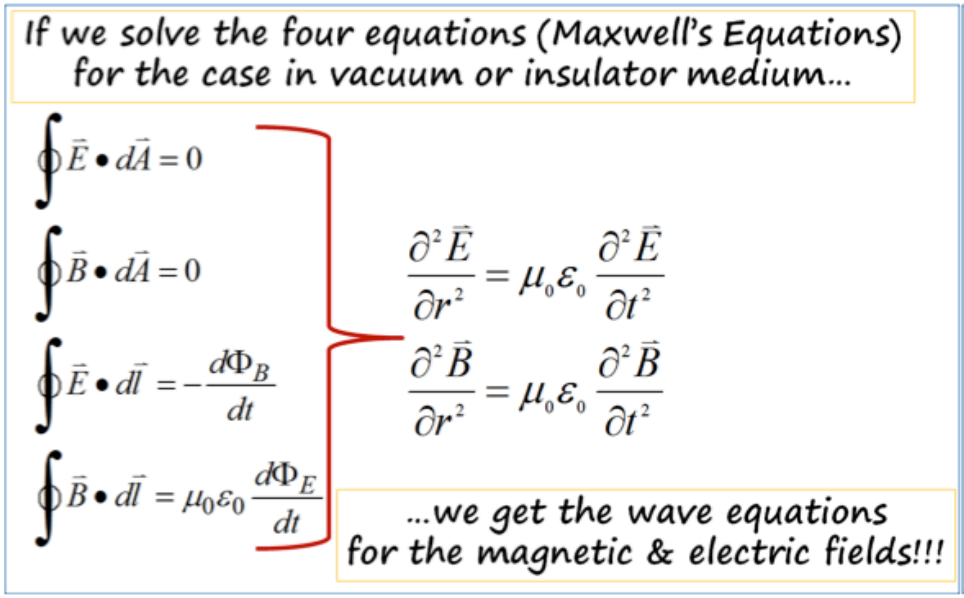
$$i_C \to \text{current is continuous} \to \text{IMAGINE} \to i_D = \varepsilon \frac{d\Phi_E}{dt}$$

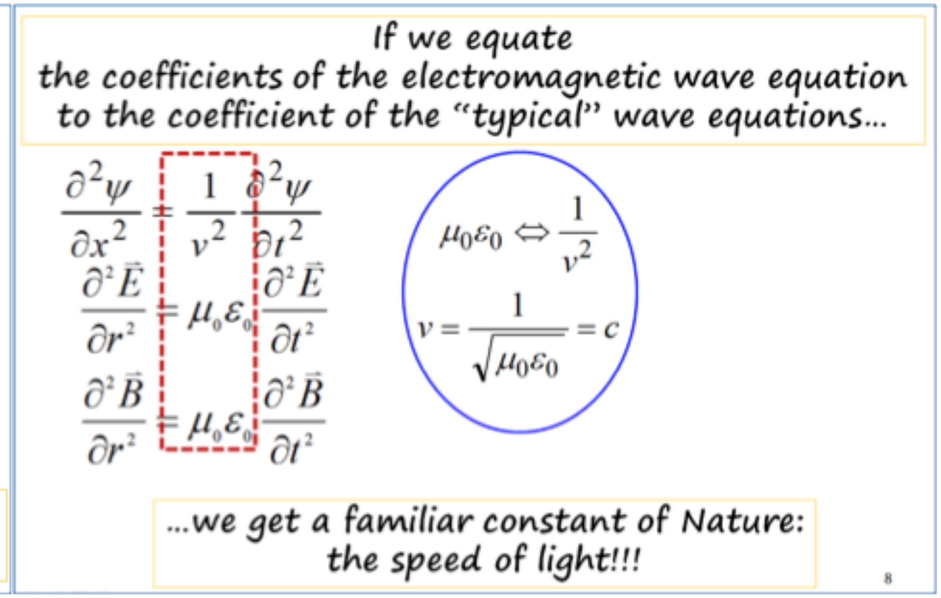
$$\oint \vec{B} \bullet d\vec{l} = \mu_0 (i_C + i_D)_{enc}$$

$$j_D = \frac{i_D}{A} = \frac{1}{A} \varepsilon \frac{d\Phi_E}{dt} = \frac{1}{A} \varepsilon \frac{d(EA)}{dt} \to j_D = \varepsilon \frac{dE}{dt}$$

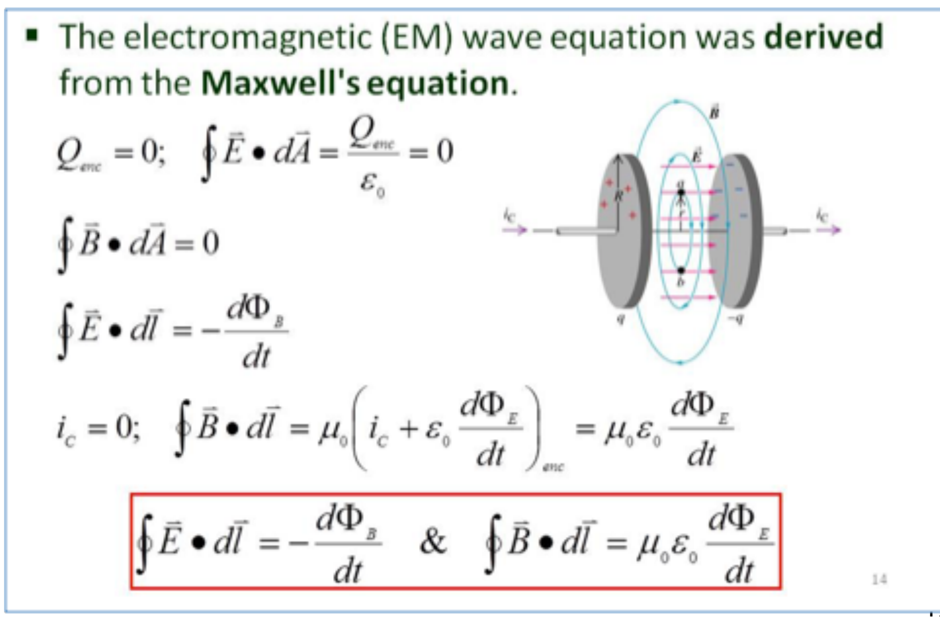
6

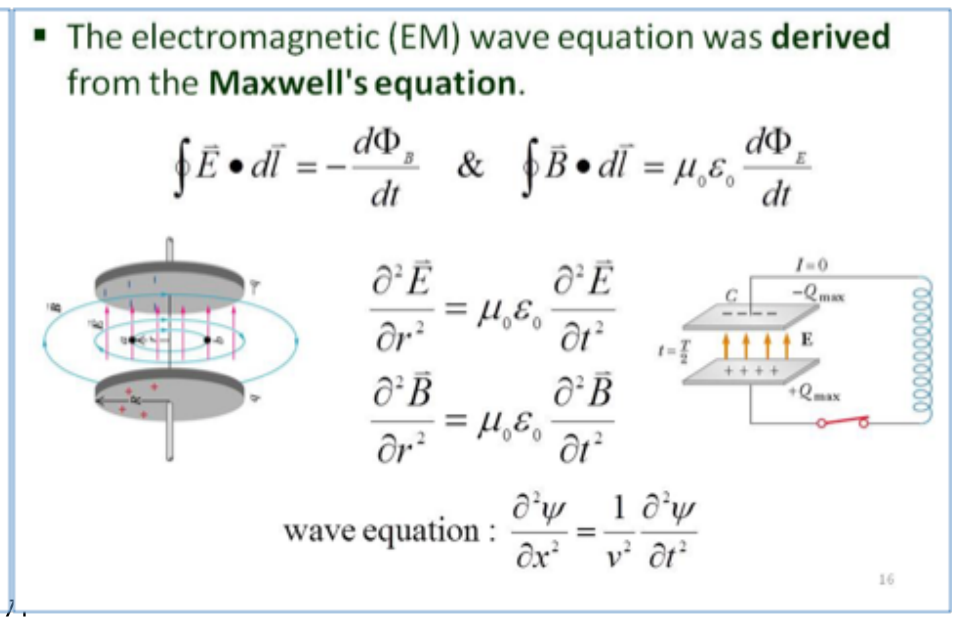
**Appendix B: Sample slides for discussion of Maxwell's synthesis of the electricity, magnetism and light.**




**Appendix D: Sample slides for the discussion of the nature and propagation of light.**



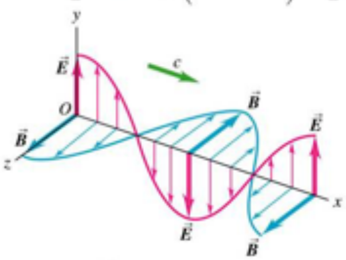



wave equation: $\frac{\partial^2\psi}{\partial x^2}=\frac{1}{v^2}\frac{\partial^2\psi}{\partial t^2}$

solution: $\psi=\psi(kx-\omega t)$

example: $\psi=A\cos(kx-\omega t)$

$A=$amplitude; $(kx-\omega t)=$phase




$$\frac{\partial^2\vec{E}}{\partial r^2}=\mu_0\varepsilon_0\frac{\partial^2\vec{E}}{\partial t^2}$$

$$\vec{E}=E\left(\vec{k}\bullet\vec{r}-\omega t\right)\hat{r}$$

$$\vec{E}=E_{MAX}\cos\left[\vec{k}\bullet\vec{r}-\omega t\right]\hat{r}$$

$$\frac{\partial^2\vec{B}}{\partial r^2}=\mu_0\varepsilon_0\frac{\partial^2\vec{B}}{\partial t^2}$$

$$\vec{B}=B\left(\vec{k}\bullet\vec{r}-\omega t\right)\hat{r}$$

$$\vec{B}=B_{MAX}\cos\left[\vec{k}\bullet\vec{r}-\omega t\right]\hat{r}$$

$$\vec{r}=\{\vec{x},\vec{y},\vec{z},\text{ or combination}\}=\text{position}$$

$\hat{r}=$ unit vector/direction

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- The wave is **transverse.** The **E**-field, **B**-field & direction of propagation of the wave , **v**, are **mutually perpendicular**.

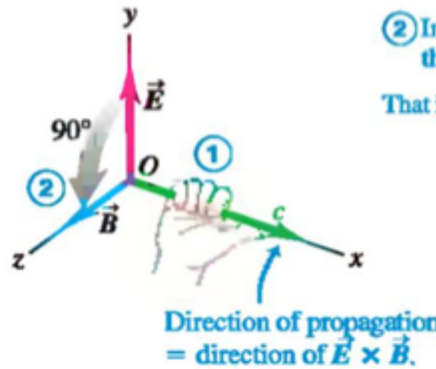
$$\vec{v}=\vec{E}\times\vec{B}$$

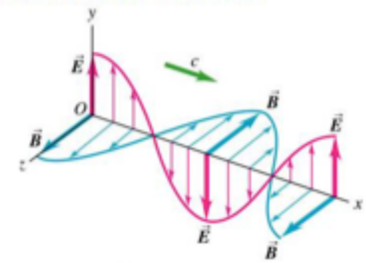
**Right-hand rule for an electromagnetic wave:**

① Point the thumb of your right hand in the wave's direction of propagation.

② Imagine rotating the $\vec{E}$ field vector 90° in the sense your fingers curl.

That is the direction of the $\vec{B}$ field.




18

- There is a **definite ratio** between the **E**-field and **B**-field.
- The EM waves **require no medium**. The EM wave travels in vacuum with a **definite and unchanging speed**.

$$E_{max}=vB_{max}$$

$$v=\frac{c}{n}\qquad c=\frac{1}{\sqrt{\mu_0\varepsilon_0}}$$

in vacuum: $n=1;\quad E_{max}=cB_{max}$

$$c=\frac{1}{\sqrt{\varepsilon_0\mu_0}}=\text{speed of light in vacuum}$$

$\kappa=$ dielectric constant

$\kappa_m=$ relative magnetic permeability

$$v=\frac{1}{\sqrt{\varepsilon\mu}}=\frac{1}{\sqrt{(\kappa\varepsilon_0)(\kappa_m\mu_0)}}=\frac{1}{\sqrt{\kappa\kappa_m}\sqrt{\varepsilon_0\mu_0}}$$

$$v=\frac{c}{n}$$

$n=\sqrt{\kappa\kappa_m}=$ index of refraction

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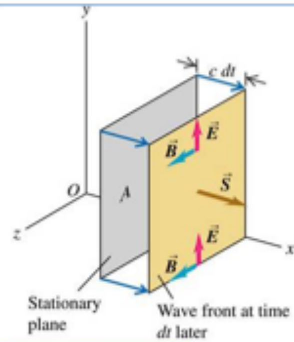
$$u = \frac{\varepsilon_0 E^2}{2} + \frac{B^2}{2\mu_0} = \varepsilon_0 E^2 = \frac{B^2}{\mu_0}$$

$$S = \frac{1}{A}\frac{dU}{dt} = \frac{1}{A}\frac{uAcdt}{dt} = uc$$

$$= \varepsilon_0 E^2 c = \frac{B^2 c}{\mu_0} = \frac{EB}{\mu_0}$$

$$dU = udV; \quad dV = Acdt$$

$$\text{Poynting vector}: \vec{S} = \frac{\vec{E}\times\vec{B}}{\mu_0}$$




John Henry Poynting (1852-1914)

http://en.wikipedia.org/wiki/John_Henry_Poynting

22

$$I = S_{AVE} = \langle S_{AVE} \rangle = \left\langle \frac{EB}{\mu_0} \right\rangle = \frac{1}{\mu_0}\frac{E_{MAX}}{\sqrt{2}}\frac{B_{MAX}}{\sqrt{2}}$$

$$= \frac{E_{MAX}B_{MAX}}{2\mu_0} = \frac{E_{MAX}^2}{2\mu_0 c} = \frac{\varepsilon_0 c E_{MAX}^2}{2}$$

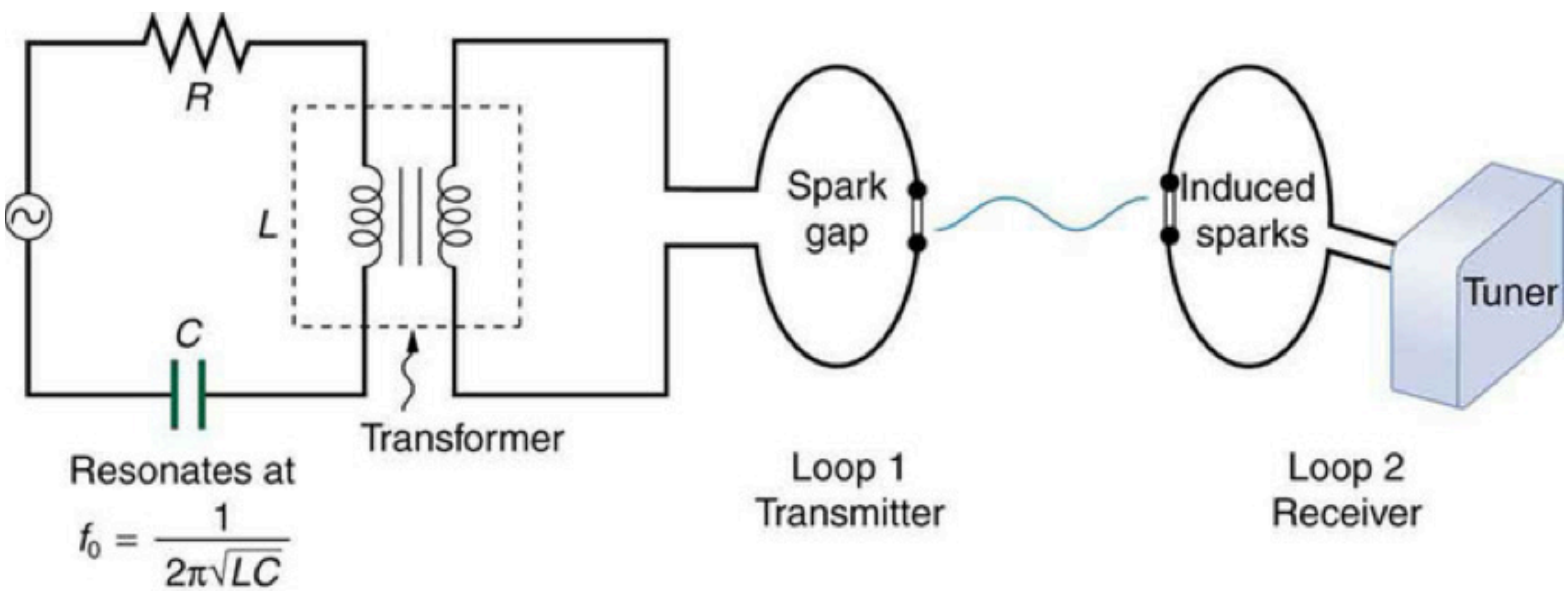
$$P_{\text{TRANSPARENT}} = 0$$

$$P_{\text{perfect ABSORB}} = \frac{I}{c}$$

$$P_{\text{perfect REFLECT}} = \frac{2I}{c}$$

23

**Appendix E: Diagram of the experiment set up of Hertz**



## Appendix F: Resources


(1) R.W. Chabay, B.A. Sherwood. Matter and Interaction II: Electric and Magnetic Interactions, 3rd Ed. (J. Wiley & Sons, Inc., 2010).

(2) H.D. Young, R.A. Freedman, A.L. Ford, University Physics, 11th Ed. (Addison-Wesley, 2011).

(3) D. Halliday, R. Resnick, J. Walker. Fundamentals of Physics Extended, 10th Ed. (J. Wiley & Sons, Inc., 2013).

120 MINS

# Ray Optics, Reflection, and Refraction

**Content Standards**

The learners demonstrate an understanding of:

1. Law of Reflection;
2. Law of Refraction (Snell's Law);
3. Total internal reflection; and
4. Applications of concepts of reflection, refraction and ray optics in experiments and real-world setting.

**Performance Standards**

The learners are able to use theoretical and experimental approaches to solve multi-concept and rich-context problems involving Geometric Optics.

**Learning Competencies**

The learners:

1. Understand the representation of the direction of propagation of waves with ray optics;
2. Know when it is valid or invalid to apply ray analysis in a system;
3. Quantitatively describe the Laws of Reflection and Refraction via experiments;
4. Relate the properties of EM wave (wavelength, frequency, speed) and the properties of vacuum and optical medium (permittivity, permeability, and index of refraction); **(STEM_GP12OPT-IVb-12)**
5. Apply the Law of Reflection and Snell's Law; **(STEM_GP12OPT-IVb-13, IVb-15)**
6. Explain the conditions for total internal reflection; **(STEM_GP12OPT-IVb-14)** and
7. Plan and perform an experiment involving ray optics and analyze the data – identifying and analyzing discrepancies between experimental results and theoretical expectations when appropriate. **(STEM_GP12OPT-IVc-19)**

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction** | Key concepts of geometric optics, reflection and refraction | 30 |
| **Motivation** | Demonstration of the mirror test | 10 |
| **Instruction/ Practice** | Hands-on experiment on reflection and refraction | 60 |
| **Evaluation** | Quiz | 10 |
| **Enrichment** | Reading homework | 10 |

**Materials**

- Protractor (2 pcs)
- Ruler (2 pcs)
- Push pins (2 pcs)
- Bond paper (2 sheets)
- Graphing paper (2 sheets)
- Cheap commercial laser pointer
- Glass plate (1 pc)
- Flat mirror (make-up mirror "from compact powder" will do)
- Lecture slides for pictures and other visual aids

**Resources**

(1) Pople, S. (1993). *Coordinated Science: Physics.* Oxford University Press.
(2) Young, H.D., Freedman, R. A., & Ford. A. L. (2011). *University Physics* (12th ed.). Boston: Addison Wesley.
(3) Tipler, P. (n.d.). *University Physics* (4th ed.). Boston: Addison Wesley.

## INTRODUCTION (30 MINS)

**Teacher Tip:**
This is optional and does not need too much emphasis.

1. **<u>Light has a wave-particle duality (prepare visual aids)</u>**
   a. Discuss the history of how the wave-particle duality of light came to be. In 1690 Christian Huygens postulated the **Wave Theory of Light**, where he defined that light is vibrating up and down, perpendicular to the direction of the propagation of light.
   b. In 1704 Isaac Newton proposed a **Corpuscular Theory of Light**, where light consists of tiny particles called **corpuscles**.
   c. In 1803 Thomas Young proposed his Wave Theory of Light, which he demonstrated using the Young's slit interference experiment. In his experiment, he demonstrated that two light sources passing through slits produce interference pattern, an alternating bright and dark bands.
   d. In 1905 Einstein proposed that light is composed of photons, which are particles with quantized energies.

2. **<u>Waves and Rays</u>**
   a. Relate the analogy of wave propagation from a source with the propagation of water waves as a rock drops in a body of water.

   (Animation: http://www.acs.psu.edu/drussell/Demos/rad2/mdq.html)

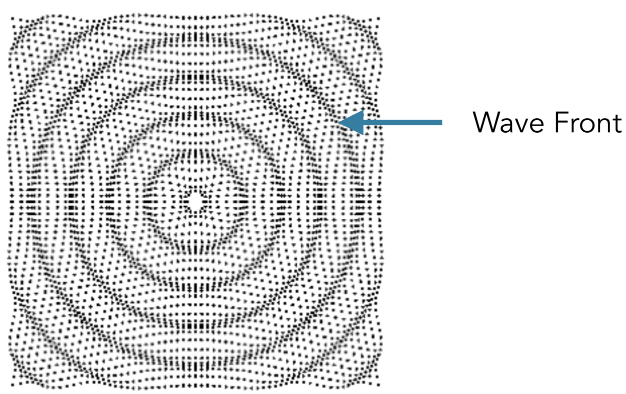
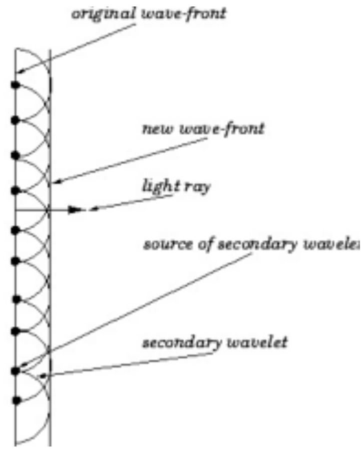



*Figure 1. A source located at the center emanates waves radially*

**Huygens' Principle**

*Every point on a wave front may be considered a source of secondary spherical wavelets, which spread out in the forward direction at the speed of light. The new wave front is the tangential surface to all of these secondary wavelets.*

Briefly mention the definition of a plane wave in relation to a wave front.




The ray of light is an imaginary line that indicates the direction of the propagation of waves. For convenience, the direction of propagation is assigned as the ray that is perpendicular to the wave fronts, as shown below. Therefore, light can be represented with a ray.

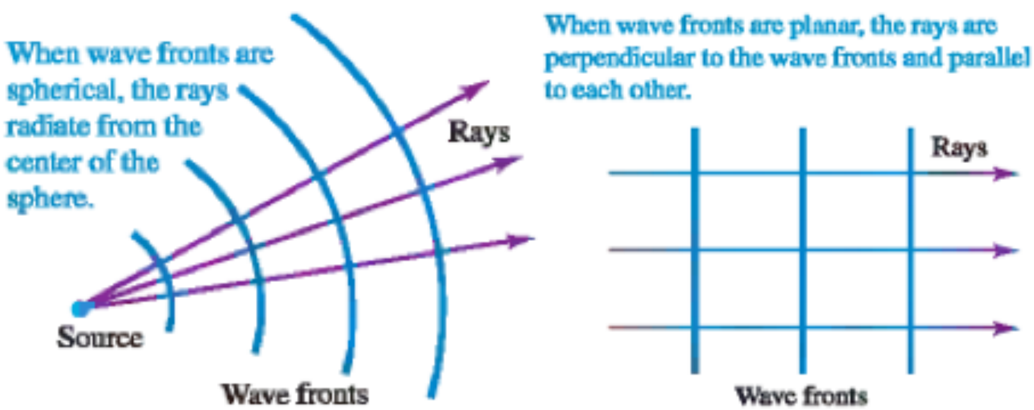



*Figure 2. Rays that indicate the direction of wave propagation.*

b. Recall that any object can be a source of wave.

