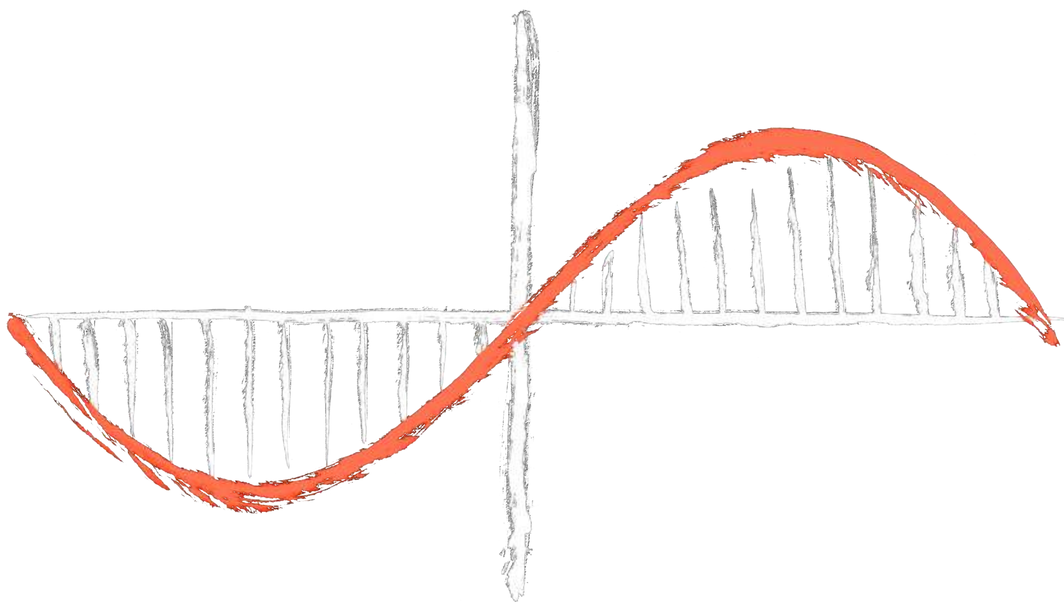
*The Commission on Higher Education*
*in collaboration with the Philippine Normal University*

*Teaching Guide for Senior High School*

# GENERAL PHYSICS 1



## 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.

**Published by the Commission on Higher Education, 2016**
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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 |

**K to 12 BASIC EDUCATION CURRICULUM**
**SENIOR HIGH SCHOOL – SCIENCE, TECHNOLOGY, ENGINEERING AND MATHEMATICS (STEM) SPECIALIZED SUBJECT**

**Grade:** 12
**Subject Title**: General Physics 1

**Quarters:** General Physics 1 (Q1&Q2)
**No. of Hours/ Quarters:** 40 hours/ quarter
**Prerequisite:** Basic Calculus

**Subject Description:** Mechanics of particles, rigid bodies, and fluids; waves; and heat and thermodynamics using the methods and concepts of algebra, geometry, trigonometry, graphical analysis, and basic calculus