## 3. Geometric Optics (Ray Optics) Vs. Diffraction Optics

This section is discussed only in brief. The key idea is the validity of use of ray optics based on the following definitions.

**Ray optics** is valid for optical systems where the wavelength of light is very small compared to the size of the system, so that we can represent light as a ray. This case focuses on ray analysis.

**Diffraction optics i**s valid for optical systems where the wavelength of light is comparable to the size of the system.

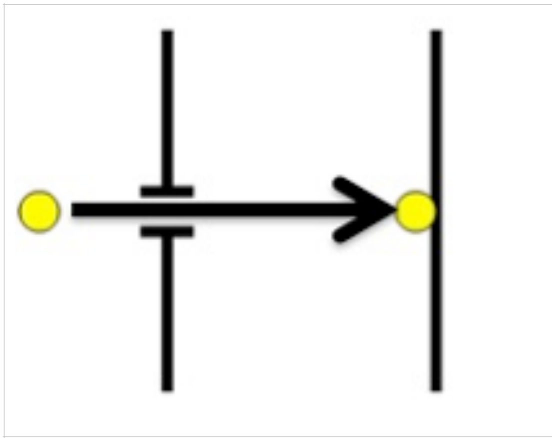


*Figure 3. Ray Optics*

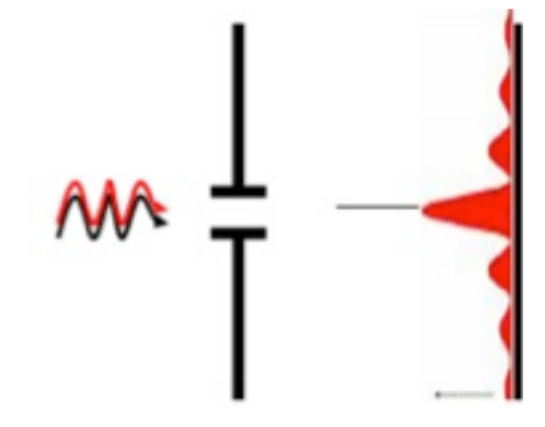
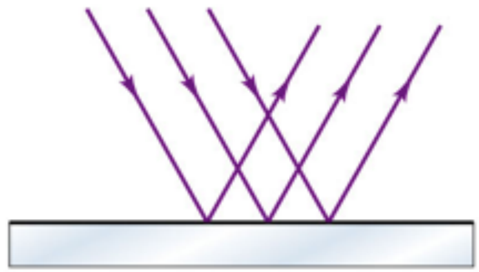
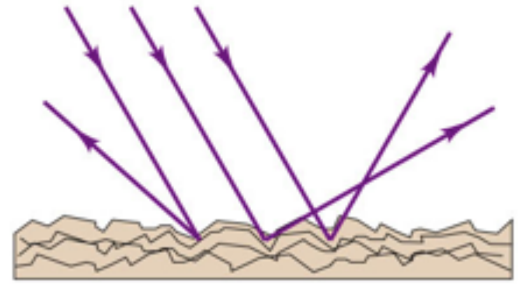


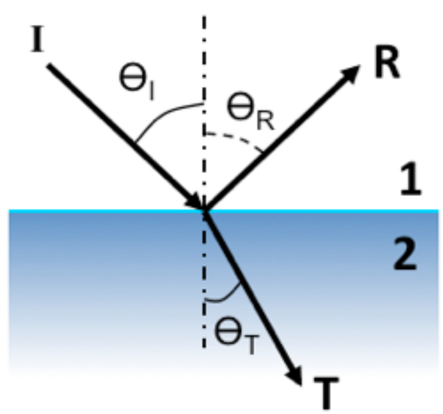
*Figure 4. Diffraction Optics*

## 4. Application of Ray Optics on Reflection and Refraction

a. Discuss the two types of reflection: diffuse and specular reflections. Provide pictures or slides, like Figures 5 and 6, for better and faster understanding.

| Specular Reflection | Diffuse Reflection |
| --- | --- |
|  |  |
| *Figure 5. Reflection on a Smooth surface* | *Figure 6. Reflection on a rough surface* |

b. Introduce the different rays in an optical system (incident, reflected ray and refracted ray), as shown in the figure below.

| | |
| --- | --- |
|  | I – incident ray of light<br>R – reflected ray of light<br>T – transmitted ray of light<br>$\theta_I$ – angle of incidence<br>$\theta_R$ – angle of reflection<br>$\theta_T$ – angle of transmission<br>1 - medium of incidence<br>2 – medium of transmission |
| *Figure 7. Light rays demonstration* | *Note: *All light rays lie on the same plane* |

**Teacher Tip:**
For all problems in geometric optics, it is assumed that the frequency of light remains constant as it passes through a medium.

c. Introduce **index of refraction**, a dimensionless number that describes the transmission of light through a medium. *n=c/v*

d. Discuss Snell's Law to learners: important keywords are index of refraction and speed of light. Relate it to the electromagnetic properties  Note that in the discussions, we assume that the frequency *f*, of light is constant in both media. This is an important assumption since Snell's Law is limited only for changing media.

## 5. **Total Internal Reflection**

Discuss that it happens when $n_I > n_T$.

At an angle of incidence equal to the critical angle $\theta_I = \theta_C$, there is no refracted light. As $\theta_I$ exceeds the $\theta_C$, all the light gets reflected in medium 1. The critical angle may be solved using: $\sin\theta_{crit} = \frac{n_t}{n_i}$

**Teacher Tip:**

The derivation of the Snell's Law makes use of Fermat's Theorem and requires calculus and beyond the scope at this level.
Thus it is better to present Snell's Law as an empirical fact.

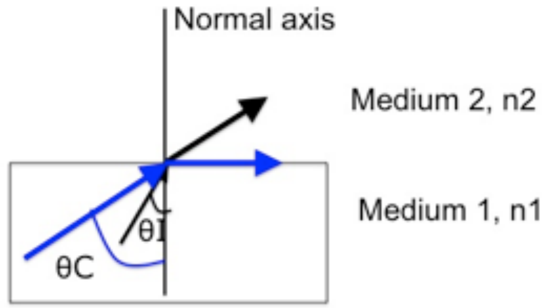



Figure 8. The refracted ray traces the surface of the medium when $\theta_I = \theta_C$

**Application: Diamonds!**

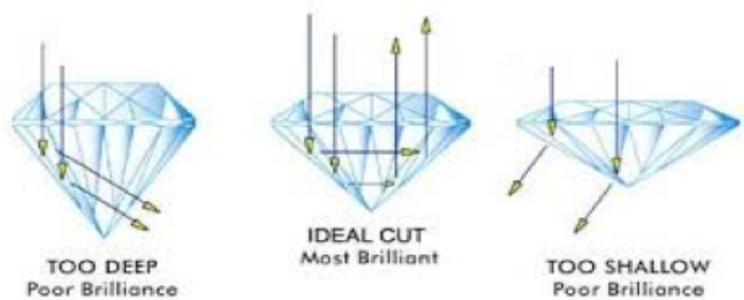



Figure 9. A diamond is most brilliant when its cut allows TIR of light.

## MOTIVATION (10 MINS)

1. Show a video how to determine if a mirror is one-way or not.
   Option 1: Play an animation from this link: http://www.acs.psu.edu/drussell/Demos/rad2/mdq.html
   Option 2: Show the pictures below from http://funnyjunk.com/funny_pictures/1120067/Oh/

*Figure 10. A public toilet built with one-way glass as mirrors.*

   Option 3: Show the difference between one way and a conventional mirror
   (http://boingboing.net/2015/06/12/how-to-tell-if-a-mirror-is-one.html)

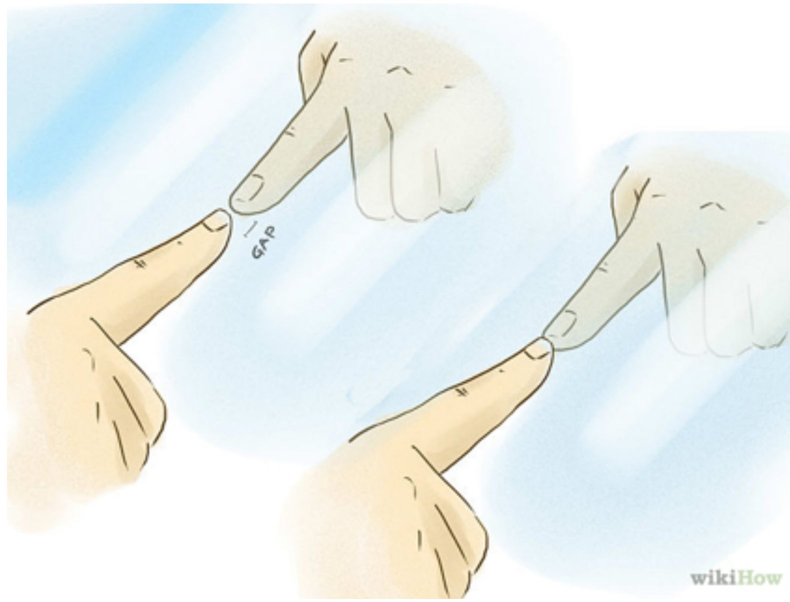



Figure 11. The fingernail test. If the reflection of your fingernail from the mirror has a gap, then the mirror is made up of a one-way glass. Otherwise it is made of a two-way glass.

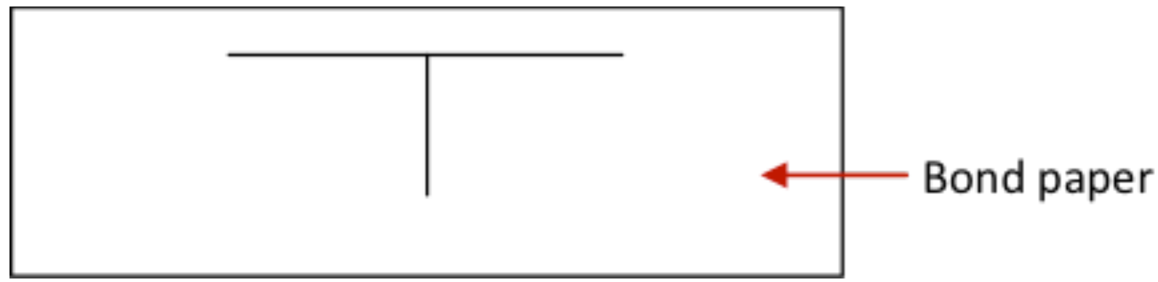
## INSTRUCTION (60 MINS)

***Hands-on experiment on Reflection***

1. Inform the learners that they will perform a simple ray optics and reflection experiments individually as outlined below. The learners must submit a short report about their experiment, that contains their data and its brief analysis. The report may be submitted next meeting.

   Experiment 1: Law of Reflection

   a. Prepare the experimental set-up. In a sheet of bond paper, use a dark pen to draw a straight horizontal line and a line perpendicular to it. Designate the intersection point as A.




b. Arbitrarily choose a location on the left side of the perpendicular line and push a pin. Designate the position of the pin as point B. Draw a straight line connecting points A and B.

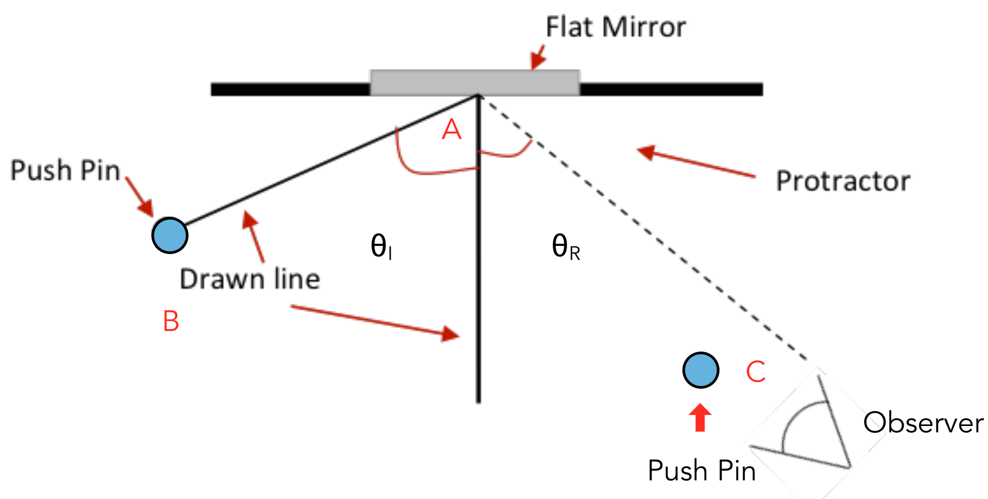
c. Position the mirror center at A such that the mirror's surface is parallel to the horizontal line.

d. Position yourself on the right hand side of the perpendicular line and locate point C. Put a pin on that location such that the line BA and line AC are perpendicular to each other.

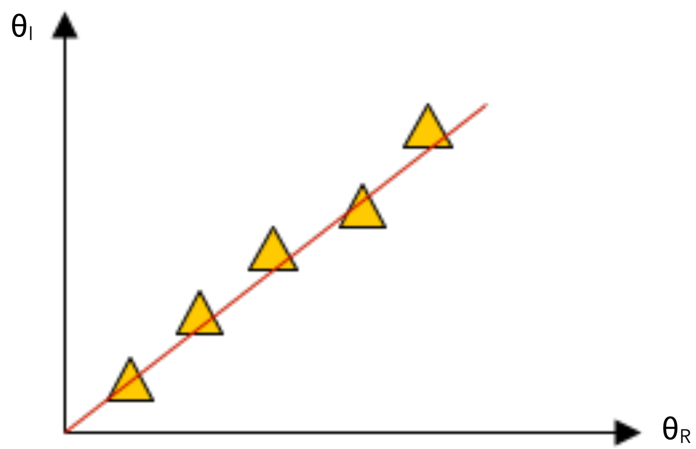
e. Using a protractor measure the angle subtended by line AB to the perpendicular line. This will be called the incident angle, $\theta_I$.

f. Using a protractor measure the angle subtended by line AC to the perpendicular line. This will be called the reflection angle, $\theta_R$.

g. Repeat steps 1-6 for five (5) different locations of point B and their corresponding point C.



2. Instruct learners to plot for each  on a graphing paper. The expected result is as follows:



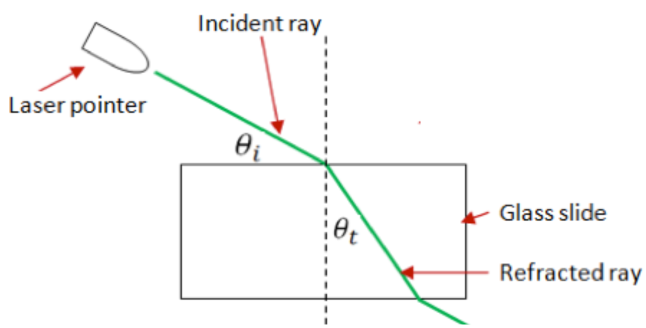

3. Instruct learners to create a report detailing their results. The learners should also be able to identify the relationship between $\theta_R$ and $\theta_I$.

**Teacher Tip:**

1. The relationship should be linear, i.e. $\theta_I=\theta_R$.
2. For maximum appreciation of the scientific method, ask the learners to perform a linear fitting, using MS Excel, to obtain the slope and the y-intercept If there is not enough time for this, you can have this as an added home work.

***Hands-on experiment on Refraction***

1. Demonstrate refraction by setting up the experiment below.




2. Using a protractor, ask a volunteer to measure the incident angle, $\theta_I$, and the refracted angle, $\theta_g$.

3. Repeat steps 4-5 for five different incident angle (and thus 5 different refracted angles). This data will then be given to all  the learners.

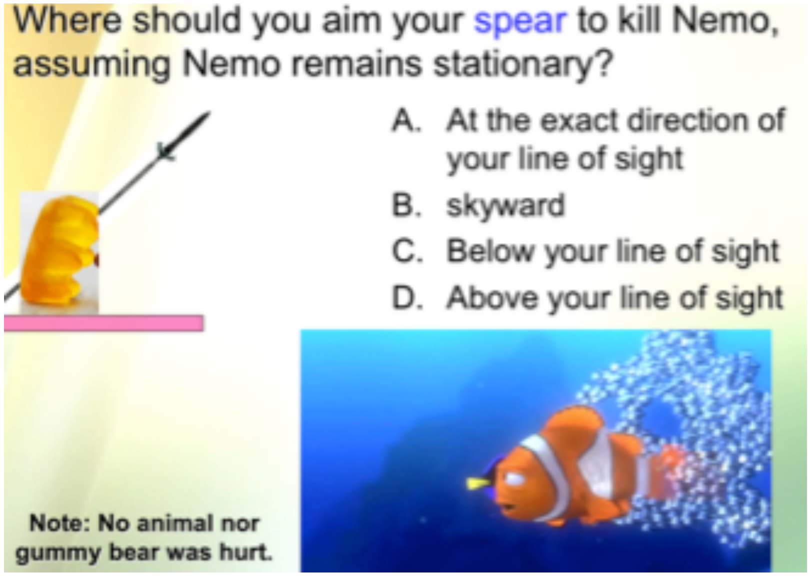
| Angle of incidence ($\theta_I$) | $\sin\theta_I$ | $\sin\theta_T$ | $\sin\theta_I$ / $\sin\theta_T$ |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

4. Instruct learners to complete the table below:
5. Ask the learners to determine the relationship between sin $\theta_t$ and sin $\theta_i$.

**Teacher Tip:**

1. Answer: the ratio, $\sin\theta_i/\sin\theta_t$, is a constant for a particular pair of material (in this case air and glass).
2. After the activities, give the formula of Law of Reflection and Snell's Law.

## EVALUATION (10 MINS)



## ENRICHMENT (10 MINS)

This is a reading homework. Ask the learners to answer the following questions:

1. Why do you think makeup makes people look better?
2. On a hot summer day, what causes the mirage or a reflection of motorcyclist on the road?
3. Why do some land patches seem to have oasis in the desert even if in fact, the oasis does not exist?

**Teacher Tip:**

The concept is similar with number 2

60 MINS

# Reflection and Refraction at Plane and Spherical Surfaces, and Mirrors and Image Formation

**Content Standards**
The learners demonstrate an understanding of reflection and refraction at plane and spherical surfaces, and of mirrors and image formation.

**Performance Standards**
The learners are able to use theoretical and experimental approaches to solve multi-concept and rich-context problems involving geometric optics.

**Learning Competencies**
The learners are able to:

1. Apply Law of Reflection; **(STEM_GP12OPT-IVb-13)**
2. Explain image formation as an application of reflection and paraxial approximation; **(STEM_GP12OPT-IVd-22)**
3. Relate properties of mirrors (radii of curvature, focal length) to image and object distance and sizes; **(STEM_GP12OPT-IVd-23)** and
4. Determine graphically and mathematically the type (virtual/real), magnification, location, and orientation of image of a point and extended object produced by a plane or spherical mirror. **(STEM_GP12OPT-IVd-24)**

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction** | Review of the Law of Reflection and Snell's Law | 5 |
| **Instruction** | Discussion and practice of reflection and refraction at plan | 10 |
| **Instruction/ Practice** | Hands-on experiment on reflection and refraction at plane and spherical surfaces | 45 |
| **Evaluation** | Two ray-tracing problems | 10 |
| **Materials** | • Slides<br>• Concave and convex mirrors (or spoon) | |

**Resources**


(1) Pople, S. (1993). *Coordinated Science: Physics.* Oxford University Press.

(2) Tipler, P. (n.d.). *University Physics* (4th ed.). Boston: Addison Wesley.

(3) Young, H.D., Freedman, R. A., & Ford. A. L. (2011). *University Physics* (12th ed.). Boston: Addison Wesley.

## INTRODUCTION (5 MINS)

1. Recall the Law of Reflection and Snell's Law.
2. Discuss some practical applications of using spherical mirrors, such as security mirrors in stores, safety mirrors in roads with sharp curves and dental procedures (concave), among others.


*Figure 1. Concave mirrors magnifies images, making it very useful for grooming.*

## INSTRUCTION (45 MINS)

**1. Reflection and refraction at plane surfaces (ray tracing)**

State that Snell's Law and paraxial approximation are useful in determining the location of the image formed using the object-image relationship or by ray-tracing method.

Using the following symbols and figures, familiarize the learners on reflection.

**P** – object's location

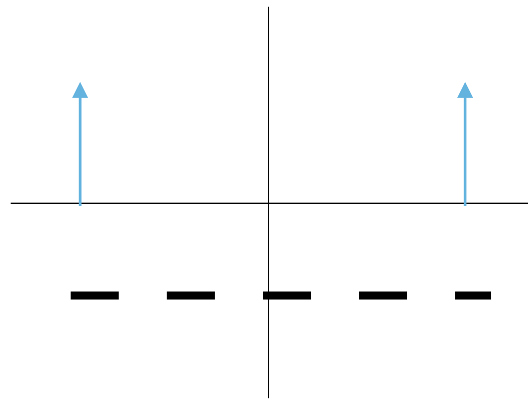
**P'** – image's location

**s** – object's distance from the surface

**s'** – image's distance from the surface

Discuss the symbols above while showing the diagrams. Then state that the images of the point objects are formed as shown below.

**Teacher Tip:**
The figures at this stage only serve as introduction. Image formation will be formally discussed in the next section.



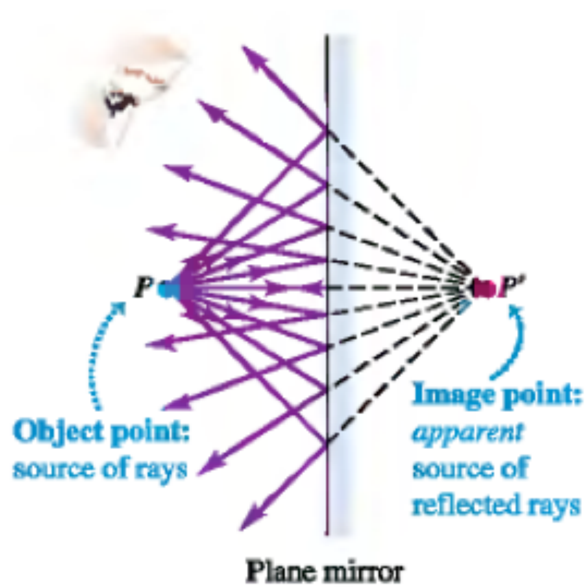



*Figure 2. The image is located at P, as if the reflected rays are all coming out of that point. (Images are taken from Pople, S. (1993)*

**2. Reflection at spherical surfaces**

State in brief that Snell's Law still holds on spherical surfaces. Assume a paraxial approximation.

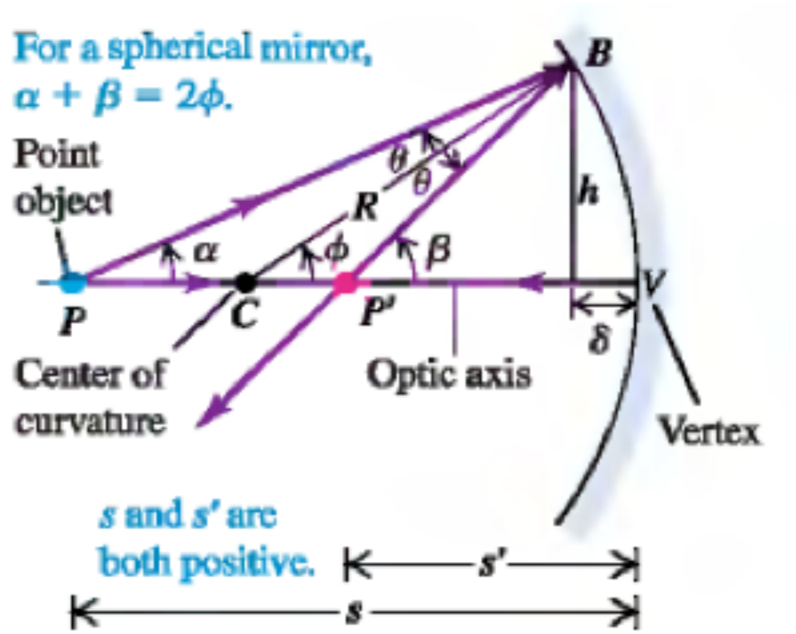



*Figure 3. Images taken from* Pople, S. *(1993)*

**3. Image formation for mirrors (ray tracing and computation)**

Discuss the details of image formation via ray-tracing in this section.

a. <u>Plane mirrors</u>

- Demonstrate the formation of an image of a point object by showing or drawing Figure 4 while discussing it.

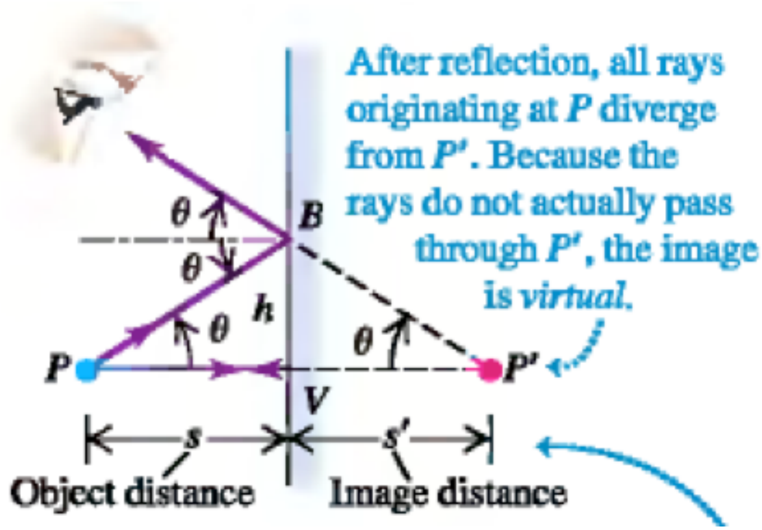



*Figure 4. Refer to the label in blue font for discussion.*

- Demonstrate image formation of an extended object by tracing the incident and reflected rays in Figure 5. Go over the symbols one item at a time.

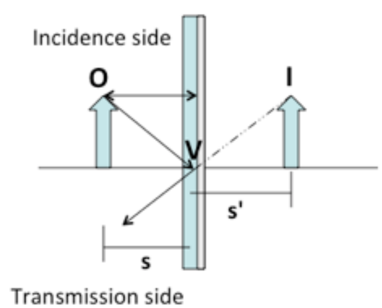



*Figure 5. Image formation of an extended object*

Symbols and sign conventions

- O - Object
- I - image
- V - vertex of the mirror
- s - object's distance from vertex

  +lsl - if object is at the incident side

  -lsl - if object is at the transmission side
- s' - image's distance from vertex

  +lsl' - image at the outgoing side

  -lsl - image at the incident side
- y - object's height
- y' - image's height

- Discuss the relation of the sign convention of the object and the formed image, in Figure 5, using the following table:

| | **Incident Side** | **Transmission Side** |
|---|---|---|
| **Object** | Real, +s | Virtual, -s |
| **Image** | Virtual, -s' | Real, +s |

- Explain how to describe the properties of the image using the following parameters:
  - s' = -s (image location from the vertex)
  - $m = \frac{y'}{y} = \frac{-s'}{s}$ (lateral magnification of the image) ;

- Enumerate how to describe the image formed following the conventions specified above:
  - Real/virtual (see the table above)
  - Upright/inverted (+m or -m)
  - Diminished/Magnified (m>1 or m<1)

- For plane mirrors, the image is always virtual, upright, left-right reversed, with m=1.

b. <u>The number of images formed by two plane mirrors separated at an angle θ. (*optional)</u>

Number of images = 360/θ – 1

Example 1. How many images of a candle placed between two plane mirrors that are separated by and angle θ=60 may be found? (*Answer: 5*)

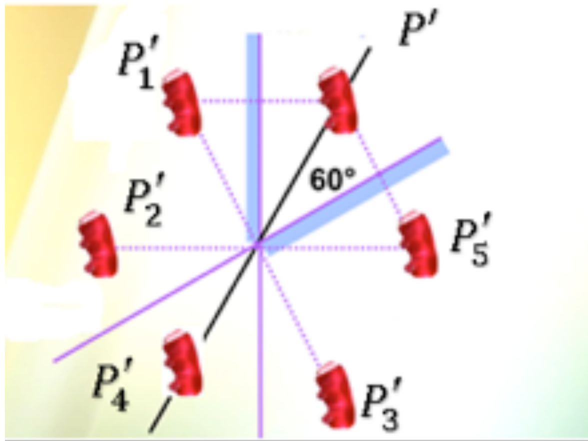



*Figure 6. P'$_1$, P'$_2$, … P'$_5$ are all virtual images. P' is a real image*

c. <u>Spherical mirrors</u>

Show Figure 7 and go over the symbols one at a time. Slowly discuss the sign conventions for R.

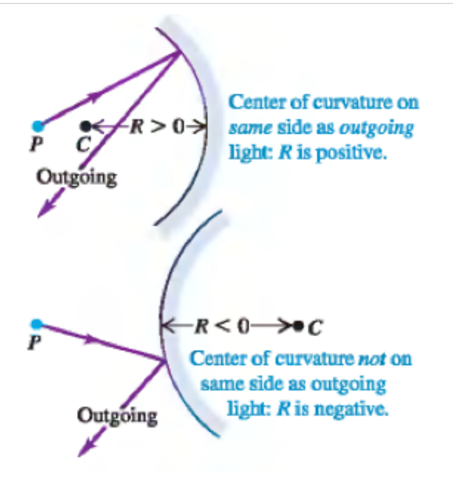



*Figure 7. Image taken from ref. 1*

Additional symbols and sign conventions

- C - center of curvature
- R - radius of curvature
- V - vertex of the mirror
- f - focal length, the distance of the point of convergence of reflected rays from V

Types of spherical mirrors:

1. Concave - C at the same side as outgoing light, +|R|(+|R| or R>0)
2. Convex mirror - C at the opposite side of outgoing light, -|R| (-|R| or R<0)

**Teacher Tip:**

- If the situation in Example 2 is reversed, i.e., the object is located at f, then the image will be seen at infinity. This may be demonstrated using a spoon. As the spoon is brought closer to your eyes, the image will disappear once the face is located at the focal point of the spoon's curved surface.
- If a convex mirror is used, R will be negative.

Give the equation for object-image relation, f-R relation, and the lateral magnification of the image formed:

$$\frac{1}{s} + \frac{1}{s'} = \frac{2}{R}$$

$$f = \frac{2}{R} \qquad f = \frac{R}{2}$$

$$m = \frac{y}{y'} = \frac{-s}{s'}$$

$$m = \frac{y'}{y} = \frac{-s'}{s}$$

Example 2. Consider an object that is placed far from a concave mirror. Locate the image formed.

Solution:

Concave mirror: +R

For an object located at a very far distance (s=∞)

$$\frac{1}{\infty} + \frac{1}{s'} = \frac{2}{+R}$$

$$s' = \frac{+R}{2}$$

The image is located at the focal point of the concave mirror.

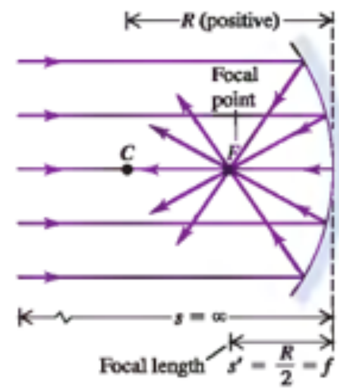



*Figure 8. Image taken form ref 1.*

**4. Ray-tracing for spherical mirrors (for extended objects)**

The image formed by a spherical mirror is located at the intersection of the following rays:

a. A ray parallel to the axis reflects through focal point, f.

b. A ray through f reflects parallel to axis.

c. A ray through C, intersects the surface normally and reflects along its original path.

d. Ray through V, reflects symmetrically about the optic axis.

* In case there is no intersection at the side of the outgoing ray, extend the ray towards the back of the mirror (refer to Figure 9 for the convex mirror).

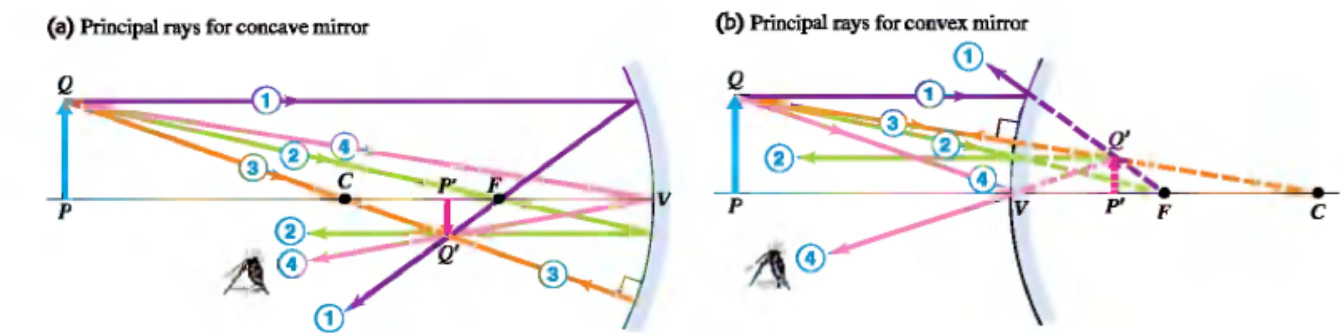



*Figure 9. Image taken from ref 1.*

## EVALUATION (10 MINS)

Give two ray-tracing problems for spherical mirrors while varying the location of the object. Ask the learners to describe the image formed based on the parameters described in Section 3-a.

**Teacher Tip:**
Demonstrate using a spoon that the image formed by a convex mirror is always reduced, upright, and virtual.

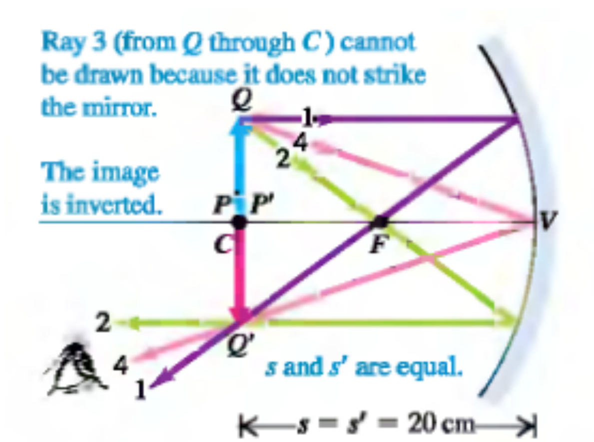



*Figure 9. Image taken form ref 1.*

120 MINS

# Refraction at Plane and Spherical Surfaces, Thin Lenses, and Image Formation

**Content Standards**
The learners demonstrate an understanding of refraction at plane and spherical surfaces, thin lenses, and image formation.

**Performance Standards**
The learners are able to use theoretical and experimental approaches to solve multi-concept and rich-context problems involving geometric optics.

**Learning Competencies**
The learners are able to:

1. Apply Snell's Law; **(STEM_GP12OPT-IVb-15)**
2. Relate properties of lenses (radii of curvature, focal length, index of refraction) to image and object distance and sizes; **(STEM_GP12OPT-IVd-23)**
3. Determine graphically and mathematically the type (virtual/real), magnification, location/apparent depth, and orientation of image of a point and extended object produced by a flat and spherical surface or interface separating two optical media; **(STEM_GP12OPT-IVd-25)**
4. Differentiate a converging lens from a diverging lens; **(STEM_GP12OPT-IVd-26)** and
5. Determine graphically and mathematically the type (virtual/real), magnification, location, and orientation of image of a point and extended object produced by a lens or series of lenses. **(STEM_GP12OPT-IVd-27)**

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction** | Review of Snell's Law and index of refraction | 5 |
| **Instruction** | Refraction at plane and spherical surfaces, thin lenses, and image formation | 90 |
| **Evaluation** | Quiz on thin lens | 25 |
| **Enrichment** | Homework | 10 |
| **Materials** | Slides | |

**Resources**

(1) Young, H.D., Freedman, R. A., & Ford. A. L. (2011). *University Physics* (12th ed.). Boston: Addison Wesley.

## INTRODUCTION (5 MINS)

1. Recall Snell's Law and the definition of index of refraction.

$$n_a \sin\theta_1 = n_b \sin\theta_2 \qquad \text{and} \qquad n = c/v$$

2. Show a picture of a fish in a shallow pond and ask the learners where to aim in order to catch the fish by hand. Slightly above the fish or slightly below the fish?

*Figure 1. Refraction from a pond.*

## INSTRUCTION

1. Discuss refraction at plane surfaces via ray-tracing method. Discuss the symbols and conventions in refraction.

   **P** – object's location

   **P'** – image's location

   **s** – object's distance from the surface

   **s'** – image's distance from the surface

**$n_a$** – index of refraction of the incident side, where the object is located

**$n_b$** – index of refraction of the side of the image

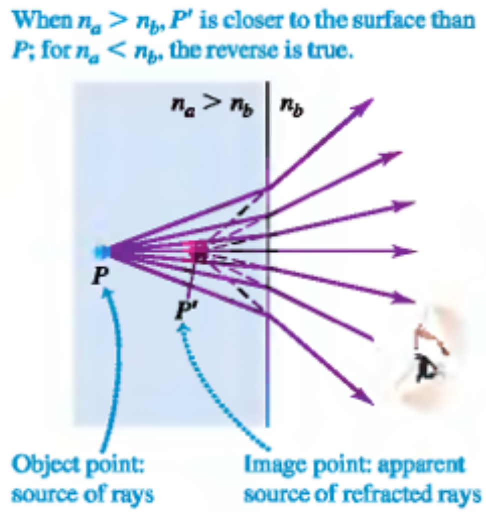



*Figure 2. Refraction of point objects on a plane surface.*

Using Figure 2, discuss *apparent depth* (P') of an object's image, which appears closer to the surface (P') than the object's location when $n_a > n_b$. Relate this to pools that look shallow but in fact are deep. The pool floor appears closer to the surface than its actual depth.

**2. Image formation for lenses via ray-tracing method and computation.**

a. Plane surfaces

   i. Discuss that Snell's Law govern refraction through plane surfaces.

   ii. Show Figure 3 and go over the symbols one item at a time.

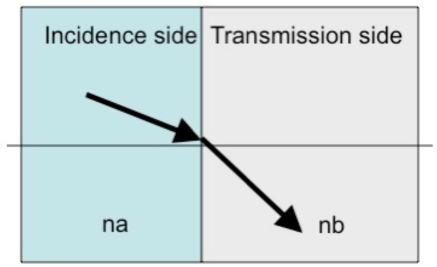



*Figure 3. Refraction at a plane surface*

Symbols and sign conventions

- O - Object
- I - image
- V - vertex of the mirror
- s - object's distance from vertex
  +lsl - if object is at the incident side
  -lsl - if object is at the transmission side
- s' - image's distance from vertex
  +lsl' - image at the outgoing side
  -lsl - image at the incident side
- y - object's height
- y' - image's height

b. Spherical surfaces

i. Show Figure 4 in the following table and slowly discuss the sign conventions for R and f.

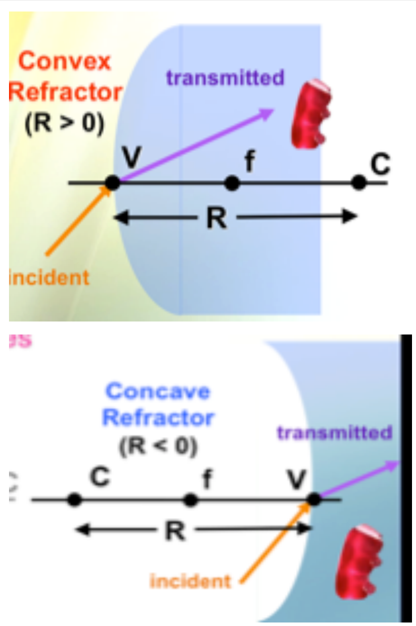



*Figure 7. Image taken from ref. 1*

Additional symbols and sign conventions

- C - center of curvature
- R - radius of curvature
- V - vertex of the mirror
- f - focal length, the distance of the point of convergence of reflected rays from V

Types of spherical surfaces:

1. Convex surface - C at the transmissions side, +lRl, +lfl
2. Concave surface - C at the incident side, -lRl, -lfl

ii. Discuss the relation of the sign convention of the object and the image formed using the following table.

| | **Incident Side** | **Transmission Side** |
|---|---|---|
| **Object** | Real, +\|s\| | Virtual, -\|s\| |
| **Image** | Virtual, -s' | Real, +\|s'\| |
| **C, R** | -\|R\| | +\|R\| |
| **f** | -\|f\| | +\|f\| |

iii. The object-image relation, lateral magnification, and the focal length are given by the following equations:

$$\frac{n_a}{s} + \frac{n_b}{s'} = \frac{n_b - n_a}{R}$$

$$m = \frac{y'}{y} = -\frac{n_a s'}{n_b s}$$

$$f = R/2$$

iv. Introduce how to describe the image formed following the conventions specified above:

- Real/virtual (see the table above)
- Upright/inverted (m>0 orm<0)
- Diminished/Magnified (m>1 or m<1)

**Teacher Tip:**

- For plane surfaces, $R=\infty$.
- Emphasize that the sign of R depends if C is at the transmission side.
- If the locations of object and image are interchanged, the image will be located at the previous location of the object.

Example 1.

What is the apparent depth of an object at the bottom of a 1m deep pool?

$n_{water} = 1.2$, $n_{air}=1.0$

*Solution:*

Locate where the incident side is. It is located inside the pool since the object is in it.

So $n_a = n_{water}$ and $n_b = n_{air}$. For plane surfaces: $R=\infty$

$$\frac{n_a}{s} + \frac{n_b}{s'} = \frac{n_b - n_a}{R = \infty}$$

$$s' = \frac{n_b s}{n_a} = -\frac{5}{6}\,m$$

$$m = -\frac{n_{inc} s'}{n_{trans} s} = \frac{(6/5)(-5/6)}{(1)(+1)} = +1$$

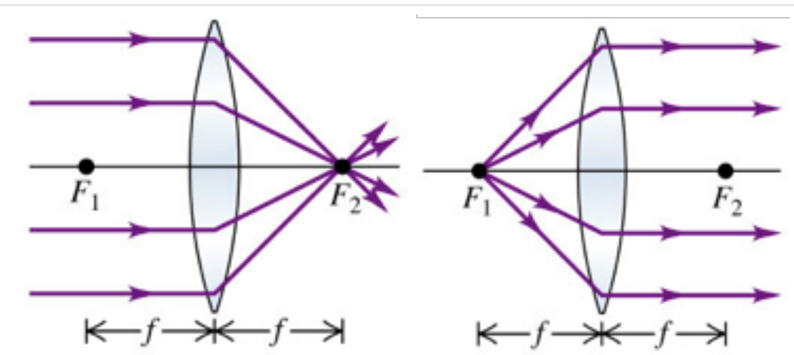
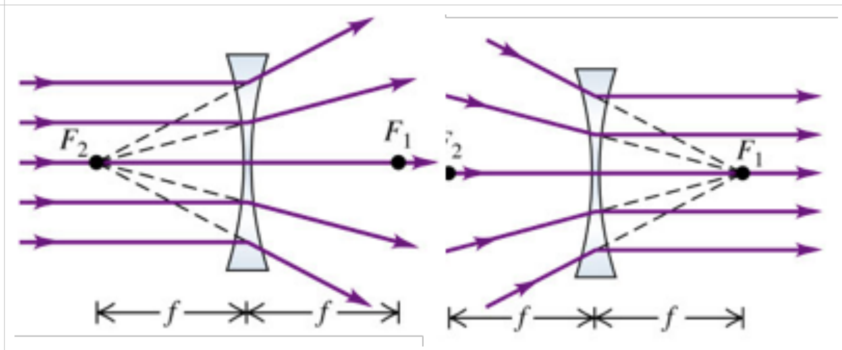
The image formed is **virtual, same size, upright, appears closer to the surface.**

### 3. Thin Lens

i. Define what a thin lens is, noting the two equal foci of the lens at the transmission and incidence side.

ii. Discuss the two types of thin lenses following the table below.

iii. Discuss refraction through thin lenses using ray-tracing method following Figures 5 and 6. That is, rays parallel to the axis will get refracted passing through f, and rays passing through f will get refracted parallel to the axis.

| Converging lens (positive lens) | Diverging lens (negative lens) |
| --- | --- |
|  |  |
| *Figure 5. Refraction of rays through convex lens* | *Figure 6. Refraction of rays through concave lens* |

iv. Discuss the object-image relation in Figure 7, given by the following equations:

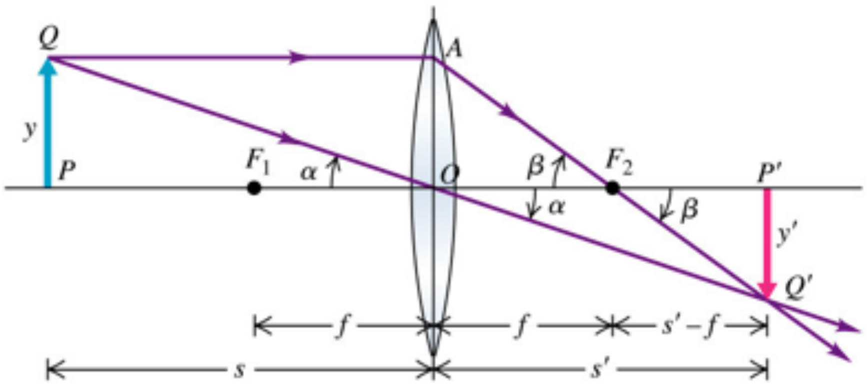



*Figure 7. Image taken from reference I.*

$$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}$$

$$m = -\frac{s'}{s}$$

<u>Example 2.</u>

A **real** object is located 2.0 m away from the lens that produces an image at infinity. What is the focal length of the lens and what type of lens is it? Report values up to one-decimal point.

**Teacher Tip:**
Objects at f will always produce images at infinity

Solution:

$$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}$$

$$\frac{1}{+2m} + \frac{1}{\infty} = \frac{1}{f}$$

$$f = 2m$$

The focal length of the lens is 2m, which coincides with the location of the object. Since f is positive, the lens is a **convex lens**.

**4. Lensmaker equation**

The image formed by a spherical mirror is located at the intersection of the following rays:

a. Discuss the lensmaker equation.

The equation used to design a lens with a particular focal length is given by:

$$\frac{1}{f} = \left(\frac{n_{lens}}{n_a} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

where $n_a$ is the medium where the lens is immersed, $R_1$ and $R_2$ are the radii of curvature of the first and second surface of the lens reached by the incident light, respectively.

b. Show the following types of general shape of the lens, taking note that the radii of curvature of each side may not be equal with each other unlike for the case of thin lenses. Again, $R=\infty$ for plane surfaces.