| CONTENT | CONTENT STANDARD | PERFORMANCE STANDARD | LEARNING COMPETENCIES | CODE | SCIENCE EQUIPMENT |
|---|---|---|---|---|---|
| 1. **Units**<br>2. **Physical Quantities**<br>3. **Measurement**<br>4. **Graphical Presentation**<br>5. **Linear Fitting of Data** | *The learners demonstrate an understanding of...*<br>1. The effect of instruments on measurements<br>2. Uncertainties and deviations in measurement<br>3. Sources and types of error<br>4. Accuracy versus precision<br>5. Uncertainty of derived quantities<br>6. Error bars<br>7. Graphical analysis: linear fitting and transformation of functional dependence to linear form | *The learners are able to...*<br>Solve, using experimental and theoretical approaches, multiconcept, rich-context problems involving measurement, vectors, motions in 1D, 2D, and 3D, Newton's Laws, work, energy, center of mass, momentum, impulse, and collisions | *The learners...*<br>1. Solve measurement problems involving conversion of units, expression of measurements in scientific notation | **STEM_GP12EU-Ia-1** | |
| | | | 2. Differentiate accuracy from precision | **STEM_GP12EU-Ia-2** | |
| | | | 3. Differentiate random errors from systematic errors | **STEM_GP12EU-Ia-3** | |
| | | | 4. Use the least count concept to estimate errors associated with single measurements | **STEM_GP12EU-Ia-4** | |
| | | | 5. Estimate errors from multiple measurements of a physical quantity using variance | **STEM_GP12EU-Ia-5** | |
| | | | 6. Estimate the uncertainty of a derived quantity from the estimated values and uncertainties of directly measured quantities | **STEM_GP12EU-Ia-6** | |
| | | | 7. Estimate intercepts and slopes—and and their uncertainties—in experimental data with linear dependence using the "eyeball method" and/or linear regression formulae | **STEM_GP12EU-Ia-7** | |
| **Vectors** | 1. Vectors and vector addition<br>2. Components of vectors<br>3. Unit vectors | | 1. Differentiate vector and scalar quantities | **STEM_GP12V-Ia-8** | |
| | | | 2. Perform addition of vectors | **STEM_GP12V-Ia-9** | |
| | | | 3. Rewrite a vector in component form | **STEM_GP12V-Ia-10** | |
| | | | 4. Calculate directions and magnitudes of | **STEM_GP12V-Ia-** | |

| CONTENT | CONTENT STANDARD | PERFORMANCE STANDARD | LEARNING COMPETENCIES | CODE | SCIENCE EQUIPMENT |
|---|---|---|---|---|---|
| | | | vectors | 11 | |
| **Kinematics: Motion Along a Straight Line** | 1. Position, time, distance, displacement, speed, average velocity, instantaneous velocity<br>2. Average acceleration, and instantaneous acceleration<br>3. Uniformly accelerated linear motion<br>4. Free-fall motion<br>5. 1D Uniform Acceleration Problems | | 1. Convert a verbal description of a physical situation involving uniform acceleration in one dimension into a mathematical description | **STEM_GP12Kin-Ib-12** | |
| | | | 2. Recognize whether or not a physical situation involves constant velocity or constant acceleration | **STEM_GP12KIN-Ib-13** | |
| | | | 3. Interpret displacement and velocity, respectively, as areas under velocity vs. time and acceleration vs. time curves | **STEM_GP12KIN-Ib-14** | |
| | | | 4. Interpret velocity and acceleration, respectively, as slopes of position vs. time and velocity vs. time curves | **STEM_GP12KIN-Ib-15** | |
| | | | 5. Construct velocity vs. time and acceleration vs. time graphs, respectively, corresponding to a given position vs. time-graph and velocity vs. time graph and vice versa | **STEM_GP12KIN-Ib-16** | NSTIC Free-FALL Set |
| | | | 6. Solve for unknown quantities in equations involving one-dimensional uniformly accelerated motion | **STEM_GP12KIN-Ib-17** | |
| | | | 7. Use the fact that the magnitude of acceleration due to gravity on the Earth's surface is nearly constant and approximately 9.8 $m/s^2$ in free-fall problems | **STEM_GP12KIN-Ib-18** | NSTIC Free-FALL Set |
| | | | 8. Solve problems involving one-dimensional motion with constant acceleration in contexts such as, but not limited to, the "tail-gating phenomenon", pursuit, rocket launch, and free-fall problems | **STEM_GP12KIN-Ib-19** | |
| **Kinematics: Motion in 2-Dimensions and 3-** | Relative motion<br>1. Position, distance, | | 1. Describe motion using the concept of relative velocities in 1D and 2D | **STEM_GP12KIN-Ic-20** | |