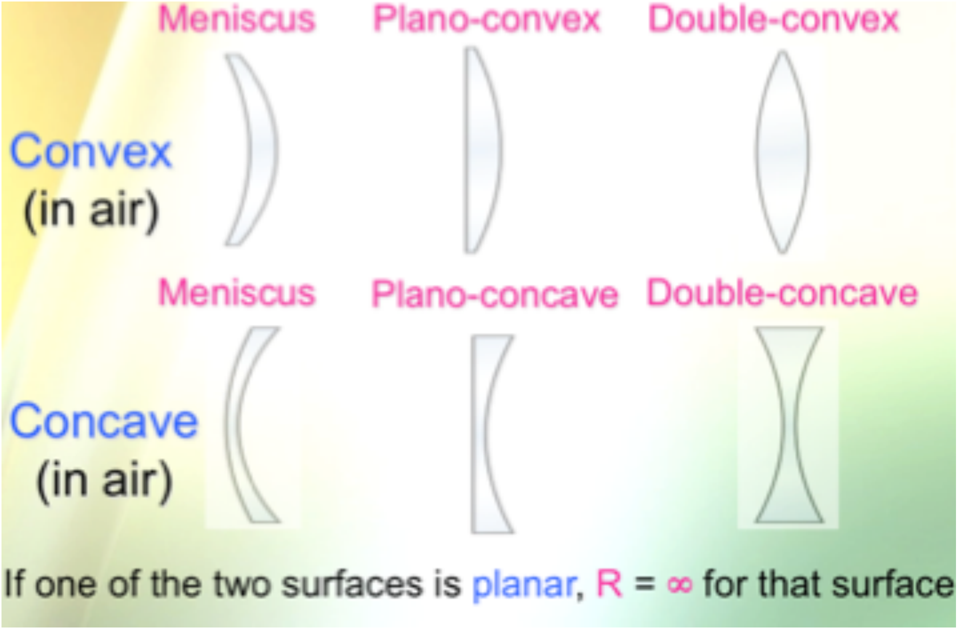



*Figure 8. Other lenses with general shapes*

**5. Ray-tracingand graphical methods for thin lenses**

a. Discuss the ray-tracing method of locating the image formed by a thin lens. Use Figure 7 as the rays enumerated below have a direct correspondence with it.

The image formed by a thin lens is located at the intersection of the following rays:

i. A ray parallel to the axis passes through the second focal point, f2.

ii. A ray through O, does not get refracted appreciably.

iii. A ray through F1 refracts parallel to axis.

*Note: In case there is no intersection at the side of the outgoing ray, extend the ray towards the back of the lens.*

b. Demonstrate ray-tracing method by locating the image for thin lenses using the images in Figure 9.

c. Take time to demonstrate other cases for each lenses, including series of thin lenses.

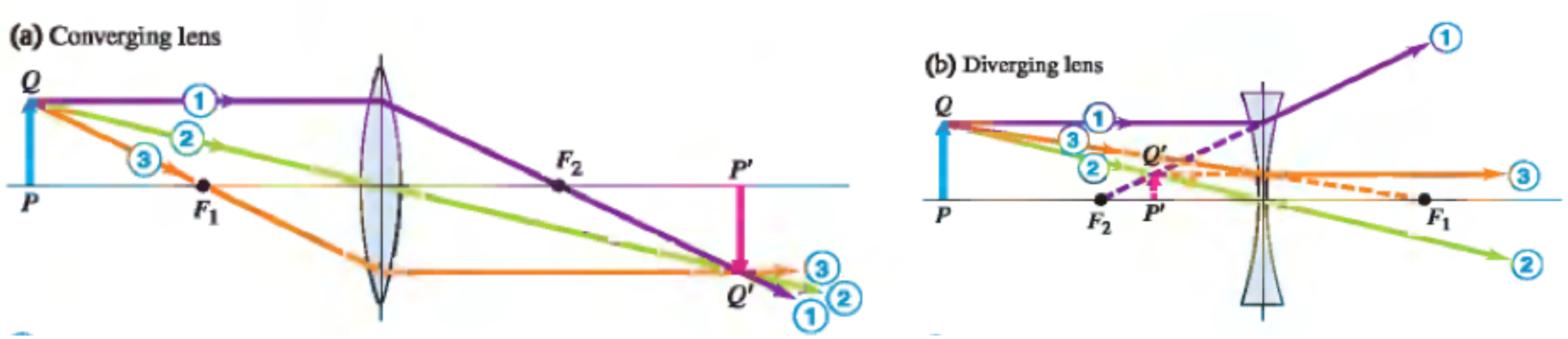



*Figure 9. Image taken from ref 1.*

## EVALUATION (25 MINS)

1. Consider a thin lens on air as shown in Figure 10 ($n_{lens}$=2). If the curved side has a radius of 4cm, what is its focal length?

2. If the lens is placed in jelly medium ($n_{jelly}$=4), what will be its new focal length?

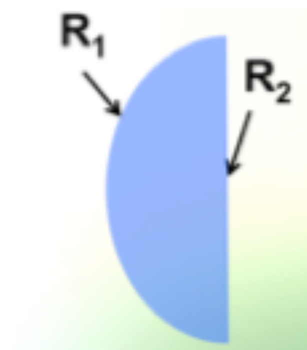



*Figure 10.*

*Solution:*

$$\frac{1}{f} = \left(\frac{n_{lens}}{n_a} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

- in air, f=+4cm (convex lens)
- in jelly medium, f=-8m (concave lens)

## ENRICHMENT (HOMEWORK)

1. Let the learners locate the image formed using a series of concave and/or convex lenses while varying the location of the object using the ray-tracing method in Section 5.

2. Using a graphing paper, use the ray-tracing method. Then show that if a (real/virtual) object is placed at one of the focal points of a thin lens, the image is located at infinity.

60 MINS

# Context-Rich Problems Involving Electric Charge, Coulomb's Law, Electric Fields, Electric Flux, Gauss's Law

**Content Standards**
The learners demonstrate an understanding of Applications of reflection, refraction, dispersion, and polarization

**Performance Standards**
The learners are able to:
1. Use theoretical and, when feasible, experimental approaches to solve multiconcept, rich-context problems using concepts from electromagnetic waves, optics, relativity, and atomic and nuclear theory
2. Apply ideas from atomic and nuclear physics in contexts such as, but not limited to, radiation shielding and inferring the composition of stars

**Learning Competencies**
Solve problems involving reflection, refraction, dispersion, and polarization in contexts such as, but not limited to, (polarizing) sunglasses, atmospheric haloes, and rainbows (**STEM-GP12EM_IVc-21**)

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction/ Motivation** | Rationale and characteristics of context-rich problem solving | |
| **Logistics and Instructions for Teachers** | Grouping, assignment, grading system | 30 |
| **Context Rich Problems** | 10 examples | |
| **Materials** | Writing materials, other materials to be determined by the students depending on the problem | |

**Resources**


(1) P. Heller and K. Heller. Cooperative Group Problem Solving in Physics. (University of Minnesota, 1999).
(2) G. Pólya, How to Solve It, (Doubleday, New York, 1957).
(3) R.D. Knight, Physics for Scientists and Engineers: A Strategic Approach with Modern Physics and Mastering Physics, 2nd Ed. (Benjamin Cummings, 2007).
(4) R.W. Chabay, B.A. Sherwood. Matter and Interaction II: Electric and Magnetic Interactions, 3rd Ed. (J. Wiley & Sons, Inc. 2010).
(5) H.D. Young, R.A. Freedman, A.L. Ford, University Physics, 11th Ed. (Addison-Wesley, 2011).
(6) Paul Hewitt, Conceptual Physics, 11th Ed. Addison-Wesley, 2009).
(7) D. Halliday, R. Resnick, J. Walker. Fundamentals of Physics Extended, 10th Ed. (J. Wiley & Sons, Inc., 2013).

## INTRODUCTION

Solving context rich problems provide students the opportunities to practice implementing the physics concepts and techniques in realistic scenarios. This learning experience is consistent with the fact that **reflection, refraction, dispersion, polarization**, and other related concepts relevant to many aspects of our daily lives.

The context rich problems are designed such that the students are part of the story and are often required to interact with other people in preparing and reporting their solutions. Unlike in the typical end-of-chapter problems, students usually need to refine the definition of the problems, specify the unknowns, design their own problem-solving strategy, use several concepts, make assumptions, recall or invoke prior knowledge or "common-sense", supply additional information, perform experiments, and interact with experts and non-experts.

## LOGISTICS AND INSTRUCTIONS FOR TEACHERS (30 MINS)

1. Discuss the rationale of solving context-rich problems in physics as articulated in the Introduction.

2. Discuss the steps or framework for problem-solving and specify the template or distribute the problem-solving sheet.

3. Discuss the grading system for this particular activity. The recommended system is to grade each step, either in equal weights in the scale of 1 to 5 (or 1 to 10) or in unequal weights, usually giving more premium to analysis than to the final answer. Allocating portions for peer- and self-evaluation in the final grade is also recommended.

4. Group the students (the recommended number is three to five students per group) and arrange their seats (the arrangement should be conducive for long discussions). Due effort should be exerted to achieve heterogeneous distribution of students in terms of gender and class-performance. Encourage the students to device a system that would allow every member of the group to contribute to the discussion for every step and to rotate the roles among themselves, especially the role of secretary or scribe.

**Teacher Tip:**

You may adopt the problem solving sheet designed by Kenneth Heller and Patricia M. Heller of University of Minnesota (see Chapter 2 of their book “Cooperative Group Problem Solving in Physics,” which is publicly available). The steps they advocate, which is consistent or similar with those of the famous mathematician G. Polya, are as follows: focus on the problem; describe the physics; plan a solution; execute the plan; and evaluate the solution. They also have discussions and recommendation for the grading system, role assignment, and student distribution.]

5. Arrange the schedule for problem solving and reporting to class. It is recommended that each group should solve at least one problem for each topic in this chapter.

6. Let the students spend the remaining class time to start solving the problems. Then they will have to solve the rest after the class and submit their final output later, e.g., after one week.

7. If there is opportunity, group reporting of output in front of the class is recommended because it will allow students be familiar with problems that they are not assigned to solve.

## CONTEXT-RICH PROBLEMS

The following are examples of context-rich problems. The major concept(s) being considered is indicated after the problem. You may design more problems considering the characteristics of context-rich problems described above.

1. You discovered a strange material such that when it is made into a triangular prism, the general order of the rainbow it produces is BIVGROY, instead of ROYGBIV. Describe or sketch the general shape of its dispersion curve (index of refraction versus wavelength). You may use seven Snell's Law equations (one for each representative color) to justify your dispersion curve. (dispersion, visible spectrum)

2. You are in a open bazaar. A vendor tries to sell to you a pair of polarizing sun glasses. Describe an experiment that you can quickly perform to verify the claim of the vendor. (transverse versus longitudinal wave, Malus' Law, Brewster's angle)

3. You work in a research department of a advertising regulatory agency. A businessman proposes to advertise "polarizing sound ear muffler". It is supposed to work like a polarizing sun glasses, except that instead of sun light, it filters sound. Write a report explaining why you recommend approval or disapproval of the said advertisement. (transverse versus longitudinal wave)

4. You are an engineer in charge of maintaining the communication of an island resort. One day, sharks gnawed at the cladding and bent the fiber optic cables. Explain and illustrate to the resort manager that, while waiting for replacements, communication signals could still be made to pass through by simply straightening the damaged cables. (total internal reflection)

5. On summer vacations, you work as a tour guide in a coral reef reservation. You observed that the common questions (or comments) of boat-riding visitors: "Some coral reefs seem so near that I thought I could reach them with my out-stretched arms. Why can't I reach them? How deep are they actually?" So you measured the depths of the various parts of the reservation and prepared a mobile phone software application ("app") that computes and tells the (frustrated) visitors ratio between their out-stretched arms and the actual depth of the coral bed. Present the flowchart and equations (derived from optics concepts) that you will implement in your "app". (index of refraction, refracting surface)

6. You work in a landscape architectural firm. Your task is to design a clubhouse and fountain such that those using the clubhouse will see a rainbow in the afternoon. Your presentation should include an illustration of how water droplets form a rainbow. (refraction, dispersion, total internal reflection)

7. You are part of the technical panel evaluating proposals sent to the DPWH to solve recurring vehicular accidents in a slightly bent portion of an expressway during hot afternoons. The accidents usually involve car slowing down and getting rear-ended by the car behind them. The usual excuse of the drivers of the car in front is that they thought they are approaching a wet part of the expressway (which is actually dry). Your committee received three proposals: 1) plant trees in strategic locations to cast shadow on the said portion of the expressway; 2) replace the road paving with materials that cools faster; and 3) put up signs that say "Road ahead is DRY". Write a report to the DPWH secretary explaining the phenomenon behind the accidents and the scientific and economic merits of the three proposals. (mirage, refraction)

8. You are the mayor of a city. Your constituents are anxious because, lately, the sky in the afternoon is more reddish than usual. They want you to explain and, if possible, act to minimize the phenomenon. You have access to information such as maps of highways, residential, industrial complexes, forest, and geological structures in your region. Furthermore, next month, you will attend an international conference on climate, weather and pollution along with the mayors of your neighbor cities and countries. (Rayleigh scattering, atmosphere)

9. You are the manager of a clothing store. Recommend the size of the mirrors to install such that the customers will be able to see their full body in the changing room. (mirrors, ray tracing)

10. Write a short semi-technical essay for a hiker's survival guide on the possible use of atmospheric haloes for weather forecasting. (dispersion, visible spectrum)

120 MINS

# Image Formation Experiments

**Content Standards**
The learners demonstrate an understanding of image formation.

**Performance Standards**
The learners are able to use theoretical and experimental approaches to solve multi-concept and rich-context problems involving geometric optics.

**Learning Competencies**
The learners:

1. Determine graphically and mathematically the type (virtual/real), magnification, location, and orientation of image of a point and extended object produced by a series of lenses; **(STEM_GP12OPT-IVd-27 and STEM GP12-OPT-11D-24)**
2. Apply the principles of geometric optics to discuss image formation by the eye, and correction of common vision defects; **(STEM_GP12-IVd-28)** and
3. Apply object-image relations for mirrors and lenses to create a telescope.

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction** | Review of the Lens maker equation and discussion of optic tools | 10 |
| **Instruction** | Discussion on ray-tracing method and hands-on experiment of telescopes | 90 |
| **Evaluation** | Distance computation and description related to a telescope | 20 |
| **Enrichment** | Question to ponder | |

**Materials**

- Slides
- 2 Magnifying glasses with different focal lengths (convex lens)
- Cardboard tube or cartolina
- Tape

**Resources**

Young, H. D., Freedman, R. A., & Ford. A. L. (2011). *University Physics* (12th ed.). Boston: Addison Wesley.

## INTRODUCTION (10 MINS)

1. Recall the Lens maker equation and the object-image relations for mirror and thin lens.

2. Discuss that most eye defects, if not all, can now be corrected by using optical tools such as eyeglasses, contact lenses, and various surgical procedures.

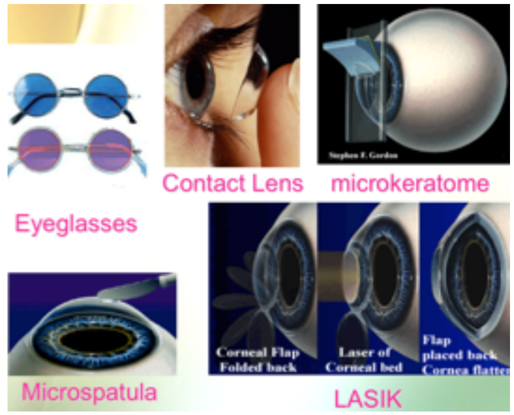
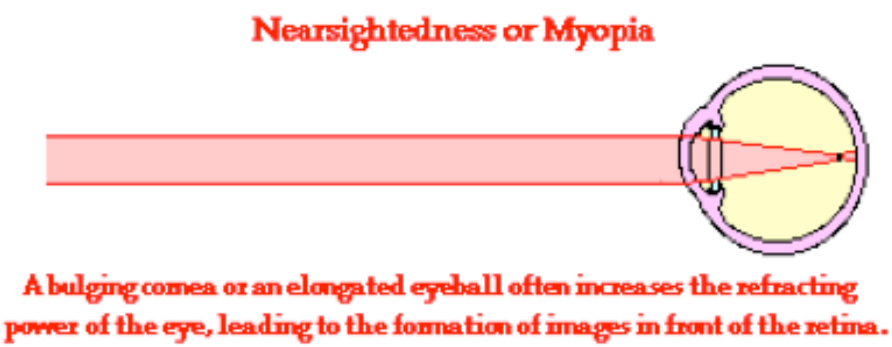


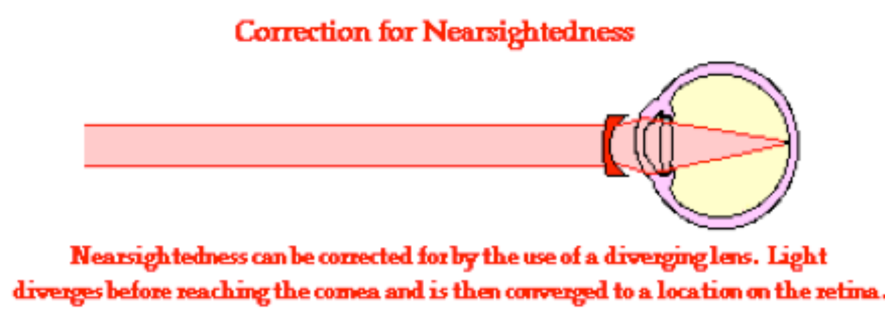

*Figure 1. Optical tools.*

3. Present pictures or visual aids that illustrate the visions of people who have common eye defects, such as in Figure 2


*Figure 2. Visions of people with common eye defects.*

4. Explain the eye's image formation for people with common eye defects presented in Figure 2 and discuss the kinds of lenses that are used in order to correct them.



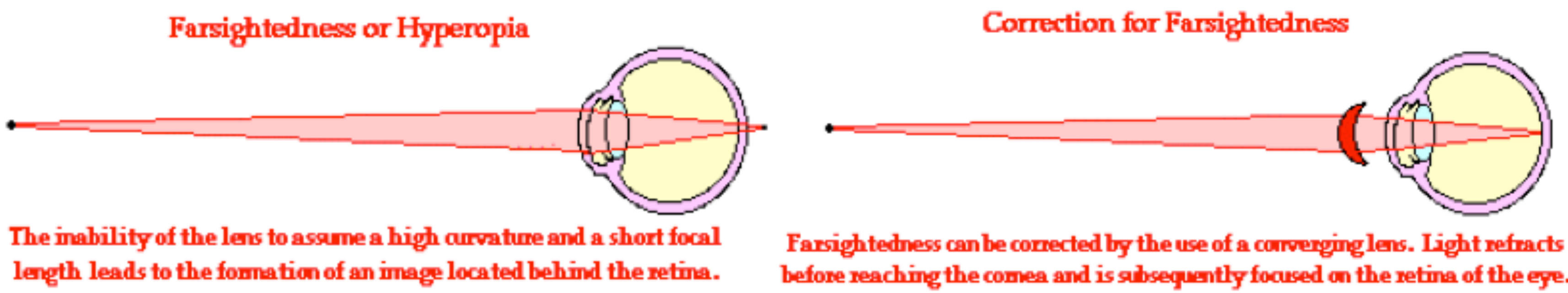



*Figure 3. Lenses used to correct common eye defects.*

## INSTRUCTION (30 MINS)

1. Recall the ray-tracing method in thin lens, specifically for convex lens. Discuss ray-tracing method for a combination of two convex lenses and relate its ability to magnify objects to its practical applications to telescopes and microscopes.

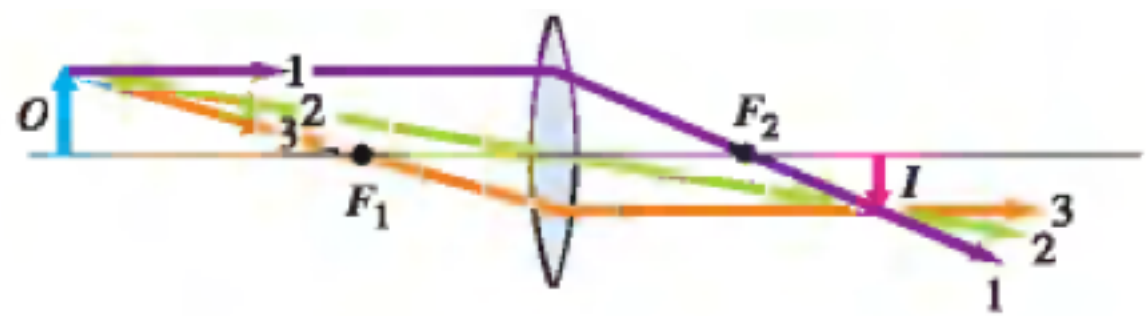



*Figure 4. Ray-tracing method for one convex lens.*

Demonstrate that for a combination of two convex lenses, the ray-tracing method is applied consecutively to each of the lenses starting from the lens closer to the object. The image of the first lens becomes the object for the second lens.

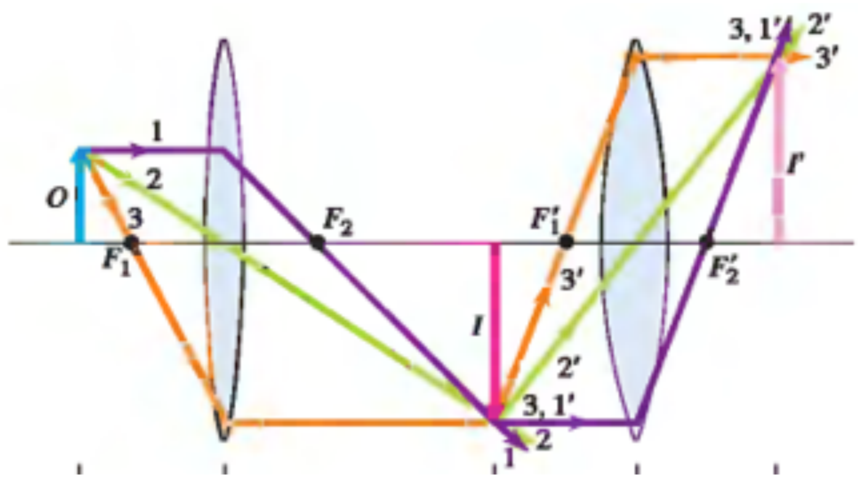



*Figure 5.*

*Note: the (angular) magnification for Figure 5 is now modified to:*

$$m = -\frac{f_1}{f_2}$$

*where $f_1$ is the focal length of the magnifying glass with a larger focal length and $f_2$ is the focal length of the eyepiece.*

2. Now the learners shall build their telescopes.

   Instruct the learners to follow the instructions in building telescopes as shown in Figure 6.

   a. Determine the focal lengths of the magnifying glasses if they are not specified.

      i. Place the magnifying glass under a light source and a viewing screen.

      ii. Adjust the magnifying glass until you see a focused light on the viewing screen.

   b. Roll up the cardboard or a cartolina into a tube. Make two tubes make sure that one of it can be inserted to the other.

   c. Tape each of the magnifying glasses into one end of each tube and join the tubes together by inserting the smaller tube to the larger tube through their open ends.

   d. The lens with shorter focal length will serve as the eyepiece.

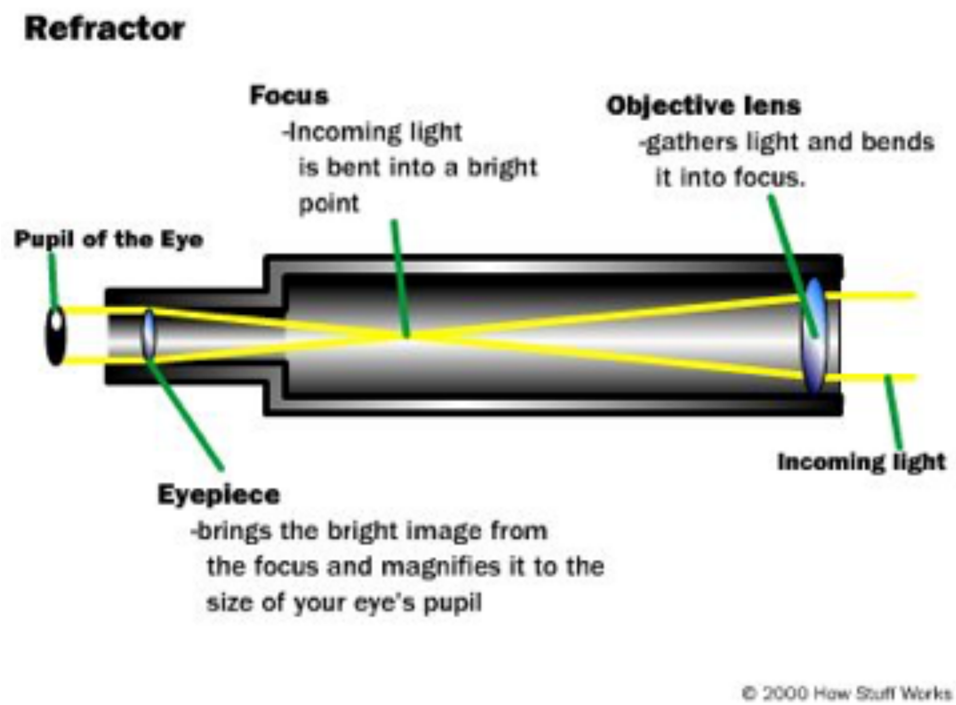



*Figure 6. A handmade telescope.*

e. Look through the handmade telescope and adjust the separation distance between the two tubes until you see a focused image of the object.
f. After getting a focused image, get the separation distance between the two lenses.
g. Compute the magnification of your telescope.
h. After computing the distance of the image formed after the first lens, the separation distance between the two lenses, the magnification of the telescope, and all other important experimental values, compute for the size of the object.

## EVALUATION (20 MINS)

1. Using the ray-tracing method and the object-image relations discussed in the previous chapter, compute the distance of the first image produced by the first lens from the first lens and describe the image formed.

2. Using the same procedure in 2-g, compute the distance of the object for the second lens (eyepiece). Describe the object for the eyepiece.

## ENRICHMENT

If the first lens is replaced with a pinhole, is it possible to see an image in your handmade telescope?

60 MINS

# Reflection, Refraction, Dispersion, and Polarization

**Content Standards**
The learners demonstrate an understanding of reflection, refraction, dispersion, and polarization.

**Performance Standards**
The learners are able to use theoretical and experimental approaches to solve multi-concept and rich-context problems involving geometric optics.

**Learning Competencies**
The learners solve problems in geometric optics in contexts such as, but not limited to, depth perception, microscopes, telescopes, and the correction of vision defects. **(STEM_GP12OPT-IVe-29)**

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction** | Overview of the essence of solving context-rich problems | 5 |
| **Instruction** | Discussion and solving of context-rich problems | 55 |
| **Materials** | Writing materials, other materials to be determined by the students depending on the problem | |

**Resources**

(1) Heller, P., and Heller, K., *Cooperative Group Problem Solving in Physics*. University of Minnesota.
(2) Pólya, G. *How to Solve It*. New York: Doubleday.
(3) Young, H.D., Freedman, R.A., & Ford, A.L., *University Physics* (11th Ed). Boston: Addison-Wesley.

## INTRODUCTION (5 MINS)

Solving context-rich problems provide learners opportunity to apply concepts and procedures in realistic scenarios. This learning experience is consistent with the fact that charge, electric field and forces, and other related concepts are descriptions of our world. In other words, physics is relevant to many aspects of our daily lives.

The context-rich problems are presented in a way that the learners are part of the story and are often required to interact with other people in making and reporting their solutions. The problems are different from the typical end-of-chapter problems where learners usually need to specify the unknowns, design a problem-solving strategy, use several concepts, make assumptions, recall or invoke prior knowledge or "common-sense", research additional information, perform experiment, and interact with experts and non-experts.

## INSTRUCTION (55 MINS)

1. Discuss the rationale of solving context-rich problems in physics as articulated in the Introduction.

2. Discuss the steps or framework for problem-solving and specify the template or distribute the problem-solving sheet.

3. Discuss the grading system for this particular activity. The recommended system is to grade each step, either in equal weights in the scale of 1 to 5 or 1 to 10 or unequal weights, usually giving premium to analysis than on the final answer. Inclusion of peer- and self-evaluation in the final grade is also recommended.

4. Group the learners with three to five members per group and arrange their seats in a way that is conducive for long discussions. Due effort should be exerted to achieve heterogeneous distribution in terms of gender and performance. Encourage the learners to device a system that would allow every member of the group to contribute to the discussion for every step and to rotate the roles

**Teacher Tip:**

You may adopt the problem-solving sheet designed by Kenneth Heller and Patricia M. Heller of University of Minnesota. See Chapter 2 of their book "Cooperative Group Problem Solving in Physics," which is publicly available. The steps advocated by Heller & Heller, which is consistent or similar with those of the famous mathematician G. Polya, are as follows: focus on the problem; describe the physics; plan a solution; execute the plan; and evaluate the solution. Heller & Heller has a discussion and recommendation for the grading system, role assignment, and student distribution.

among themselves, especially the role of secretary or scribe.

5. Arrange the schedule for problem solving and reporting to class. Each group should solve at least one problem for each topic in this chapter. Reporting to class will allow the learners to be familiar with problems that they are not assigned to solve.

## CONTEXT-RICH PROBLEMS

1. Assume that the surface of an astronaut's helmet is circular on the outside but flat on the inside and is made of light glass. Compare what an astronaut sees if he puts on the helmet while on earth, underwater (not in the deep sea), and in a different world with a very high index of refraction.

2. Why do we only see a flattened sun during sunrise or sunset? Give a possible reason why it appears flat. Propose the possible physical properties of a lens that mimics this flattening of an image so that a tall person seem to get shorter and a thin person seem to be a little fatter when seen through this type of lens.

3. Like an archerfish that is underwater, try shooting a fly from the ground. Describe how you should aim your spear from the water if you are aiming at an apple. If your spear was changed to a laser gun, how will your aim change?

4. If you have red, green, and blue light sources that shine parallel to each other at the same time, create a device that adds the color of these light sources to produce white light.

5. Given three lenses of different focal length, then provide a method that determines the focal lengths of the lenses.

6. An Oceanpark architect was asked to make the sharks in the huge aquarium look bigger than their real size. If the architect asks for some tips about geometric optics to you, what will be your proposal? Show your proof that it will work by either presenting your calculations or your ray-tracing diagrams.

60 MINS

# Interference and Diffraction: Double Slit Diffraction Experiment

**Content Standards**

The learners demonstrate an understanding of two-source interference of light.

**Performance Standards**

The learners are able to:

1. Use theoretical and, when feasible, experimental approaches to solve multiconcept, rich-context problems using concepts from electromagnetic waves, optics, relativity, and atomic and nuclear theory
2. Apply ideas from atomic and nuclear physics in contexts such as, but not limited to, radiation shielding and inferring the composition of stars

**Learning Competencies**

At the end of the session, the students should be able to :

1. Relate the geometry of the two slit experiment set-up (slit size, and screen to slit distance) and properties of light (wavelength) to the properties of the diffraction pattern (width, location of intensity of the fringes). (STEM_GP12OPT-Ivf-33)
2. Narrate the story behind Young's two slit experiments (wave versus particle) (STEM_GP12OPT-Ivf-31)

**Prerequisite Skills**

STEM_GP12MWS-Ie-34

## LESSON OUTLINE

| | |
|---|---|
| **Introduction** | Observation |
| **Instruction** | Discussion Proper |
| **Discussion** | Sample activity questions |
| **Individual Work** | Problem solving activity |
| **Enrichment** | More examples of double-slit experiment |
| **Materials** | |

**Resources**


(1) Arons, Teaching Introductory Physics

(2) Giancoli, Physics, 6th ed.

(3) Cummings et al Understanding Physics

(4) https://www.khanacademy.org/science/physics/light-waves/interference-of-light-waves/v/youngs-double-split-part-1

## INTRODUCTION

1. Using a ripple tank and a plane wave generator , demonstrate how water waves pass through the Young double slit. How does one perform an analogous experiment for light? This phenomenon is called double-slit diffraction.

2. Historically, the double slit experiment was one of the first experiments that led to the acceptance of the wave theory of light.

## INSTRUCTION

Each of these points should be made:

1. Most light sources are not coherent. To experimentally observe the wave behaviour, we must have a readily accessible source of coherent light. In contrast, it is relatively easy to produce coherent water waves.

2. Although lasers are coherent light sources, these were discovered only within the 21st century. Physicists built on previous experience with mechanical waves. When Maxwell first wrote his equations  for electromagnetism, he relied on a mechanical mental model. Physicists invented experiments to look for wave behaviour in light using mechanical waves (for example, sound and waves on a string and other flexible objects) as inspiration.

3. Although Huygens was a contemporary of Newton, his work only predicted the same things that Newton could predict using the corpuscular theory. Given Newton's authoritative work on mechanics, people of that time had to choose between two theories that could predict (at that time) the same things. People naturally chose Newton.

4. The wave theory of light gained prominence only when it could predict the same phenomena that Newton could predict, as well as phenomena beyond those predictable using the corpuscular theory. The first notable experiments were those of Thomas Young in the early 1800's.

5. The wavelengths of visible light are in the order of hundreds of nanometers. This means experimental detection of wave behaviour in light could only be achieved when (1) people had a method for producing coherent light for experiments, (2) slit widths of the same order of magnitude as light could be constructed, and (3) when physicists of sufficient imagination could propose experiments using coherent light and slits of the requisite width.

6. In this lesson, we focus on diffraction due to a double slit. (If the teacher desires, this lesson may be switched with single -slit diffraction.)

7. The diffracted light falling on a screen will have alternating bands of dark and bright regions called *fringes*. The location of the bright fringes on the screen can be obtained using the relation

$$d \sin(\theta) = m \lambda$$

where
d is the distance between the two slits,
$\theta$ is the angle between the line from the slit to the center of the screen and the line connecting the slit to the dark fringe,
and m is an integer.

The following figure is from Cummings et al, Understanding Physics Please redraw.

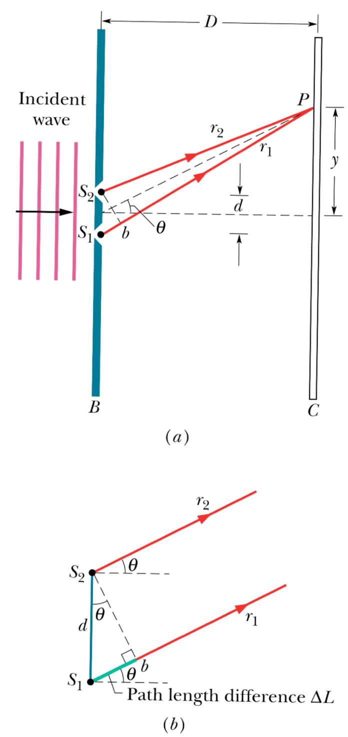



Figure GP12-46

8. The derivation hinges on two things:
   A. The far-screen condition is also important: $d/D << 1$. this guarantees that the right triangle in the lower part of Figure GP12-46 is a right triangle.
   B. comparing path differences of point sources from each  slit . For a dark fringe to occur, the path length difference must be an integer and a half wavelength (n+1/2) \lambda.

9. For a bright fringe to occur, the path length difference between must be an integer multiple of the wavelength. N \lambda

## DISCUSSION

Provide sample questions and demonstrate the solution. See Appendix A

## INDIVIDUAL WORK

1. Assign a short exercise for students to solve in class. See Appendix A
2. Check student work.

## EVALUATION

Ask students a multiple choice to check for understanding. See Appendix A.

## HOMEWORK

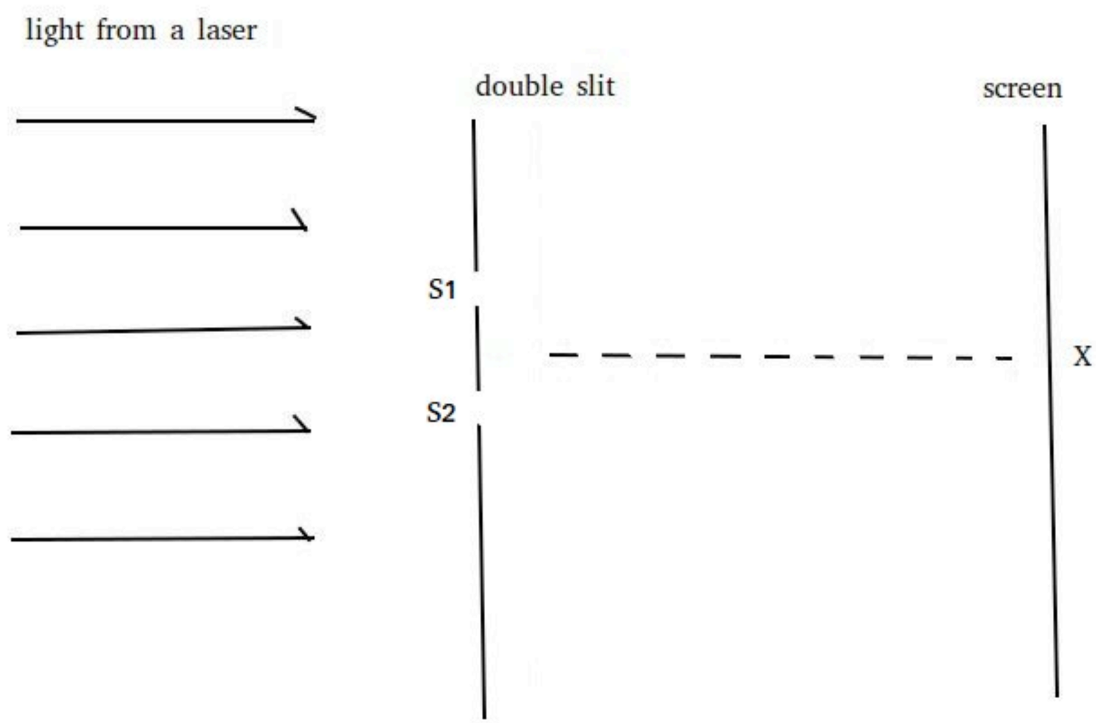
Ask students to solve a problem similar to the homework question in Appendix A.

## ENRICHMENT

Ask students to give another example of the double-slit experiment, this time involving particles/ waves other than light.

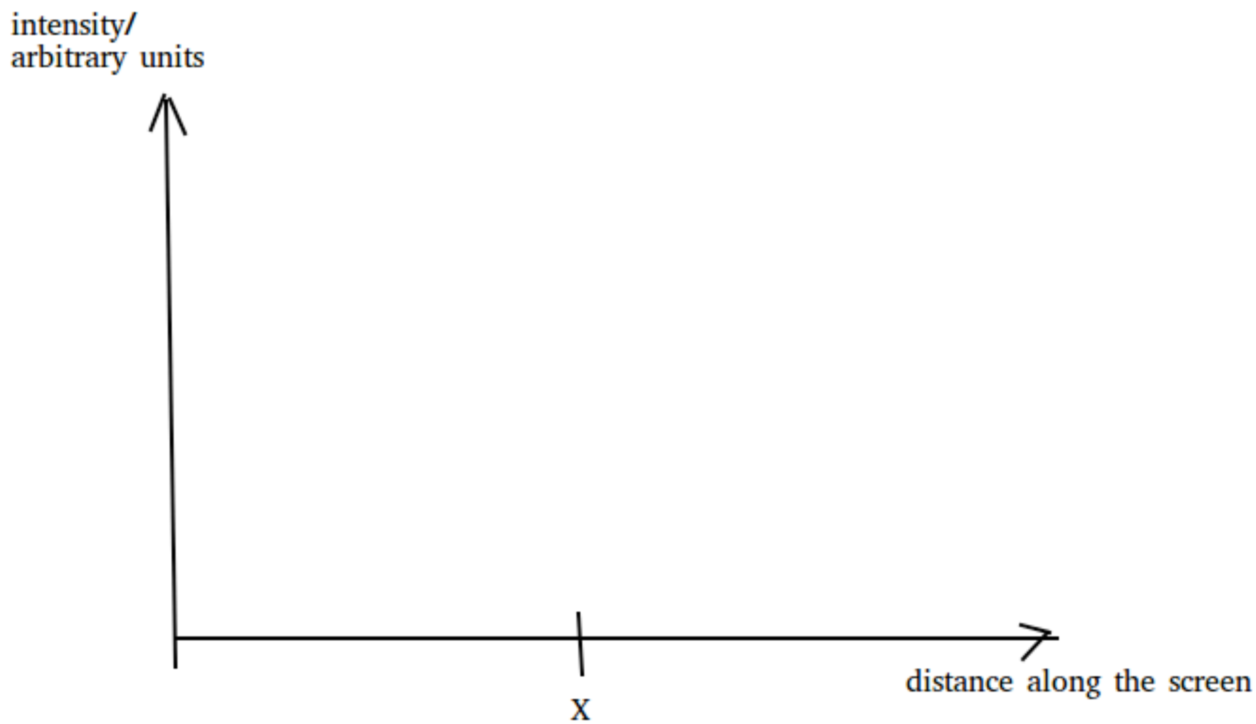
**Appendix A**

The  diagram below (not to scale) is an arrangement fpr observing the interference pattern produced on a screen when light has passed through narrow slits S1 and S2. A beam of light from a laser is incident on the screen. The width of the slit is w, and the distance of the slit from the screen is d. We assume that d/w << 1.




A. Explain why an interference pattern will not be observed on the screen if the laser is replaced with a tungsten filament lamp.

B. On the axes below, draw a sketch-graph to show the intensity of the observed interference pattern varies with distance along the screen.




C. The wavelength of light from the laser is 633 nm and the distance between the two slits is the 100 nm. If the screen is 200 cm, at what distance from the point X on the screen will the first dark fringe occur?

60 MINS

# Interference and Diffraction: Diffraction in Thin Films

**Content Standard**
The learners demonstrate an understanding of interference and diffraction on thin films.

**Performance Standards**
The learners shall be able to:
1. Use theoretical and, when feasible, experimental approaches to solve multi-concept and rich-context problems using concepts from electromagnetic waves, optics, relativity, and atomic and nuclear theory; and
2. Apply ideas from atomic and nuclear physics in contexts such as, but not limited to, radiation shielding and inferring the composition of stars.

**Learning Competencies**
The learners predict the occurrence of constructive and destructive reflection from thin films based on their thickness, index of refraction, and wavelength of illumination. **(STEM_GP12OPT-IVf-34)**

**Prerequisite Skills**
STEM_GP12MWS-Ie-34

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction** | Demonstration of a soap bubble with a rainbow | 10 |
| **Instruction** | Discussion on diffraction in thin films | 35 |
| **Evaluation** | Quiz and homework | 10 |
| **Enrichment** | Example of double slit experiment | 5 |
| **Materials** | | |

**Resources**

(1) Cummings et al Understanding Physics
(2) Arons, A. B. (1996). *Teaching Introductory Physics*. USA: Wiley.
(3) Giancoli, D. C. (2010). *Physics* (6th ed.). Boston: Addison-Wesley.
(4) Khan Academy (2014, July 7). *Young's Double slit part 1* [Video file]. Retrieved from https://www.youtube.com/watch?v=Pk6s2O1KzKQ&feature=youtu.be

## INTRODUCTION

1. Using a soap solution, make bubbles and let learners see the pattern of light reflected on a soap film. Alternatively, show a photo of a soap bubble.

2. Ask learners to take note of the color. Why does a soap bubble show a rainbow?

3. State that the task today is to find the underlying explanation for the colors seen on a soap film.

## INSTRUCTION

Discuss the following key points:

1. You have previously dealt with coherent light sources to display wave phenomena in light. Today's task is to display how interference can play out even with incoherent, non-monochromatic sources. Our analysis mainly used path length differences. By multiplying the path length difference by $\frac{2\pi}{\lambda}$, your analysis can also be done primarily by talking about phase differences.

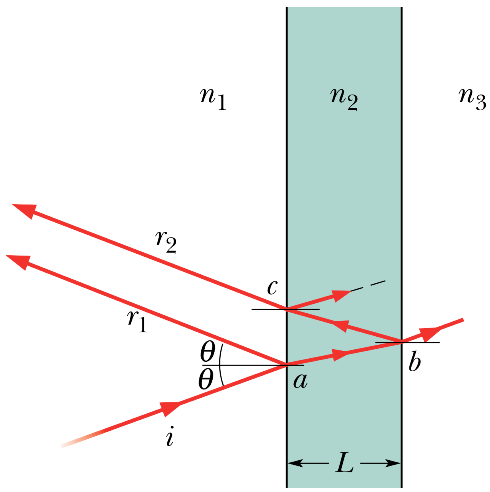
2. However, the previous lesson has not discussed the effect of reflection on the phase of a wave. For light, it is known that:
    a. the phase gets shifted by \pi if light travels in a medium with a lower index of refection and gets reflected by a medium with a higher index. For example, if light travels through air and gets reflected by glass, then the phase of light gets shifted (or added) by $\pi$; and
    b. the phase does not get shifted if the reflecting medium has lower index of refraction.

3. When light in air impinges on a thin film, one component (called A) gets reflected, while the other component (called B) refracts into the medium, partially reflects at the interface between the medium and the inner layer of air and then refracts out again. See the figure.

   The reflected component A of the wave will interfere with the reflected component B. The brightness of the resulting superposition depends on the wavelength, thickness of the film, and index of refraction of the film.

   If you let monochromatic light, impinge on the film, assuming that the film has uniform thickness. The amount of light that comes back to an observer will depend on the wavelength. It effectively filters out what will be reflected.

For some wavelengths, there will be almost no reflection due to totally destructive interference, and the soap film will appear dark. For




other wavelengths, there will be constructive interference, and will therefore appear bright.

Figure 1. The derivation hinges on two things:

a. The far-screen condition is also important: d/D << 1. This guarantees that the right triangle in the lower part of the figure above is a right triangle.
b. Comparing path differences of point sources from each slit. For a dark fringe to occur, the path length difference must be an integer and a half wavelength (n+1/2)* λ.

For a bright fringe to occur, the path length difference between must be an integer multiple of the wavelength. N \lambda

## DISCUSSION

Provide sample questions and demonstrate the solution.

## INDIVIDUAL WORK

Assign a short exercise for learners to solve in class then check their work.

## EVALUATION (10 MINS)

1. Ask learners a multiple choice type of questions to check for understanding.
2. As homework, ask learners to solve similar problems.

## ENRICHMENT (5 MINS)

Ask learners to give another example of the double slit experiment, this time involving particles/waves other than light.

60 MINS

# Interference and Diffraction: Single Slit Diffraction Experiment

**Content Standard**
The learners demonstrate an understanding of diffraction from single slits.

**Performance Standards**
The learners shall be able to:

1. Use theoretical and, when feasible, experimental approaches to solve multi-concept and rich-context problems using concepts from electromagnetic waves, optics, relativity, and atomic and nuclear theory; and
2. Apply ideas from atomic and nuclear physics in contexts such as, but not limited to, radiation shielding and inferring the composition of stars.

**Learning Competencies**
At the end of the session, the students should be able to relate the geometry of the diffraction experiment set-up (slit size, and screen to slit distance) and properties of light (wavelength) to the properties of the diffraction pattern (width, location of intensity of the fringes). **(STEM_G12OPT-IVf35)**

**Prerequisite Skills**
STEM_GP12MWS-Ie-34

## LESSON OUTLINE

| | |
|---|---|
| **Introduction** | Experiment demonstration |
| **Instruction** | Discussion proper |
| **Discussion** | Sample Activity Questions |
| **Individual Work** | Problem Solving activity |
| **Evaluation** | Multiple choice test |
| **Materials** | |

**Resources**

(1) Arons, Teaching Introductory Physics
(2) Giancoli, Physics, 6th ed.
(3) Cummings et al Understanding Physics
(4) https://www.khanacademy.org/science/physics/light-waves/interference-of-light-waves/v/youngs-double-split-part-1

## INTRODUCTION

1. Using a ripple tank, demonstrate how water waves pass through successive slits of smaller and smaller width. The bending of water waves as they pass through slits of size near the wavelength of the water wave is known as *single-slit diffraction*.