| CONTENT | CONTENT STANDARD | PERFORMANCE STANDARD | LEARNING COMPETENCIES | CODE | SCIENCE EQUIPMENT |
|---|---|---|---|---|---|
| **Dimensions** | displacement, speed, average velocity, instantaneous velocity, average acceleration, and instantaneous acceleration in 2- and 3- dimensions<br>2. Projectile motion<br>3. Circular motion<br>4. Relative motion | | 2. Extend the definition of position, velocity, and acceleration to 2D and 3D using vector representation | **STEM_GP12KIN-Ic-21** | |
| | | | 3. Deduce the consequences of the independence of vertical and horizontal components of projectile motion | **STEM_GP12KIN-Ic-22** | |
| | | | 4. Calculate range, time of flight, and maximum heights of projectiles | **STEM_GP12KIN-Ic-23** | |
| | | | 5. Differentiate uniform and non-uniform circular motion | **STEM_GP12KIN-Ic-24** | |
| | | | 6. Infer quantities associated with circular motion such as tangential velocity, centripetal acceleration, tangential acceleration, radius of curvature | **STEM_GP12KIN-Ic-25** | |
| | | | 7. Solve problems involving two dimensional motion in contexts such as, but not limited to ledge jumping, movie stunts, basketball, safe locations during firework displays, and Ferris wheels | **STEM_GP12KIN-Ic-26** | |
| | | | 8. Plan and execute an experiment involving projectile motion: Identifying error sources, minimizing their influence, and estimating the influence of the identified error sources on final results | **STEM_GP12KIN-Id-27** | |
| **Newton's Laws of Motion and Applications** | 1. Newton's Law's of Motion<br>2. Inertial Reference Frames<br>3. Action at a distance forces<br>4. Mass and Weight<br>5. Types of contact forces: tension, normal force, kinetic and static friction, fluid | | 1. Define inertial frames of reference | **STEM_GP12N-Id-28** | |
| | | | 2. Differentiate contact and noncontact forces | **STEM_GP12N-Id-29** | |
| | | | 3. Distinguish mass and weight | **STEM_GP12N-Id-30** | |
| | | | 4. Identify action-reaction pairs | **STEM_GP12N-Id-31** | NSTIC Cart-Rail System |
| | | | 5. Draw free-body diagrams | **STEM_GP12N-Id-32** | |
| | | | 6. Apply Newton's 1st law to obtain quantitative and qualitative conclusions about the contact and noncontact forces | **STEM_GP12N-Ie-33** | |

| CONTENT | CONTENT STANDARD | PERFORMANCE STANDARD | LEARNING COMPETENCIES | CODE | SCIENCE EQUIPMENT |
|---|---|---|---|---|---|
| | resistance<br>6. Action-Reaction Pairs<br>7. Free-Body Diagrams<br>8. Applications of Newton's Laws to single-body and multibody dynamics<br>9. Fluid resistance<br>10. Experiment on forces<br>11. Problem solving using Newton's Laws | | acting on a body in equilibrium (1 lecture) | | |
| | | | 7. Differentiate the properties of static friction and kinetic friction | **STEM_GP12N-Ie-34** | NSTIC Friction Set |
| | | | 8. Compare the magnitude of sought quantities such as frictional force, normal force, threshold angles for sliding, acceleration, etc. | **STEM_GP12N-Ie-35** | |
| | | | 9. Apply Newton's 2nd law and kinematics to obtain quantitative and qualitative conclusions about the velocity and acceleration of one or more bodies, and the contact and noncontact forces acting on one or more bodies | **STEM_GP12N-Ie-36** | |
| | | | 10. Analyze the effect of fluid resistance on moving object | **STEM_GP12N-Ie-37** | |
| | | | 11. Solve problems using Newton's Laws of motion in contexts such as, but not limited to, ropes and pulleys, the design of mobile sculptures, transport of loads on conveyor belts, force needed to move stalled vehicles, determination of safe driving speeds on banked curved roads | **STEM_GP12N-Ie-38** | |
| | | | 12. Plan and execute an experiment involving forces (e.g., force table, friction board, terminal velocity) and identifying discrepancies between theoretical expectations and experimental results when appropriate | **STEM_GP12N-If-39** | 1. Force Table<br>2. NSTIC Friction Set |
| **Work, Energy, and Energy Conservation** | 1. Dot or Scalar Product<br>2. Work done by a force<br>3. Work-energy relation<br>4. Kinetic energy | | 1. Calculate the dot or scalar product of vectors | **STEM_GP12WE-If-40** | |
| | | | 2. Determine the work done by a force (not necessarily constant) acting on a system | **STEM_GP12WE-If-41** | |
| | | | 3. Define work as a scalar or dot product of force and displacement | **STEM_GP12WE-If-42** | |
| | | | 4. Interpret the work done by a force in | **STEM_GP12WE-If-** | |