2. If light is a wave, light must also exhibit this phenomenon. Why did it take so long to discover?

3. If we let coherent light pass through a slit, what would be the pattern produced on a screen?

## INSTRUCTION

Each of these points should be made:

1. Most light sources are not coherent. To experimentally observe the wave behaviour, we must have a readily accessible source of coherent light. In contrast, it is relatively easy to produce coherent water waves.

2. Although lasers are coherent light sources, these were discovered only within the 21st century. Physicists built on previous experience with mechanical waves. When Maxwell first wrote his equations for electromagnetism, he relied on a mechanical mental model. Physicists invented experiments to look for wave behaviour in light using mechanical waves (for example, sound and waves on a string and other flexible objects) as inspiration.

3. Although Huygens was a contemporary of Newton, his work only predicted the same things that Newton could predict using the corpuscular theory. Given Newton's authoritative work on mechanics, people of that time had to choose between two theories that could predict (at that time) the same things. People naturally chose Newton.

4. The wave theory of light gained prominence only when it could predict the same phenomena that Newton could predict, as well as phenomena beyond those predictable using the corpuscular theory. The first notable experiments were those of Thomas Young in the early 1800's.

5. The wavelengths of visible light are in the order of hundreds of nanometers. This means experimental detection of wave behaviour in light could only be achieved when (1) people had a method for producing coherent light for experiments, (2) slit widths of the same order of

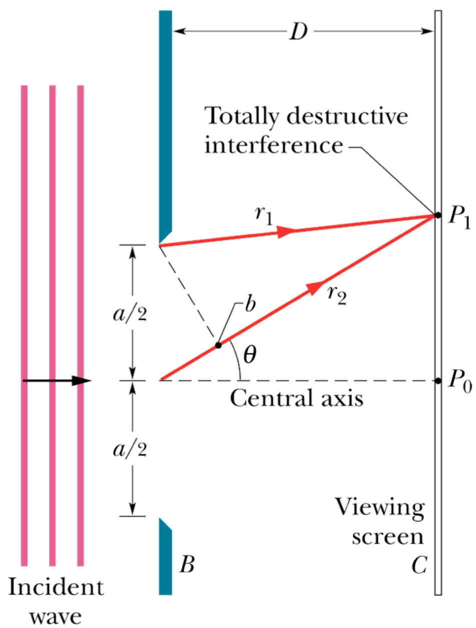
magnitude as light could be constructed, and (3) when physicists of sufficient imagination could propose experiments using coherent light and slits of the requisite width.

6. In this lesson, we focus on diffraction due to a single slit. (If the teacher desires, this lesson may be switched with double -slit diffraction.)

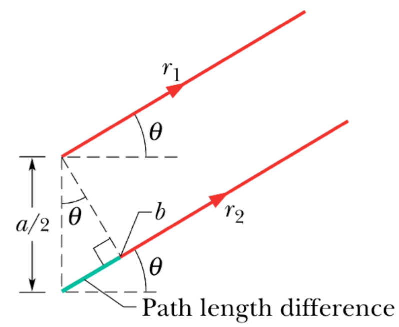
7. The diffracted light falling on a screen will have alternating bands of dark and bright regions called *fringes*. The location of the dark fringes on the screen can be obtained using the relation

a sin (\theta) = m \lambda
where
a is the slid width,
\theta is the angle between the line from the slit to the center of the screen and the line connecting the slit to the dark fringe,
and m is an integer.

The following figure is from Cummings et al, *Understanding Physics* Please redraw.



(a)



8. The derivation hinges on comparing path differences of point sources half a slit width away from each other. For a dark fringe to occur, a pairwise cancellation as one travels along the length of the slit is enough to guarantee the relationship shown in 7. (The derivation can be assigned as enrichment material.)

## DISCUSSION

Provide sample questions and demonstrate the solution. See Appendix A

## INDIVIDUAL WORK

1. Assign a short exercise for students to solve in class. See Appendix A.
2. Check student work.

## EVALUATION

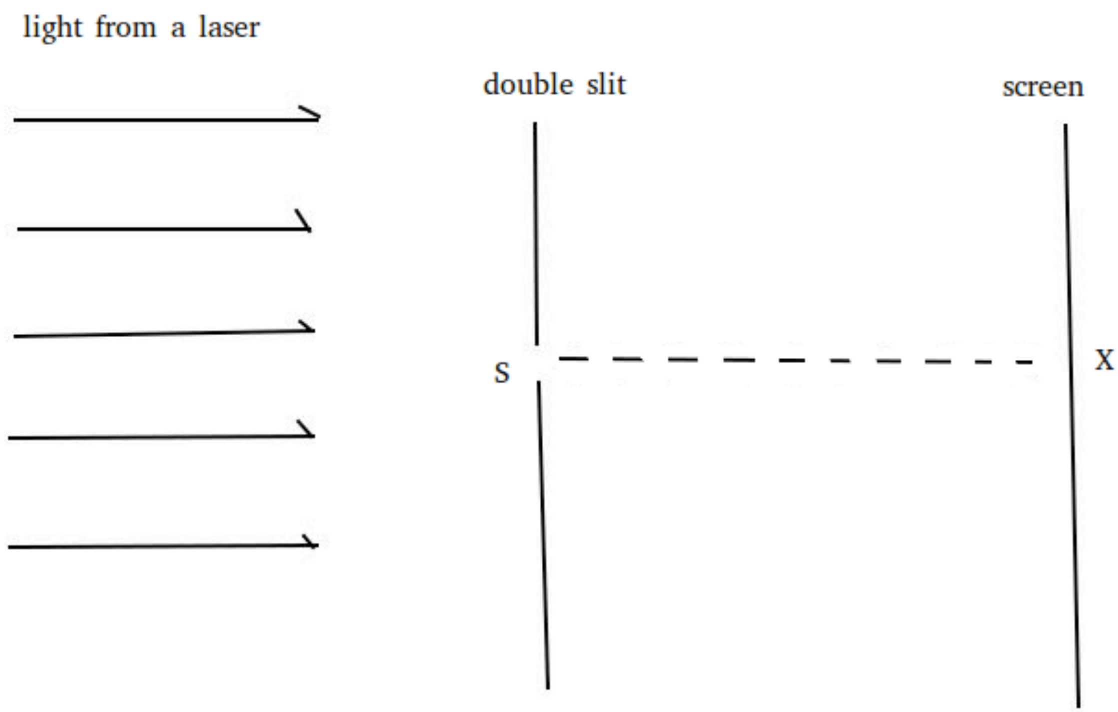
Ask students a multiple choice to check for understanding. See Appendix A.

## HOMEWORK

Ask students to solve a problem similar to the homework question in Appendix A.

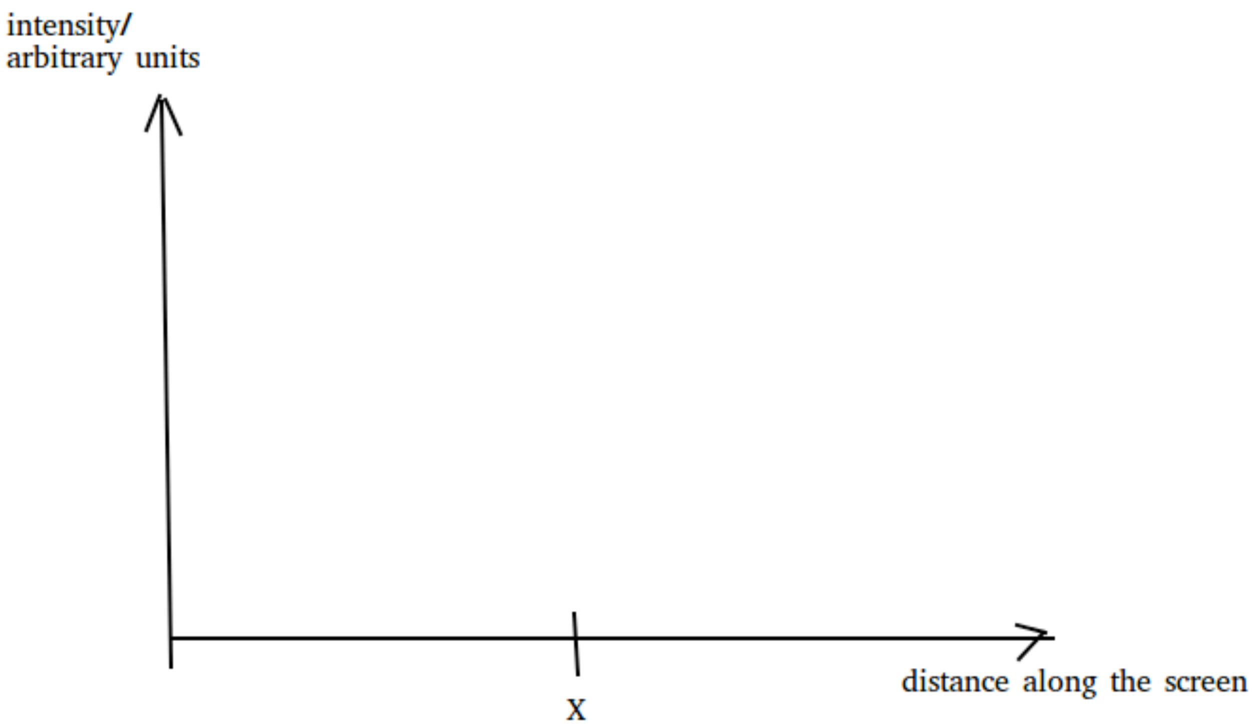
**Appendix A**

The  diagram below (not to scale) is an arrangement fpr observing the interference pattern produced on a screen when light has passed through a narrow slit S. A beam of light from a laser is incident on the screen. The width of the slit is w, and the distance of the slit from the screen is d. We assume that d/w << 1.




A. Explain why an interference pattern will not be observed on the screen if the laser is replaced with a tungsten filament lamp.

B. On the axes below, draw a sketch-graph to show the intensity of the observed interference pattern varies with distance along the screen.




C. The wavelength of light from the laser is 633 nm and the width of the 50 nm. If the screen is 200 cm, at what distance from the point X on the screen will the first dark fringe occur?

60 MINS

# Postulate of relativity; Relativity of times and lengths; Relativistic Doppler Effect

**Content Standard**

The learners demonstrate an understanding of:

1. Postulates of Special Relativity
2. Relativity of times and lengths
3. Relativistic Doppler effect

**Performance Standards**

The learners shall be able to:

1. Use theoretical and, when feasible, experimental approaches to solve multi-concept and rich-context problems using concepts from electromagnetic waves, optics, relativity, and atomic and nuclear theory; and
2. Apply ideas from atomic and nuclear physics in contexts such as, but not limited to, radiation shielding and inferring the composition of stars.

**Learning Competencies**

At the end of the session, the students should be able to:

1. State the postulates of Special Relitivity and their consequences **(STEM_GP12MP-IVg-39 )**
2. Apply the time dilation and -----=length contraction formulae **(STEM_GP12MP-IVg-40)**

**Prerequisite Knowledge**

Newtonian Mechanics, Electromagnetism

**Prerequisite Skills**

Algebra, Vector calculations

## LESSON OUTLINE

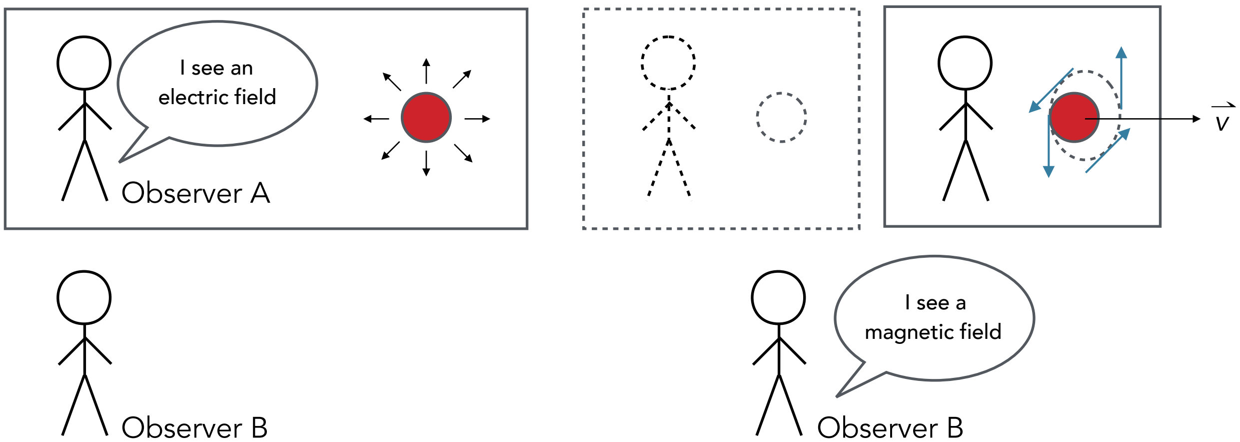
| | | |
|---|---|---|
| **Introduction** | Overview of the essence of solving context-rich problems | 5 |
| **Instruction** | Discussion and solving of context-rich problems | 55 |
| **Materials** | Writing materials, other materials to be determined by the students depending on the problem | |

**Resources**

(1) Young and Freedman. University Physics 9th Edition
(2) Tipler. University Physics 4th Edition
(3) Stephen Pople, Co-Ordinated Science Physics, Oxford University Press (1993).
(4) M. Andre and P. Andre, Classroom fundamentalis: measuing the Plancks constant. http://www.scienceinschool.org/2014/issue28/planck

## INTRODUCTION (5 MINS)

1. Recall about the difference of electric and magnetic field and discuss Einstein thought experiment on some seeming "contradiction" regarding electric and magnetic field produced by a charge.
   a. Electric field are created by charges at rest
   b. Magnetic field are created by charges in motion




**Teacher Tip:**

a. ask the students who is right? Observer A or Observer B? ask them to explain?
b. both observers are correct as proved by the special theory of relativity. Use this result to convince the students the importance of studying relativity.

2. Discuss application of relativity to daily life.

**Teacher Tip:**

Some applications of relativity:

a. Lifetime of some exotic particles like muon in the Large Hadron Collider is longer
b. Precision of GPS tracking. Without relativity consideration, the precision can be off by kilometers

## INSTRUCTION (30 MINS)

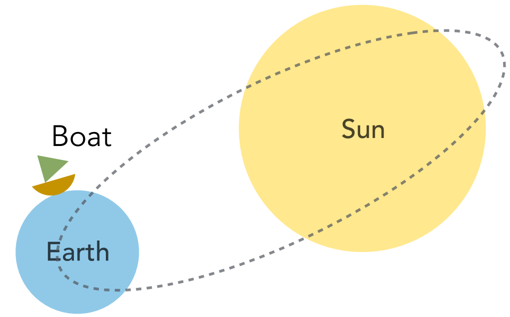
1. Discuss about the concept of Frames of Reference
   a. Emphasize to students that the inertial frame of reference is the frame wherein Newton's Laws of Motion is valid. (please see Teacher hint in the next page)

**Teacher Tip:**

Emphasize to students that when we measure the motion of an object, we are measuring it relative to some frame. For instance in the diagram below, the boat is moving with respect to the earth, the earth

b. Explain to students that a frame moving at constant velocity relative to an inertial frame is in itself an inertial frame

is moving with respect to the Sun, the Sun is moving with respect to the Milky Way and so on…




2. Discuss the First Postulate of Special Relativity that **the Laws of Physics are the same in all inertial frames of references**

3. Discuss the Second Postulate of Special Relativity that **the speed of light in free space has the same value in all inertial frames of reference**

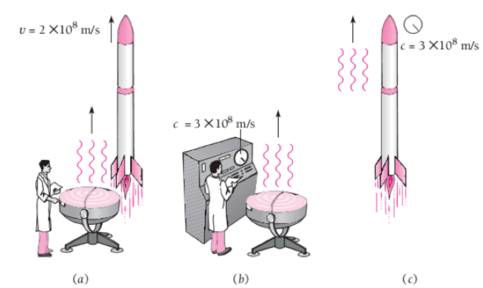
**Teacher Tip:**

a. the speed of light is $2.998 \times 10^8$ m/s
b. it has the symbol c

4. Introduce time dilation and length contraction as consequences of the two postulates mentioned above

**Teacher Tip:**

Discuss a thought experiment on measuring the speed of light




5. Explain time dilation, i.e. a moving clock ticks slower than that of a clock at rest on the ground as seen by an observer on the ground. Specifically, the time of the moving clock is given by,

$$t = \frac{t_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

where

$t_0$ is the time interval on clock at rest relative to an observer

t is the time interval on clock in motion relative to an observer

v is the speed of relative motion

6. Explain length contraction, i.e. the length of an object in motion with respect to the observer appears smaller than its length when it is at rest with respect to the observer. Specifically,

$$L = L_0\sqrt{1 - \frac{v^2}{c^2}}$$

where

$L_0$ is the time interval on clock at rest relative to an observer

L is the time interval on clock in motion relative to an observer

v is the speed of relative motion

**Teacher Tip:**
only lengths in the direction of motion undergo contraction

## PRACTICE AND EVALUATION (20 MINS) - FIRST SESSION

1. Solve (step by step) in the board two sample problems:
   a. ---- one can choose from Ref.[1]
   b. ---- one can choose from Ref.[1]

2. The students are given a seatwork:
   c. ---- one can choose from Ref.[1]

## ENRICHMENT - FIRST SESSION

HW1: students are asked to solve some problems from Ref.[1]

**Appendix**

Suggested Resources for Further Readings:

(1) Sears and Zemanskys, University Physic with Moder Physics Technology Update, vol. 2,
(2) Young and Freedman. University Physics 9th Edition
(3) Tipler. University Physics 4th Edition
(4) Stephen Pople, Co-Ordinated Science Physics, Oxford University Press (1993).
(5) M. Andre and P. Andre, Classroom fundamentails: measuing the Plancks constant. http://www.scienceinschool.org/2014/issue28/planck

60 MINS

# Relativistic velocity addition and Relativistic Doppler Formula

**Content Standard**

The learners demonstrate an understanding of:

1. Relativistic velocity addition
2. Relativistic Doppler formula

**Performance Standards**

The learners shall be able to:

1. Use theoretical and, when feasible, experimental approaches to solve multi-concept and rich-context problems using concepts from electromagnetic waves, optics, relativity, and atomic and nuclear theory; and
2. Apply ideas from atomic and nuclear physics in contexts such as, but not limited to, radiation shielding and inferring the composition of stars.

**Learning Competencies**

At the end of the session, the students should be able to:

1. Apply the relativistic velocity addition formula **(STEM_GP12MP-IVg-41)**
2. Apply the relativistic Doppler formula for Electromagnetic waves

**Prerequisite Knowledge**

Newtonian Mechanics, Waves, Electromagnetism

**Prerequisite Skills**

Algebra, Vector calculations

## LESSON OUTLINE

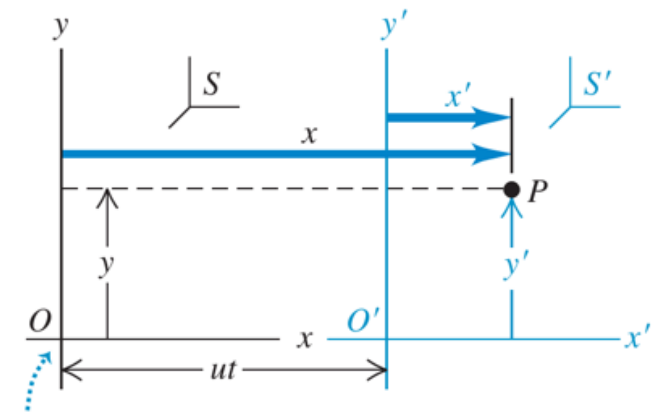
| | | |
|---|---|---|
| **Introduction/ Motivation** | Sample observation experiments | 15 |
| **Instruction** | Discussion proper | 30 |
| **Practice/ Evaluation** | Solving of sample problems | 15 |
| **Enrichment** | Additional problems as homework | |
| **Materials** | Writing materials, other materials to be determined by the students depending on the problem | |

**Resources**


(1) Young and Freedman. University Physics 9th Edition
(2) Tipler. University Physics 4th Edition
(3) Stephen Pople, Co-Ordinated Science Physics, Oxford University Press (1993).
(4) M. Andre and P. Andre, Classroom fundamentalis: measuing the Plancks constant. http://www.scienceinschool.org/2014/issue28/planck

## INTRODUCTION AND MOTIVATION

1. Start by considering the classical case of velocity addition which fails when velocities reaches the speed of light. Consider the case of describing the position of an object on two frames of



Origins $O$ and $O'$ coincide at time $t = 0 = t'$.

reference, the rest/Lab frame (O) and a moving frame with respect to the Lab frame (called O′).

The coordinates in the O′ frame yields,

$$x' = x + ut$$
$$y' = y \qquad (1)$$
$$z' = z$$

Furthermore, the velocities are given by,

$$v'_x = v_x + u$$
$$v'_y = v_y \qquad (2)$$
$$v'_z = v_z$$

2. Ask the students to use Eq. 2 and explain the result for the case when when u = c

**Teacher Tip:**
$v'_x = \frac{d}{dt}x = \frac{d}{dt}(x + ut) = \frac{dx}{dt} + u = v_x + u$

**Teacher Tip:**

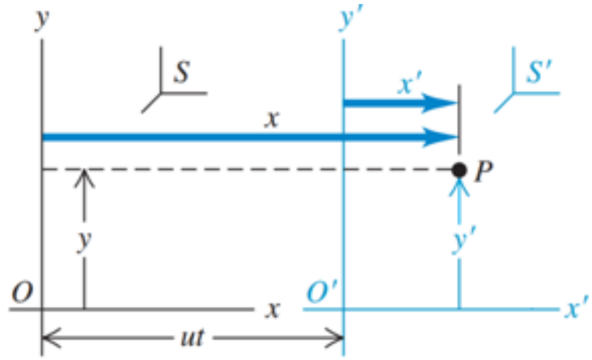
a) $v'x = vx + c > c \rightarrow$ violation of 2nd Postulate of Special Relativity
**b)** **Use this example to emphasize that it is important to modify the velocity addition formula to incorporate relativistic effect.**

## INSTRUCTION (30 MINS)

1. Discuss about the Lorentz coordinate transformation that solves the problem of the Galilean transformation above. Consider an event occuring on Frame O at position (xy,z) at time t. The same event occurs at Frame O' at time t' at position (x',y',z'). The transformation is given by:

$$x' = \gamma\,(x-ut)$$
$$y' = y \qquad (3)$$
$$z' = z$$
$$t' = \gamma\,(t-ux/c^2)$$

where $\gamma = \dfrac{1}{\sqrt{1 - \dfrac{u^2}{c^2}}}$




**Teacher Tip:**

Due to time constraints, it is advisable that you only discuss the implication of the formulas and show how the formulas can be used. Please do not derive them.

2. Ask the students the implication of Equation 3 for the case when u << c

**Teacher Tip:**

For small velocities, Eq. 1 is recovered, i.e.

a) For u << c then $\frac{u^2}{c^2} \sim 0$ thus $\gamma = 1$. Since $\frac{u}{c^2} \sim 0$ then t' = t.

b) Furthermore, since $\gamma = 1$ then x' = x - ut, y'=y and z'=z

3. Discuss the corresponding transformation of velocity (along x) given by

$$v'_x = \frac{v_x - u}{1 - \dfrac{uv^2}{c^2}} \qquad (4)$$

**Teacher Tip:**

It is enough to discuss two limiting cases, $v_x$ << c and $v_x = c$

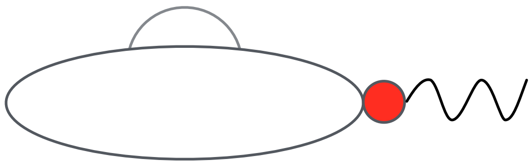
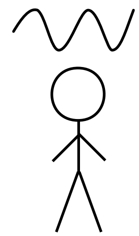
a) For $v_x$ << c then $\frac{v_x}{c^2} \sim 0$ and $v'_x = v_x - u$ which is the same result using the Galilean transformation

b) For $v_x = c$, then

$$v'_x = \frac{c - u}{1 - \dfrac{u^2}{c^2}} = c\,\frac{1 - \dfrac{u^2}{c^2}}{1 - \dfrac{u^2}{c^2}} = c$$

which is consistent of the 2nd Postulate of Special Relativity

4. As an introduction to relativistic doppler effect, ask the students what will be the percieved frequency of an observer in the O frame when the event P in the O' frame is actually the sending of an EM wave:

| | |
|---|---|
|  |  |
| A spaceship approaching an observer at a velocity u lights up a laser with frequency $f_0$ | The observer sees that same EM wave but with a frequency of f |

**Teacher Tip:**

a) Thus the percieved frequency of the Observer is greater than

b) When the spaceship is moving away from the Observer then u ➝ -u and

$$f = \sqrt{\frac{c + u}{c - u}}\ f_0 \qquad (5)$$

The percieved frequency is lesser than $f_0$.