| CONTENT | CONTENT STANDARD | PERFORMANCE STANDARD | LEARNING COMPETENCIES | CODE | SCIENCE EQUIPMENT |
|---|---|---|---|---|---|
| | 5. Power<br>6. Conservative and nonconservative forces<br>7. Gravitational potential energy<br>8. Elastic potential energy<br>9. Equilibria and potential energy diagrams<br>10. Energy Conservation, Work, and Power Problems | | one-dimension as an area under a Force vs. Position curve | **43** | |
| | | | 5. Relate the work done by a constant force to the change in kinetic energy of a system | **STEM_GP12WE-Ig-44** | |
| | | | 6. Apply the work-energy theorem to obtain quantitative and qualitative conclusions regarding the work done, initial and final velocities, mass and kinetic energy of a system. | **STEM_GP12WE-Ig-45** | |
| | | | 7. Represent the work-energy theorem graphically | **STEM_GP12WE-Ig-46** | |
| | | | 8. Relate power to work, energy, force, and velocity | **STEM_GP12WE-Ig-47** | |
| | | | 9. Relate the gravitational potential energy of a system or object to the configuration of the system | **STEM_GP12WE-Ig-48** | |
| | | | 10. Relate the elastic potential energy of a system or object to the configuration of the system | **STEM_GP12WE-Ig-49** | |
| | | | 11. Explain the properties and the effects of conservative forces | **STEM_GP12WE-Ig-50** | |
| | | | 12. Identify conservative and nonconservative forces | **STEM_GP12WE-Ig-51** | |
| | | | 13. Express the conservation of energy verbally and mathematically | **STEM_GP12WE-Ig-52** | |
| | | | 14. Use potential energy diagrams to infer force; stable, unstable, and neutral equilibria; and turning points | **STEM_GP12WE-Ig-53** | |
| | | | 15. Determine whether or not energy conservation is applicable in a given example before and after description of a physical system | **STEM_GP12WE-Ig-54** | |

| CONTENT | CONTENT STANDARD | PERFORMANCE STANDARD | LEARNING COMPETENCIES | CODE | SCIENCE EQUIPMENT |
|---|---|---|---|---|---|
| | | | 16. Solve problems involving work, energy, and power in contexts such as, but not limited to, bungee jumping, design of roller-coasters, number of people required to build structures such as the Great Pyramids and the rice terraces; power and energy requirements of human activities such as sleeping vs. sitting vs. standing, running vs. walking. (Conversion of joules to calories should be emphasized at this point.) | **STEM_GP12WE-Ih-i-55** | |
| **Center of Mass, Momentum, Impulse, and Collisions** | 1. Center of mass<br>2. Momentum<br>3. Impulse<br>4. Impulse-momentum relation<br>5. Law of conservation of momentum<br>6. Collisions<br>7. Center of Mass, Impulse, Momentum, and Collision Problems<br>8. Energy and momentum experiments | | 1. Differentiate center of mass and geometric center | **STEM_GP12MMIC-Ih-56** | |
| | | | 2. Relate the motion of center of mass of a system to the momentum and net external force acting on the system | **STEM_GP12MMIC-Ih-57** | |
| | | | 3. Relate the momentum, impulse, force, and time of contact in a system | **STEM_GP12MMIC-Ih-58** | |
| | | | 4. Explain the necessary conditions for conservation of linear momentum to be valid. | **STEM_GP12MMIC-Ih-59** | |
| | | | 5. Compare and contrast elastic and inelastic collisions | **STEM_GP12MMIC-Ii-60** | |
| | | | 6. Apply the concept of restitution coefficient in collisions | **STEM_GP12MMIC-Ii-61** | |
| | | | 7. Predict motion of constituent particles for different types of collisions (e.g., elastic, inelastic) | **STEM_GP12MMIC-Ii-62** | |
| | | | 8. Solve problems involving center of mass, impulse, and momentum in contexts such as, but not limited to, rocket motion, vehicle collisions, and ping-pong. (*Emphasize also the concept of whiplash and the sliding, rolling, and mechanical deformations in vehicle collisions.*) | **STEM_GP12MMIC-Ii-63** | |

| CONTENT | CONTENT STANDARD | PERFORMANCE STANDARD | LEARNING COMPETENCIES | CODE | SCIENCE EQUIPMENT |
|---|---|---|---|---|---|
| | | | 9. Perform an experiment involving energy and momentum conservation and analyze the data identifying discrepancies between theoretical expectations and experimental results when appropriate | **STEM_GP12MMIC-Ii-64** | |
| **Integration of Data Analysis and Point Mechanics Concepts** | Refer to weeks 1 to 9 | | (Assessment of the performance standard) | (1 week) | |
| **Rotational equilibrium and rotational dynamics** | 1. Moment of inertia<br>2. Angular position, angular velocity, angular acceleration<br>3. Torque<br>4. Torque-angular acceleration relation<br>5. Static equilibrium<br>6. Rotational kinematics<br>7. Work done by a torque<br>8. Rotational kinetic energy<br>9. Angular momentum<br>10. Static equilibrium experiments<br>11. Rotational motion problems | Solve multi-concept, rich context problems using concepts from rotational motion, fluids, oscillations, gravity, and thermodynamics | 1. Calculate the moment of inertia about a given axis of single-object and multiple-object systems *(1 lecture with exercises)* | **STEM_GP12RED-IIa-1** | |
| | | | 2. Exploit analogies between pure translational motion and pure rotational motion to infer rotational motion equations (e.g., rotational kinematic equations, rotational kinetic energy, torque-angular acceleration relation) | **STEM_GP12RED-IIa-2** | |
| | | | 3. Calculate magnitude and direction of torque using the definition of torque as a cross product | **STEM_GP12RED-IIa-3** | |
| | | | 4. Describe rotational quantities using vectors | **STEM_GP12RED-IIa-4** | |
| | | | 5. Determine whether a system is in static equilibrium or not | **STEM_GP12RED-IIa-5** | |
| | | | 6. Apply the rotational kinematic relations for systems with constant angular accelerations | **STEM_GP12RED-IIa-6** | |
| | | | 7. Apply rotational kinetic energy formulae | **STEM_GP12RED-IIa-7** | |
| | | | 8. Solve static equilibrium problems in contexts such as, but not limited to, see-saws, mobiles, cable-hinge-strut system, leaning ladders, and weighing a heavy suitcase using a small bathroom scale | **STEM_GP12RED-IIa-8** | |
| | | | 9. Determine angular momentum of different systems | **STEM_GP12RED-IIa-9** | |

| CONTENT | CONTENT STANDARD | PERFORMANCE STANDARD | LEARNING COMPETENCIES | CODE | SCIENCE EQUIPMENT |
|---|---|---|---|---|---|
| | | | 10. Apply the torque-angular momentum relation | **STEM_GP12RED-IIa-10** | |
| | | | 11. Recognize whether angular momentum is conserved or not over various time intervals in a given system | **STEM_GP12RED-IIa-11** | |
| | | | 12. Perform an experiment involving static equilibrium and analyze the data—identifying discrepancies between theoretical expectations and experimental results when appropriate | **STEM_GP12RED-IIa-12** | |
| | | | 13. Solve rotational kinematics and dynamics problems, in contexts such as, but not limited to, flywheels as energy storage devices, and spinning hard drives | **STEM_GP12RED-IIa-13** | |
| **Gravity** | 1. Newton's Law of Universal Gravitation<br>2. Gravitational field<br>3. Gravitational potential energy<br>4. Escape velocity<br>5. Orbits | | 1. Use Newton's law of gravitation to infer gravitational force, weight, and acceleration due to gravity | **STEM_GP12G-IIb-16** | |
| | | | 2. Determine the net gravitational force on a mass given a system of point masses | **STEM_GP12Red-IIb-17** | |
| | | | 3. Discuss the physical significance of gravitational field | **STEM_GP12Red-IIb-18** | |
| | | | 4. Apply the concept of gravitational potential energy in physics problems | **STEM_GP12Red-IIb-19** | |
| | | | 5. Calculate quantities related to planetary or satellite motion | **STEM_GP12Red-IIb-20** | |
| | 6. Kepler's laws of planetary motion | | 6. Apply Kepler's 3rd Law of planetary motion | **STEM_GP12G-IIc-21** | |
| | | | 7. For circular orbits, relate Kepler's third law of planetary motion to Newton's law of gravitation and centripetal acceleration | **STEM_GP12G-IIc-22** | |
| | | | 8. Solve gravity-related problems in contexts such as, but not limited to, inferring the mass of the Earth, inferring the mass of Jupiter from the motion of its moons, and calculating escape speeds from the Earth and from the solar system | **STEM_GP12G-IIc-23** | |
| **Periodic Motion** | 1. Periodic Motion | | 1. Relate the amplitude, frequency, angular | **STEM_GP12PM-** | |