5. Introduce to the students the relativistic Doppler formula for the thought experiment described above and discuss the implication,

$$f = \sqrt{\frac{c + u}{c - u}}\ f_0 \qquad (5)$$

## PRACTICE AND EVALUATION (15 MINS)

Solve (step by step) in the board one sample problems:

A. one sample example on relativistic velocity addition from Ref.[1]

B. one sample example on relativistic velocity addition from Ref.[1]

## ENRICHMENT - FIRST SESSION

HW1: students are asked to solve some problems from Ref.[1]

## Appendix

Suggested Resources for Further Readings:


(1) Sears and Zemanskys, University Physic with Moder Physics Technology Update, vol. 2,

(2) Young and Freedman. University Physics 9th Edition

(3) Tipler. University Physics 4th Edition

(4) Stephen Pople, Co-Ordinated Science Physics, Oxford University Press (1993).

(5) M. Andre and P. Andre, Classroom fundamentails: measuing the Plancks constant. http://www.scienceinschool.org/2014/issue28/planck

60 MINS

# Relativistic Dynamics

**Content Standard**
The learners demonstrate an understanding of Relativistic Dynamics.

**Performance Standards**
The learners shall be able to:
1. Use theoretical and, when feasible, experimental approaches to solve multi-concept and rich-context problems using concepts from electromagnetic waves, optics, relativity, and atomic and nuclear theory; and
2. Apply ideas from atomic and nuclear physics in contexts such as, but not limited to, radiation shielding and inferring the composition of stars.

**Learning Competencies**
At the end of the session, the students should be able to calculate kinetic energy, rest energy, momentum, and speed of objects moving with speeds comparable to the speed of light **(STEM_GP12MP-IVg-42)**

**Prerequisite Knowledge**
Mechanics: conservation laws, work and kinetic energy

**Prerequisite Skills**
Algebra, Vector calculations

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction/ Motivation** | Recall of prerequisite knowledge | 5 |
| **Instruction** | Discussion proper | 40 |
| **Practice/ Evaluation** | Solving of sample problems | 15 |
| **Enrichment** | Additional problems as homework | |
| **Materials** | • Graphing paper (2 pcs)<br>• Ruler (1 pc) | |

**Resources**

(1) Young and Freedman. University Physics 9th Edition
(2) Tipler. University Physics 4th Edition
(3) Stephen Pople, Co-Ordinated Science Physics, Oxford University Press (1993).
(4) M. Andre and P. Andre, Classroom fundamentalis: measuing the Plancks constant. http://www.scienceinschool.org/2014/issue28/planck

## INTRODUCTION AND MOTIVATION

1. Recall the formula for the momentum in classical physics and discuss that it does not correctly predicts the momentum of mass less particles.

2. Additional motivation only when time permits: Introduce (or show a youtube video) the optical tweezer which uses the momentum of a photon to trap small particles, i.e. using light to hold objects!

**Teacher Tip:**

a) Classical definition of momentum is,

$$\vec{p} = m\vec{v} \quad (1)$$

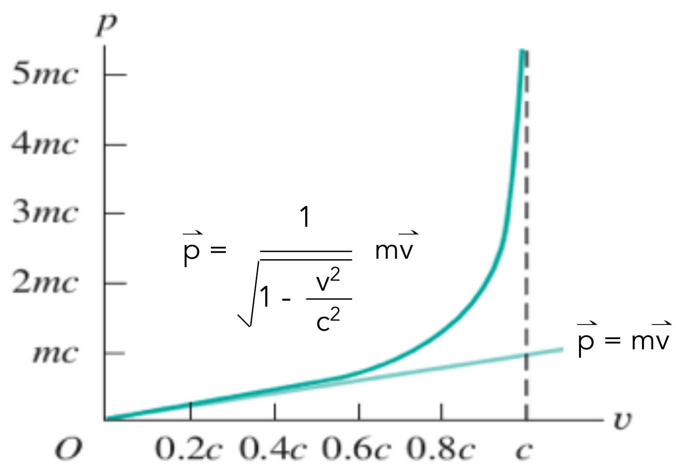
where m is the mass of the particle and $\vec{v}$ is the velocity.

b) Classically, for a particle with zero mass, m=0, the momentum is also zero, $\vec{p}$=0. This is not true!!! Photons (mass less particles) have momentum

## INSTRUCTION (40 MINS)

1. Discuss about the Lorentz coordinate transformation that solves the problem of the Galilean transformation above. Consider an event occurring on Frame O at position (xy,z) at time t. The same event occurs at Frame O' at time t' at position (x',y',z'). The transformation is given by:

$$\vec{p} = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} m\vec{v} \qquad (2)$$




**Teacher Tip:**

a) Ask students to plot Eq. 1 and Eq. 2 for different values of v similar to the Figure at the right

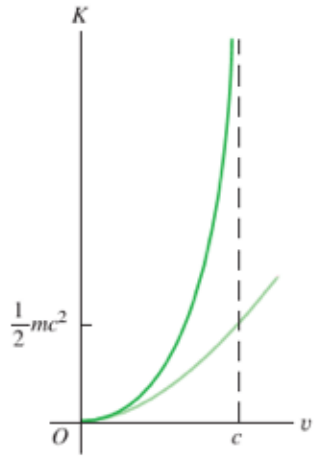
b) In classical physics, velocities could be > c

c) From Eq. 1, the momentum becomes infinite for v = c

2. Introduce the relativistic Kinetic energy and ask students to discuss it graphically

$$K = \frac{mc^2}{\sqrt{1 - \frac{v^2}{c^2}}} - mc^2 = (\gamma - 1)mc^2 \qquad (3)$$

Rest energy




3. Introduce the total energy for a particle with mass m as the sum of the Kinetic energy and the rest energy

$$E = \frac{mc^2}{\sqrt{1 - \frac{v^2}{c^2}}} = \gamma mc^2 \qquad (4)$$

**Teacher Tip:**

Ask students to plot Eq. 2 and compare to the plot of the classical formula, $K = ½ mv^2$ similar to the Figure at the right.

## PRACTICE AND EVALUATION (15 MINS)

1. Solve (step by step) in the board one sample problem from Ref.[1]
2. Ask students (as a seatwork) to prove (using Eq. 2 and Eq.4) that the Energy can be related to the momentum via,

$$E^2 = (mc^2)^2 + (pc)^2 \qquad (5)$$

**Teacher Tip:**

a) $p = E/c$ (6)
b) Inform students that the energy of the photon will be describe in the section on photoelectric effect.

3. On the same seatwork, ask students to find the formula for the momentum of a particle with zero mass, $m = 0$.

## ENRICHMENT - FIRST SESSION

1. HW1: Ask the students to plot Eq. 4
2. HW2: Ask students to think about another possible way of understanding Eq. 2; could it be that the mass is the one that is changing, i.e. from $m$ $\gamma m$? Ask them to explain if this is correct?

### Appendix

Suggested Resources for Further Readings:

(1) Sears and Zemanskys, University Physic with Modern Physics Technology Update, vol. 2,

(2) Young and Freedman. University Physics 9th Edition

(3) Tipler. University Physics 4th Edition

(4) Stephen Pople, Co-Ordinated Science Physics, Oxford University Press (1993).

(5) M. Andre and P. Andre, Classroom fundamentals: measuring the Planck's constant. http://www.scienceinschool.org/2014/issue28/planck

60 MINS

# Relativity Problem Solving

**Content Standard**

The learners demonstrate an understanding of:

1. Postulates of Special Relativity
2. Relativity of times and lengths
3. Relativistic velocity addition
4. Relativistic dynamics
5. Relativistic Doppler effect

**Performance Standards**

The learners shall be able to:

1. Use theoretical and, when feasible, experimental approaches to solve multi-concept and rich-context problems using concepts from electromagnetic waves, optics, relativity, and atomic and nuclear theory; and
2. Apply ideas from atomic and nuclear physics in contexts such as, but not limited to, radiation shielding and inferring the composition of stars.

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction/ Motivation** | Recall of formula from previous discussion | 10 |
| **Instruction** | Problem-solving | 30 |
| **Enrichment/ Evaluation** | Additional step-by-step problems | 20 |
| **Materials** | • Graphing paper (2 pcs)<br>• Ruler (1 pc) | |

**Resources**

(1) Young and Freedman. University Physics 9th Edition
(2) Tipler. University Physics 4th Edition
(3) Stephen Pople, Co-Ordinated Science Physics, Oxford University Press (1993).
(4) M. Andre and P. Andre, Classroom fundamentalis: measuing the Plancks constant. http://www.scienceinschool.org/2014/issue28/planck

**Learning Competencies**

At the end of the session, the students should be able to solve simple problems in special relativity involving time dilation, length contraction, principle of invariance, mass-energy relation, relativistic velocity addition, and relativistic momentum **(STEM_GP12MP-IVh-44)**

**Prerequisite Knowledge**

Previous discussion on Special Theory of Relativity

**Prerequisite Skills**

Algebra, Vector calculations

## INTRODUCTION AND MOTIVATION

1. Recall the formula that was obtained so far from previous discussion on Special Relativity

**Teacher Tip:**

a) Arrange formulas in a tabulated form:

| | |
|---|---|
| Time Dilation | $\Delta t = \dfrac{\Delta t}{\sqrt{1 - \dfrac{v^2}{c^2}}}$ |
| Length Contraction | $L = L_0\sqrt{1 - \dfrac{u^2}{c^2}}$ |
| Velocity Transformation | $v'_x = \dfrac{vx - u}{1 - \dfrac{uv_x}{c^2}}$ |
| Doppler Effect | $f = \sqrt{\dfrac{c+u}{c-u}}\, f_0$ |
| Momentum | $\vec{p} = \dfrac{1}{\sqrt{1 - \dfrac{v^2}{c^2}}}\, m\vec{v}$ |
| Kinetic Energy | $K = \dfrac{mc^2}{\sqrt{1-\dfrac{v^2}{c^2}}} - mc^2 = (\gamma-1)mc^2$ |
| Total Energy | $E = \dfrac{mc^2}{\sqrt{1 - \dfrac{v^2}{c^2}}} = \gamma mc^2$ |
| Energy-Momentum Equivalence | $E^2 = (mc^2)^2 + (pc)^2$ |

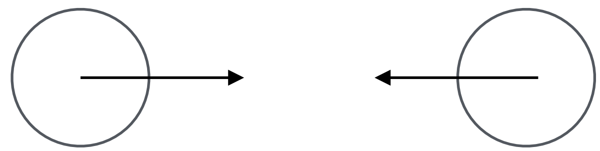
b) Emphasize the difference of u and v

## INSTRUCTION (30 MINS)

Solve step by step two problems found in Ref.[1]

a. Sample problem

Two are approaching each other head-on. Each has a speed of 0.90c, as measured in the laboratory. What is the speed of one particle relative to the other?

| Objective | Detail |
|---|---|
| Draw a diagram |  |
| Velocity Transformation Formula | $v'x = \dfrac{v_x - u}{1 - \frac{uv_x}{c^2}}$ |
| Rewrite to get $u$ | $u = \dfrac{v_x + v'_x}{1 - \frac{v_x v'_x}{c^2}} = \dfrac{v_x + v'_x}{1 + \frac{v_x^2}{c^2}}$ (since $v'_x = -v_x$) |
| Plug-in values | u = 0.994c |

b. Sample problem

A π meson moves at a speed of 0.98c with respect to earth as measured by a stationary observer. The lifetime of π meson is 26.0ns as measured in its own frame of reference. Find the lifetime of the π meson as measured by the stationary observer on earth.

| Objective | Detail |
|---|---|
| Consideration | S frame: Earth<br>S’ frame: Meson<br>$u = 0.98c$<br>$\Delta t_0 = 26.0$ ns<br>$\Delta t = ?$ |
| Time dilation formula | $\Delta t_0 = \dfrac{\Delta t_0}{\sqrt{1 - \frac{u^2}{c^2}}}$ |
| Plug-in values | $u = 130.65$ ns |

## EVALUATION (20 MINS)

As a seatwork, ask students to solve (step by step) one problem from Ref.[1]

## ENRICHMENT - FIRST SESSION

HW1: Ask the students to solve (step by step) one problem from Ref.[1]

### Appendix

Suggested Resources for Further Readings:

(1) Sears and Zemanskys, University Physic with Modern Physics Technology Update, vol. 2,

(2) Young and Freedman. University Physics 9th Edition

(3) Tipler. University Physics 4th Edition

120 MINS

# The Photoelectric Effect and Determination of the Planck's Constant

**Content Standard**

The learners demonstrate an understanding of the Photoelectric Effect

**Performance Standards**

The learners shall be able to:

1. Use theoretical and, when feasible, experimental approaches to solve multi-concept and rich-context problems using concepts from electromagnetic waves, optics, relativity, and atomic and nuclear theory; and
2. Apply ideas from atomic and nuclear physics in contexts such as, but not limited to, radiation shielding and inferring the composition of stars.

**Learning Competencies**

At the end of the session, the students should be able to:

1. Identify the limitation of classical physics in elucidating the photoelectric effect phenomena
2. Explain how Einstein theory correctly described the Photoelectric effect
3. Compare the standard value of Planck's constant with that obtained via experiments

**Prerequisite Knowledge**

Mechanics, Energy, Electrodynamics, Black Body radiation (thermodynamics)

**Prerequisite Skills**

Measuring current and voltage difference, linear regression

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction/ Motivation** | Recall of previous discussion on light | 10 |
| **Instruction** | Discussion and problem solving | 30 |
| **Practice/ Evaluation** | | 20 |
| **Enrichment** | Additional activities for homework | |
| **Instruction** | | 60 |
| **Enrichment/ Evaluation** | 2nd session | |
| **Materials** | • 1 set of Light Emitting diode (with different "color"<br>• Potentiometer/Rheostat<br>• 2 Multimeter (one as an ammeter and another one as a voltmeter)<br>• 9 volt battery | |

**Resources**

(1) Young and Freedman. University Physics 9th Edition
(2) Tipler. University Physics 4th Edition
(3) Stephen Pople, Co-Ordinated Science Physics, Oxford University Press (1993).
(4) M. Andre and P. Andre, Classroom fundamentails: measuing the Plancks constant. http://www.scienceinschool.org/2014/issue28/planck

## INTRODUCTION AND MOTIVATION (10 MINS)

1. Recall about the debate of light being a particle or a wave.

2. In connection to 1), the ask students whether the energy of light can be thought of as continuous or discrete.

3. Recall other similar debate like the, the black body radiation, and how Planck solves it by quantization.

$$E_{light} = hf \qquad \text{(Equation 2)}$$

   where h is the Planck's constant and f is the light frequency.

4. Briefly describes the photo-electric effect, i.e. how light energy is used to excite an electron in a metal.

5. Present technological uses of the photo-electric effect such as digital camera and video camera tube.

**Teacher Tip:**
Historical view on Lord Kelvin's speech on the dark clouds in physics

**Teacher Tip:**
1. Video recording – operation of digital camera and video camera tube
2. Laser

## INSTRUCTION (30 MINS) - FIRST SESSION

1. Discuss about a typical photoelectric effect experiment given schematically below:

Conservation of energy leads to,

$$1/2mv^2 = E_{light} - \varnothing \qquad \text{(Equation 1)}$$

where

a. $1/2mv^2$ is the kinetic energy of the ejected electron
b. $E_{light}$ is the energy of the light shining on the metal
c. $\varnothing$ is the work function, i.e. the energy required to release the electron from the metal

2. Discuss experimental results (from literature) and then compare the predictions of the wave model in classical physics

**Teacher Tip:**
prediction of classical physics does not agree with the experiments.

3. Introduce the quantization of the photon energy as first proposed by Einstein,

$$E_{light} - hf \qquad \text{(Equation 2)}$$

where h is the Planck's constant and f is the light frequency

4. Ask the students the implication of Equation 2.
5. In connection to 3) discuss how Einstein solution correctly accounts the observations in the photoelectric effect experiments.

## PRACTICE AND EVALUATION (20 MINS) - FIRST SESSION

1. Solve (step by step) in the board two sample problems:
   A. ---- one can choose from Ref.[1]

B. ---- one can choose from Ref.[1]

2. The students are given a seatwork:
    C. ---- one can choose from Ref.[1]

## ENRICHMENT - FIRST SESSION

HW1: students are asked to solve some problems from Ref.[1]

## INSTRUCTION (60 MINS) - SECOND SESSION

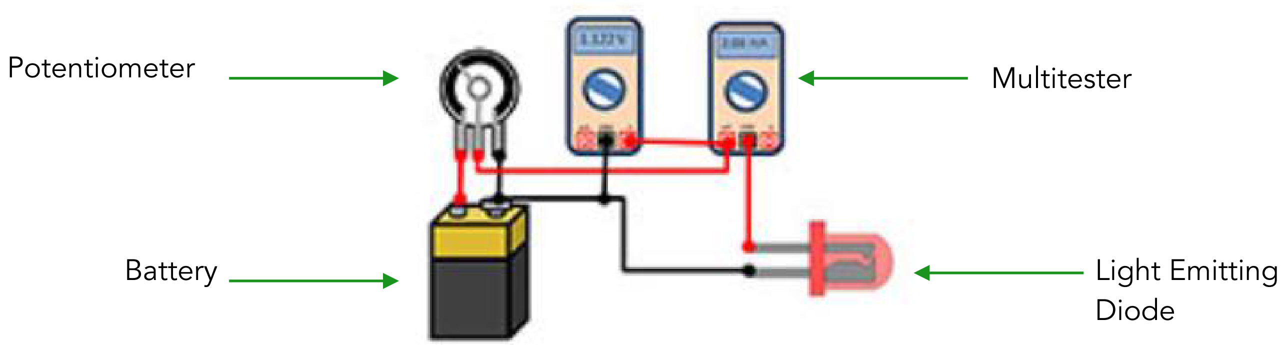
1. Recall about the discussion on the photo-electric effect in the previous meeting. Emphasize the role of the Planck's constant.

2. Inform students that they will conduct a simple experiment to measure the Planck's constant. The step by step procedure is outlined below.

**Teacher Tip:**
student should submit a report on the experiment as a means of evaluation.

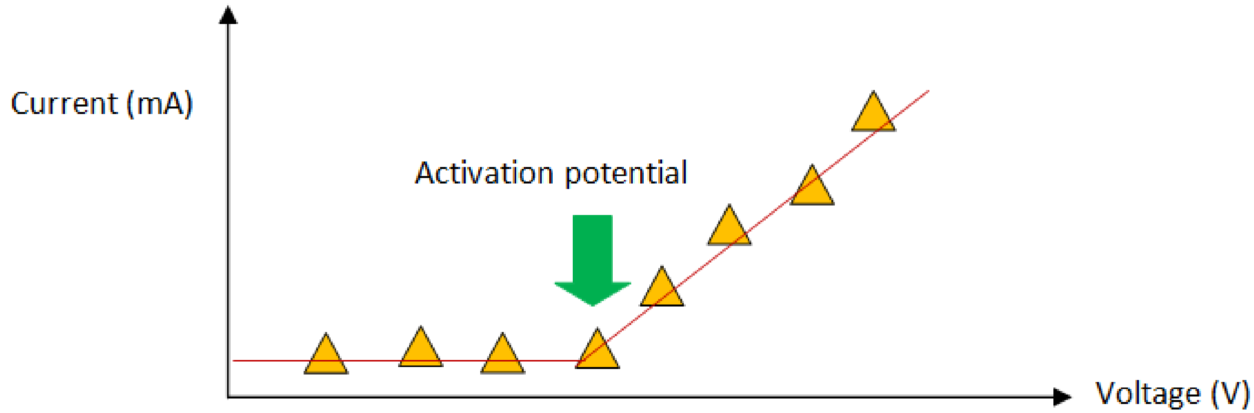
<u>Experiment to measure the Planck's constant</u>

1. Construct the circuit below. [Image taken from [4]]

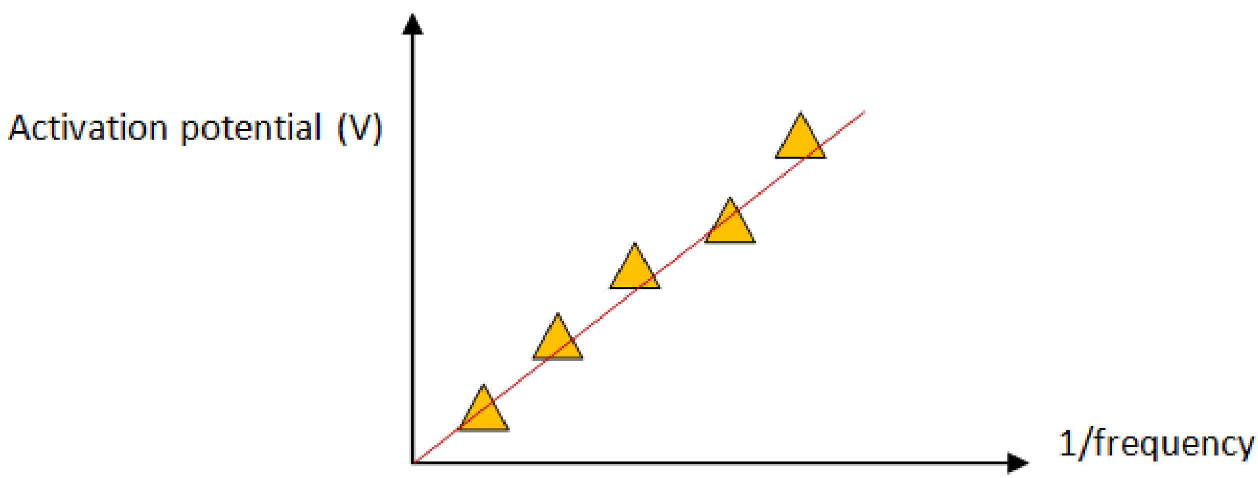



**Teacher Tip:**
1. ask student which of the multi-tester act as an ammeter or the voltmeter?
2. often times there will be difficulty in the measurement, make sure that the wires are not cut and the batteries are full.
3. explain what parameters in Equation 1 corresponds to the parameters in the experiment.

2. Measure the current for different input voltate (adjust using the potentiometer) and recover the activation potential as indicated below:




3. Perform step 2 for different color of LET ("different frequencies").
4. Plot the activation potential versus the 1/frequency:




5. Perform a linear regression of the plot obtained above (Activation potential vs 1/frequency).
6. Compare the computed Planck's constant to the world standard (with current accuracy of course)
7.