| CONTENT | CONTENT STANDARD | PERFORMANCE STANDARD | LEARNING COMPETENCIES | CODE | SCIENCE EQUIPMENT |
|---|---|---|---|---|---|
| | 2. Simple harmonic motion: spring-mass system, simple pendulum, physical pendulum | | frequency, period, displacement, velocity, and acceleration of oscillating systems | **IIc-24** | |
| | | | 2. Recognize the necessary conditions for an object to undergo simple harmonic motion | **STEM_GP12PM-IIc-25** | |
| | | | 3. Analyze the motion of an oscillating system using energy and Newton's 2nd law approaches | **STEM_GP12PM-IIc-26** | |
| | | | 4. Calculate the period and the frequency of spring mass, simple pendulum, and physical pendulum | **STEM_GP12PM-IIc-27** | |
| | 3. Damped and Driven oscillation<br>4. Periodic Motion experiment | | 5. Differentiate underdamped, overdamped, and critically damped motion | **STEM_GP12PM-IId-28** | |
| | | | 6. Describe the conditions for resonance | **STEM_GP12PM-IId-29** | |
| | | | 7. Perform an experiment involving periodic motion and analyze the data—identifying discrepancies between theoretical expectations and experimental results when appropriate | **STEM_GP12PM-IId-30** | |
| | 5. Mechanical waves | | 8. Define mechanical wave, longitudinal wave, transverse wave, periodic wave, and sinusoidal wave | **STEM_GP12PM-IId-31** | Slinky Coil |
| | | | 9. From a given sinusoidal wave function infer the (speed, wavelength, frequency, period, direction, and wave number | **STEM_GP12PM-IId-32** | |
| | | | 10. Calculate the propagation speed, power transmitted by waves on a string with given tension, mass, and length (*1 lecture*) | **STEM_GP12PM-IId-33** | |
| **Mechanical Waves and Sound** | 1. Sound<br>2. Wave Intensity<br>3. Interference and beats<br>4. Standing waves<br>5. Doppler effect | | 1. Apply the inverse-square relation between the intensity of waves and the distance from the source | **STEM_GP12MWS-IIe-34** | |
| | | | 2. Describe qualitatively and quantitatively the superposition of waves | **STEM_GP12MWS-IIe-35** | |
| | | | 3. Apply the condition for standing waves | **STEM_GP12MWS-** | 1. DC String Vibrator |

| CONTENT | CONTENT STANDARD | PERFORMANCE STANDARD | LEARNING COMPETENCIES | CODE | SCIENCE EQUIPMENT |
|---|---|---|---|---|---|
| | | | on a string | **IIe-36** | 2. Musical Instrument, Miniature Guitar |
| | | | 4. Relate the frequency (source dependent) and wavelength of sound with the motion of the source and the listener | **STEM_GP12MWS-IIe-37** | Resistance Board |
| | | | 5. Solve problems involving sound and mechanical waves in contexts such as, but not limited to, echolocation, musical instruments, ambulance sounds | **STEM_GP12MWS-IIe-38** | Musical Instrument, Miniature Guitar |
| | | | 6. Perform an experiment investigating the properties of sound waves and analyze the data appropriately—identifying deviations from theoretical expectations when appropriate | **STEM_GP12MWS-IIe-39** | 1. Loudspeaker<br>2. Resonance Tube<br>3. Sound Signal Generator<br>4. Tuning Fork Set |
| **Fluid Mechanics** | 1. Specific gravity<br>2. Pressure<br>3. Pressure vs. Depth Relation<br>4. Pascal's principle<br>5. Buoyancy and Archimedes' Principle<br>6. Continuity equation<br>7. Bernoulli's principle | | 1. Relate density, specific gravity, mass, and volume to each other | **STEM_GP12FM-IIf-40** | |
| | | | 2. Relate pressure to area and force | **STEM_GP12FM-IIf-41** | |
| | | | 3. Relate pressure to fluid density and depth | **STEM_GP12FM-IIf-42** | Open U-Tube Manometer with Pressure Sensor |
| | | | 4. Apply Pascal's principle in analyzing fluids in various systems | **STEM_GP12FM-IIf-43** | |
| | | | 5. Apply the concept of buoyancy and Archimedes' principle | **STEM_GP12FM-IIf-44** | 1. Archimedes Principle<br>2. Beaker, Plastic |
| | | | 6. Explain the limitations of and the assumptions underlying Bernoulli's principle and the continuity equation | **STEM_GP12FM-IIf-45** | Air Blower |

| CONTENT | CONTENT STANDARD | PERFORMANCE STANDARD | LEARNING COMPETENCIES | CODE | SCIENCE EQUIPMENT |
|---|---|---|---|---|---|
| | | | 7. Apply Bernoulli's principle and continuity equation, whenever appropriate, to infer relations involving pressure, elevation, speed, and flux | **STEM_GP12FM-IIf-46** | 1. Air Blower<br>2. Archimedes Principle |
| | | | 8. Solve problems involving fluids in contexts such as, but not limited to, floating and sinking, swimming, Magdeburg hemispheres, boat design, hydraulic devices, and balloon flight | **STEM_GP12FM-IIf-47** | Beaker, Plastic |
| | | | 9. Perform an experiment involving either Continuity and Bernoulli's equation or buoyancy, and analyze the data appropriately—identifying discrepancies between theoretical expectations and experimental results when appropriate | **STEM_GP12FM-IIf-48** | 1. Archimedes Principle<br>2. Air Blower<br>3. Beaker, Plastic |
| **Temperature and Heat** | 1. Zeroth law of thermodynamics and Temperature measurement<br>2. Thermal expansion<br>3. Heat and heat capacity<br>4. Calorimetry | | 1. Explain the connection between the Zeroth Law of Thermodynamics, temperature, thermal equilibrium, and temperature scales | **STEM_GP12TH-IIg-49** | |
| | | | 2. Convert temperatures and temperature differences in the following scales: Fahrenheit, Celsius, Kelvin | **STEM_GP12TH-IIg-50** | |
| | | | 3. Define coefficient of thermal expansion and coefficient of volume expansion | **STEM_GP12TH-IIg-51** | Coefficient of Linear Expansion |
| | | | 4. Calculate volume or length changes of solids due to changes in temperature | **STEM_GP12TH-IIg-52** | |
| | | | 5. Solve problems involving temperature, thermal expansion, heat capacity,heat transfer, and thermal equilibrium in contexts such as, but not limited to, the design of bridges and train rails using steel, relative severity of steam burns and water burns, thermal insulation, sizes of stars, and surface temperatures of planets | **STEM_GP12TH-IIg-53** | Coefficient of Linear Expansion |