**Teacher Tip:**

1. Why plot the activation potential with 1/frequency not frequency?
2. What is the shape of the graph? ans.linear

**Teacher Tip:**

1. What is the meaning of the slope? Ans. from the slope one can extract the Plancks constant.
2. How about the y-intercept? Ans. the y-intercept give us the work function of that material

## ENRICHMENT AND EVALUATION - SECOND SESSION

1. HW1: list the fundamental constants you know, without knowing physics, what thus these constants tells us (hint. dimensional analysis)

2. HW2: ask students to write an essay about quantization in nature..can you observe it when looking at a mirror?

**Appendix**

Suggested Resources for Further Readings:

(1) Sears and Zemanskys, University Physic with Moder Physics Technology Update, vol. 2,
(2) Young and Freedman. University Physics 9th Edition
(3) Tipler. University Physics 4th Edition
(4) Stephen Pople, Co-Ordinated Science Physics, Oxford University Press (1993).
(5) M. Andre and P. Andre, Classroom fundamentails: measuing the Plancks constant. http://www.scienceinschool.org/2014/issue28/planck

**60 MINS**

# Atomic Spectra

**Content Standard**
The learners demonstrate an understanding of the Atomic Spectra.

**Performance Standards**
The learners shall be able to:
1. Use theoretical and, when feasible, experimental approaches to solve multi-concept and rich-context problems using concepts from electromagnetic waves, optics, relativity, and atomic and nuclear theory; and
2. Apply ideas from atomic and nuclear physics in contexts such as, but not limited to, radiation shielding and inferring the composition of stars.

**Learning Competencies**
At the end of the session, the students should be able to explain qualitatively the properties of atomic emission and absorption spectra using the concept of energy levels. **(STEM_GP12MP-IVh-46)**

**Prerequisite Knowledge**
Photoelectric effect, Electromagnetic Wave, Diffraction

**Prerequisite Skills**
Algebra

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction/ Motivation** | Experiment demonstration | 10 |
| **Instruction** | Discussion proper | 40 |
| **Practice/ Evaluation** | Step-by-step calculation of sample problem | 15 |
| **Enrichment** | Homework | |
| **Materials** | • 1 cardboard box<br>• 1 toilet paper tube<br>• 1 DVD or CD<br>• Aluminum foil<br>• Illustration board (for the slit)<br>• Glue, pair of scissors, ruler, pen, tape | |

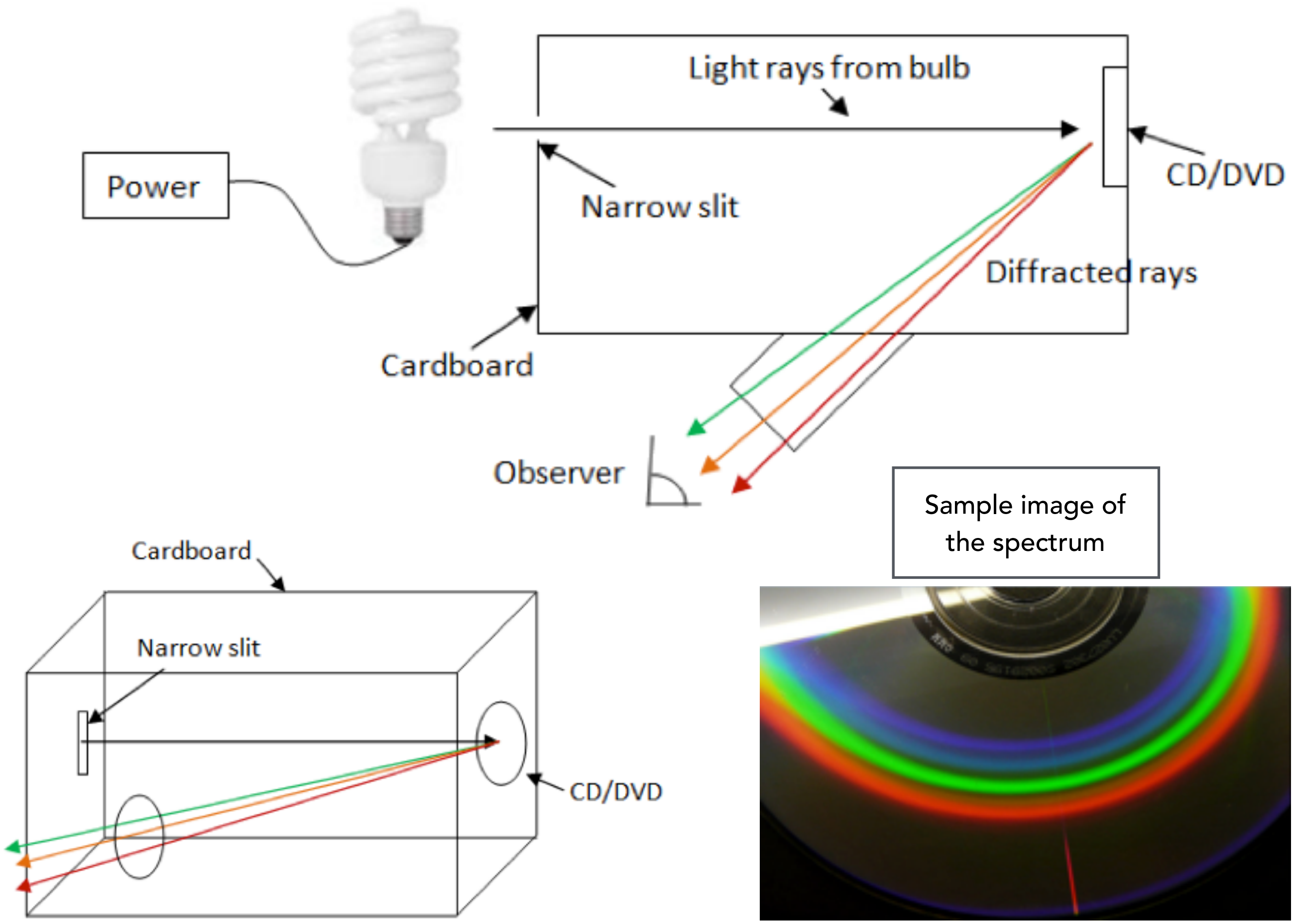
**Resources**

(1) Young and Freedman. University Physics 9th Edition
(2) Tipler. University Physics 4th Edition
(3) Stephen Pople, Co-Ordinated Science Physics, Oxford University Press (1993).
(4) M. Andre and P. Andre, Classroom fundamentalis: measuing the Plancks constant. http://www.scienceinschool.org/2014/issue28/planck

## INTRODUCTION AND MOTIVATION

Demonstrate an experiment showing the atomic spectra of a fluorescent bulb using a homemade spectroscope

a. Build the following homemade spectroscope using easily accessible materials:




b. If possible, please print a sample of the fluorescent bulb spectra and gave a copy for every two students.

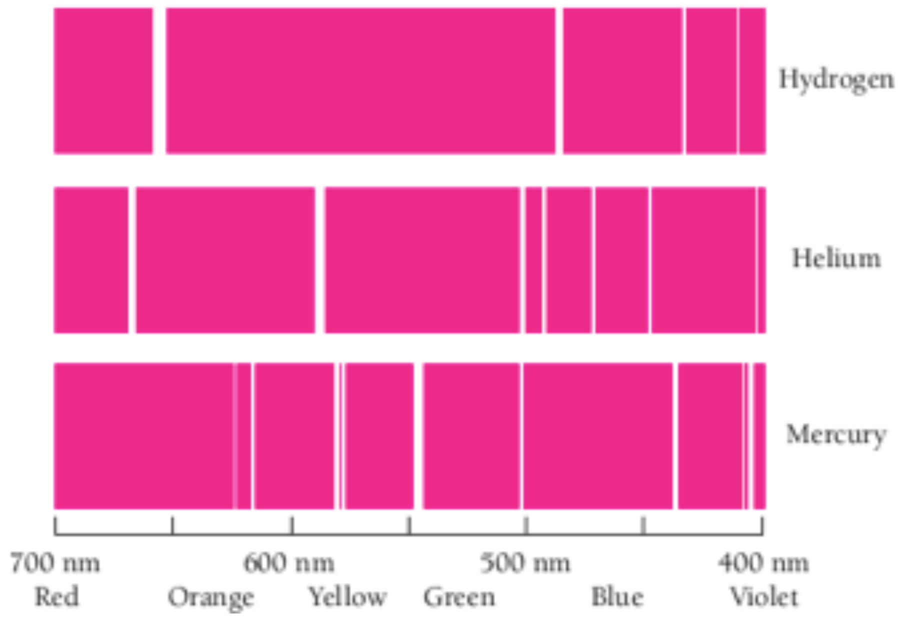
**Teacher Tip:**

Important Reminders:

a) make sure no stray light comes in
b) be careful with the bulb, it might get so hot and could result to accident
c) don't stare too long on the spectra

## INSTRUCTION (40 MINS)

1. Introduce the phenomena that elements have their characteristic atomic line spectra

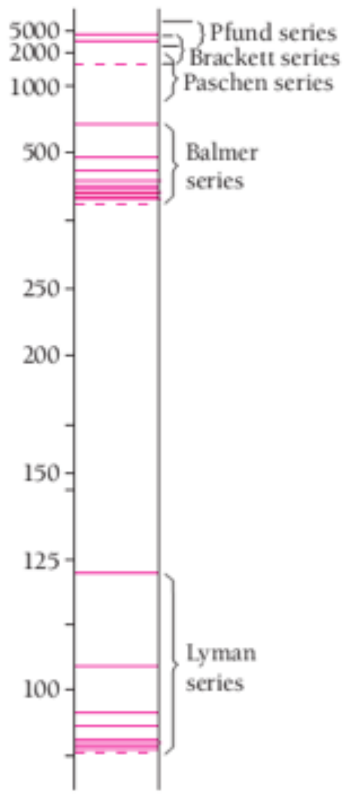



Emission line spectra pf various elements. Taken from beiser

2. Discuss that for the hydrogen several spectral lines were measured and found to follow some rules:

| | |
|---|---|
| Lyman series | $\frac{1}{\lambda} = R\,(\frac{1}{1^2} - \frac{1}{n^2})$ $n = 2, 3, 4, \ldots$<br>where the Rydbeg constant is given by, $R = 1.097 \times 10^7\ m^{-1}$ |
| Balmer series | $\frac{1}{\lambda} = R\,(\frac{1}{2^2} - \frac{1}{n^2})$ $n = 3, 4, 5, \ldots$ |

| | |
|---|---|
| Paschen series | $\frac{1}{\lambda} = R\left(\frac{1}{3^2} - \frac{1}{n^2}\right) \quad n = 4, 5, 6, \ldots$ |
| Brackett series | $\frac{1}{\lambda} = R\left(\frac{1}{4^2} - \frac{1}{n^2}\right) \quad n = 5, 6, 7 \ldots$ |
| Pfund series | $\frac{1}{\lambda} = R\left(\frac{1}{5^2} - \frac{1}{n^2}\right) \quad n = 6, 7, 8, \ldots$ |




Emission line spectra of hydrogen. Taken from beiser

3. Proceed by introducing the Bohr model of the atom to obtain the different series above. Start by describing the Bohr model of the atom: in the Bohr model of the hydrogen atom, the nucleus is surrounded by an electron which is located at any permitted radius. These orbits also correspond to different energies given by,

$$E_n = \frac{E_1}{n^2}, \qquad n = 1,2,3, \ldots \quad (1)$$

and $E_1 = -2.18 \times 10^{-18}$ J = -13.6 eV.

4. Discuss that the spectral lines actually correspond to transition of electrons from a state of energy ni to a state with energy nf. The energy difference corresponds to the energy of an emitted photon with frequency, i.e.

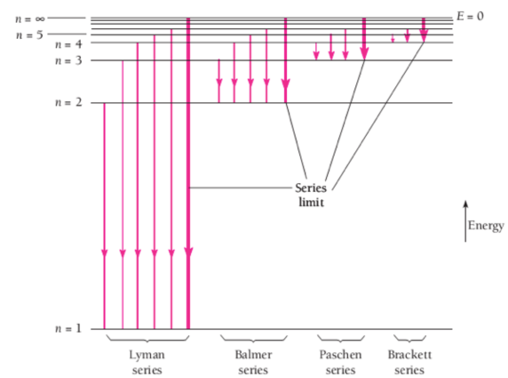
$$hf = \frac{E_1}{ni^2} - \frac{E_1}{nf^2} = -E_1\left(\frac{1}{nf^2} - \frac{1}{ni^2}\right) \quad (2)$$

since $c = \lambda f$ we then have

$$\frac{1}{\lambda} = -\frac{E_1}{cf^2}\left(\frac{1}{nf^2} - \frac{1}{ni^2}\right) \quad (3)$$

**Teacher Tip:**

a) $n_f > n_i$
b) $n_f = 1$ corresponds to Lyman series, $n_f = 2$ corresponds to Balmer series, $n_f = 3$ corresponds to Paschen series, $n_f = 4$ corresponds to Brackett series, $n_f = 5$ corresponds to Pfund series.
c) graphical representation of the transitions corresponding to different spectral series




Taken from beiser

## PRACTICE AND EVALUATION (15 MINS)

1. Show step-by-step calculation of a sample problem in Ref. [1]

2. As a seatwork, ask students to verify if $R = -\frac{E_1}{cf^2}$

## ENRICHMENT - FIRST SESSION

HW1: students are asked to solve some problems from Ref.[1]

**Appendix**

Suggested Resources for Further Readings:

(1) Sears and Zemanskys, University Physic with Modern Physics Technology Update, vol. 2,
(2) Young and Freedman. University Physics 9th Edition
(3) Tipler. University Physics 4th Edition
(4) Stephen Pople, Co-Ordinated Science Physics, Oxford University Press (1993).
(5) M. Andre and P. Andre, Classroom fundamentals: measuring the Planck's constant. http://www.scienceinschool.org/2014/issue28/planck

60 MINS

# Radioactive Decay

**Content Standard**

The learners demonstrate an understanding of radioactive decay.

**Performance Standards**

The learners shall be able to:

1. Use theoretical and, when feasible, experimental approaches to solve multi-concept and rich-context problems using concepts from electromagnetic waves, optics, relativity, and atomic and nuclear theory; and
2. Apply ideas from atomic and nuclear physics in contexts such as, but not limited to, radiation shielding and inferring the composition of stars.

**Learning Competencies**

At the end of the session, the students should be able to calculate radioisotope activity using the concept of half-life **(STEM_GP12MP-IVh-i-47 )**

**Prerequisite Knowledge**

Photoelectric effect, Electromagnetic Wave, Diffraction

**Prerequisite Skills**

Algebra

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction/ Motivation** | Introduction of carbon dating | 5 |
| **Instruction** | Discussion proper | 45 |
| **Practice/ Evaluation** | Step-by-step calculation of sample problem | 15 |
| **Enrichment** | Homework | |
| **Materials** | • 1 graphing paper<br>• 1 ruler | |

**Resources**

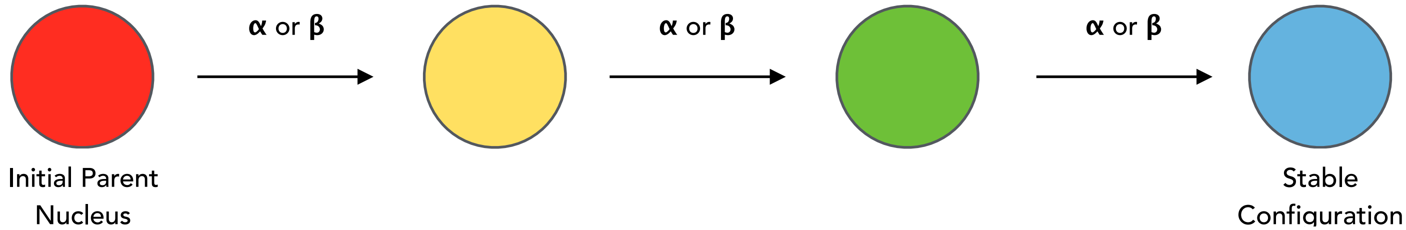
Sears and Zemanskys, University Physics with Modern Physics Technology Update, vol. 2

## INTRODUCTION AND MOTIVATION (5 MINS)

Ask students on how to measure the age of a rock? Then introduce briefly carbon dating as a means on measuring the age of rocks.

## INSTRUCTION (45 MINS)

1. Describe briefly gamma, alpha and beta decay.
2. Mention that in general elements undergo successive decay until they reach a stable configuration.




3. Proceed by introducing that the nature of decay is statistical in nature. However, bulk measurements will actually reveal a lowering in the amount of susbstance with time. Consider for instance the sample table below:

| Time (/hr) | Amount of Substance |
|---|---|
| 0 | N(0) |
| 1 | N(1) |
| 2 | N(2) |
| 3 | N(3) |
| 4 | N(4) |
| 5 | N(5) |

where $N(5) < N(4) < N(3) < N(2) < N(1) < N(0)$.

4. Introduce a mathematical description in the previous observation. Since the amount of substance lowers as a function of time, then

$$-\frac{dN(t)}{dt} = \lambda N(t) \qquad (2)$$

where N(t) is the amount of substance at time t and λ as the decay rate. The solution of Eq. 2 is given by

$$N(t) = N(0)\, e^{-\lambda t} \qquad (3)$$

5. Introduce the concept of half-life: the half life, $T_{1/2}$ , refers to the time that the amount of original substance has decreased by 1/2. From Eq.3 we have,

$$\frac{N(0)}{2} = N(0)\, e^{-\lambda t_{1/2}} \quad (4)$$

which results to

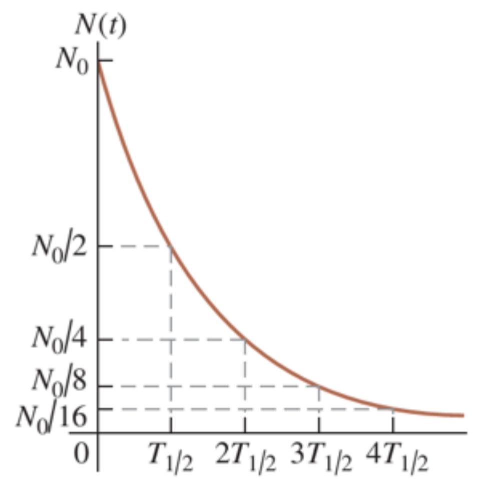
$$1/2 = e^{-\lambda t_{1/2}} \quad (5)$$

and finally,

$$T_{1/2} = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda} \qquad (6)$$

**Teacher Tip:**

a) the left hand side of Eq. 2 is negative because the rate of change of N(t) is decreasing.
b) the decreasing amount of N(t) is due to the decay of the current substance at a rate of λ (λ has a unit of $s^{-1}$), this is given by the right hand side of Eq. 2.
c) as a means of checking Eq. 3, for t=0, we have $N(t = 0) = N(0)e^{-\lambda \cdot 0} = N(0)$.
d) Graphical representation of Eq. 3:




## PRACTICE AND EVALUATION (15 MINS)

1. Show step-by-step calculation of a sample problem in Ref. [1].

2. As a seatwork, ask students to perform the operations below for the following data:

| Time (/hr) | Amount of Substance N(t) |
|---|---|
| 0 | 10 |
| 1 | 3.67879 |
| 2 | 1.35335 |
| 3 | 0.497871 |
| 4 | 0.183156 |
| 5 | 0.06738 |
| 6 | 0.024788 |
| 7 | 0.009119 |
| 8 | 0.003355 |
| 9 | 0.001234 |

a)Plot N(t) vs time

b)Plot logN(t) vs time

c)Find the decay constant by linear regression of the logN(t) vs time

## ENRICHMENT - FIRST SESSION

HW1: students are asked to solve some problems from Ref.[1]

**Appendix**

Suggested Resources for Further Readings:


(1) Young and Freedman. University Physics 9th Edition

(2) Tipler. University Physics 4th Edition

(3) Stephen Pople, Co-Ordinated Science Physics, Oxford University Press (1993).

(4) M. Andre and P. Andre, Classroom fundamentals: measuring the Planck's constant. http://www.scienceinschool.org/2014/issue28/planck

120 MINS

# Contemporary Applications of Atomic and Nuclear Phenomena (Reporting)

**Content Standard**

The learners demonstrate an understanding of experiments on atomic and nuclear phenomena and applications of atomic and nuclear concepts.

**Performance Standards**

The learners shall be able to:

1. Use theoretical and, when feasible, experimental approaches to solve multi-concept and rich-context problems using concepts from electromagnetic waves, optics, relativity, and atomic and nuclear theory; and
2. Apply ideas from atomic and nuclear physics in contexts such as, but not limited to, radiation shielding and inferring the composition of stars.

| LESSON OUTLINE | |
|---|---|
| **Reporting** | Group reporting |
| **Practice/ Evaluation** | Submissions |
| **Materials** | • 1 LCD Projector (or Overhead Projector)<br>• 1 computer |
| **Resources** | |

**Learning Competencies**

At the end of the session, the students should be able to:

1. Identify technological progress brought by discoveries in atomic and nuclear phenomena
2. Appreciate recent directions of research in atomic and nuclear phenomena

**Prerequisite Knowledge**

Previous lesson on Relativity, Atomic and Nuclear Phenomena

**Prerequisite Skills**

Curiosty, Oral Communication Skills

## REPORTING

A. Separate student into 8 groups. Each group will be given 15 minutes for reporting inclusive of question and answer. Each group will submit a written report of their topic before their presentation.

B. The following are suggested topics for reporting:

1. Laser types and their operational principle (Nobel Prize Physics  1964,1981,1997,2005)
2. Optical Communication in Fiber optic lines (Nobel Prize Physics  2009)
3. Bose Einstein Condensate: What is it? (Nobel Prize Physics  2001)
4. Bose Einstein Condensate: How to make one? (focus on magneto-optical trapping technology) (Nobel Prize Physics  1997,2001)
5. Hubble Telescope and the principle of determing the chemical composition of stars?
6. How Curiosity (a Mars rover) measures the composition of rocks in Mars?
7. Radiation induced DNA damaged (Nobel Prize Chemistry 2015)
8. Positron emission tomography (positron discovery leads to Nobel Prize Physics  1933, 1936)

## PRACTICE AND EVALUATION (15 MINS)

1. Quality of material presented and the presentation
2. Submitted Report

# Biographical Notes

## JOEL T. MAQUILING, PH.D.

*Team Leader*

Dr. Joel T. Maquiling is currently a full-time faculty member of the Physics Department in the Ateneo de Manila University. He obtained his doctorate degree in Geophysics at Universita degli Studi di Padova in Italy. His research interests range from Geophysics (Granular Matter Dynamics, Rheology, and Fracture Mechanics and Failure Mechanisms) to Physics Education.

Dr. Maquiling actively participates in researches on Optics and Photonics. With his contributions to the field, he was able to lead his team, called the Active Learning in Optics & Photonics Team, as a recipient of the 2011 SPIE Educator Award. The SPIE Educator Award is presented annually in recognition of outstanding contributions to optics education by an SPIE instructor or an educator in the field. His team literally "brought light" to hundreds of teachers and students with the numerous hands-on workshops, inspiring a new generation of scientists in those nations involved in the study.

## MICHAEL REUBEN SOLIS

*Writer*

Mr. Michael Solis has been an active partner of academic institutions such as De La Salle University and the University of the Philippines. Michael accomplished his undergraduate and master's degree in Physics at UP Diliman. He has a wide range of contributions in the field of Physics, ranging from Physics education research to general relativity & statistical mechanics. He is currently accomplishing his doctorate degree in Physics at UP Diliman.

## MARK NOLAN P. CONFESOR, PH.D.

*Writer*

Dr. Mark Nolan Confesor is an Associate Professor V at Mindanao State University - Iligan Institute of Technology (MSU-IIT). His teaching interests include statistical mechanics, soft matter physics, optics, & science and faith dialogue. Dr. Confesor obtained his bachelor's and master's degree in Physics at MSU-IIT. Afterwards, he completed his doctorate studies in Physics at National Central University at Taiwan. He has a vast amount of experience and exposure in presentations,  through conferences, and publications gearing towards improving physics research and education in the Philippines.

## JUNIUS ANDRE F. BALISTA, PH.D.

*Writer*

Dr. Junius Balista accomplished his undergraduate, master's, and doctorate degree in Physics at the University of Diliman. He is currently designed as an assistant professor for the Institute of Mathematical Sciences and Physics at UP Los Baños, teaching Introductory Physics, Classical Electromagnetism, Classical Mechanics, and Research Methods. Dr. Balista has consistently participated in submitting written research work for conferences and international peer-reviewed publications since 2004.

## MARISSA G. PASTOR, PH.D.

*Writer*

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