| CONTENT | CONTENT STANDARD | PERFORMANCE STANDARD | LEARNING COMPETENCIES | CODE | SCIENCE EQUIPMENT |
|---|---|---|---|---|---|
| | | | 6. Perform an experiment investigating factors affecting thermal energy transfer and analyze the data—identifying deviations from theoretical expectations when appropriate (such as thermal expansion and modes of heat transfer) | **STEM_GP12TH-IIg-54** | |
| | | | 7. Carry out measurements using thermometers | **STEM_GP12TH-IIg-55** | |
| | 5. Mechanisms of heat transfer | | 8. Solve problems using the Stefan-Boltzmann law and the heat current formula for radiation and conduction (1 lecture) | **STEM_GP12TH-IIh-56** | |
| **Ideal Gases and the Laws of Thermodynamics** | 1. Ideal gas law<br>2. Internal energy of an ideal gas<br>3. Heat capacity of an ideal gas<br>4. Thermodynamic systems<br>5. Work done during volume changes<br>6. 1st law of thermodynamics Thermodynamic processes: adiabatic, isothermal, isobaric, isochoric | | 1. Enumerate the properties of an ideal gas | **STEM_GP12GLT-IIh-57** | |
| | | | 2. Solve problems involving ideal gas equations in contexts such as, but not limited to, the design of metal containers for compressed gases | **STEM_GP12GLT-IIh-58** | |
| | | | 3. Distinguish among system, wall, and surroundings | **STEM_GP12GLT-IIh-59** | |
| | | | 4. Interpret PV diagrams of a thermodynamic process | **STEM_GP12GLT-IIh-60** | |
| | | | 5. Compute the work done by a gas using dW=PdV (1 lecture) | **STEM_GP12GLT-IIh-61** | |
| | | | 6. State the relationship between changes internal energy, work done, and thermal energy supplied through the First Law of Thermodynamics | **STEM_GP12GLT-IIh-62** | |
| | | | 7. Differentiate the following thermodynamic processes and show them on a PV diagram: isochoric, isobaric, isothermal, adiabatic, and cyclic | **STEM_GP12GLT-IIh-63** | |
| | | | 8. Use the First Law of Thermodynamics in combination with the known properties of adiabatic, isothermal, isobaric, and | **STEM_GP12GLT-IIh-64** | |

| CONTENT | CONTENT STANDARD | PERFORMANCE STANDARD | LEARNING COMPETENCIES | CODE | SCIENCE EQUIPMENT |
|---|---|---|---|---|---|
| | | | isochoric processes | | |
| | | | 9. Solve problems involving the application of the First Law of Thermodynamics in contexts such as, but not limited to, the boiling of water, cooling a room with an air conditioner, diesel engines, and gases in containers with pistons | **STEM_GP12GLT-IIh-65** | |
| | 7. Heat engines<br>8. Engine cycles<br>9. Entropy<br>10. 2nd law of Thermodynamics<br>11. Reversible and irreversible processes<br>12. Carnot cycle<br>13. Entropy | | 10. Calculate the efficiency of a heat engine | **STEM_GP12GLT-IIi-67** | |
| | | | 11. Describe reversible and irreversible processes | **STEM_GP12GLT-IIi-68** | |
| | | | 12. Explain how entropy is a measure of disorder | **STEM_GP12GLT-IIi-69** | |
| | | | 13. State the 2nd Law of Thermodynamics | **STEM_GP12GLT-IIi-70** | |
| | | | 14. Calculate entropy changes for various processes e.g., isothermal process, free expansion, constant pressure process, etc. | **STEM_GP12GLT-IIi-71** | |
| | | | 15. Describe the Carnot cycle (enumerate the processes involved in the cycle and illustrate the cycle on a PV diagram) | **STEM_GP12GLT-IIi-72** | |
| | | | 16. State Carnot's theorem and use it to calculate the maximum possible efficiency of a heat engine | **STEM_GP12GLT-IIi-73** | |
| | | | 17. Solve problems involving the application of the Second Law of Thermodynamics in context such as, but not limited to, heat engines, heat pumps, internal combustion engines, refrigerators, and fuel economy | **STEM_GP12GLT-IIi-74** | Engine Model |
| **Integration of Rotational motion, Fluids, Oscillations, Gravity and Thermodynamic Concepts** | Refer to weeks 1 to 9 | | (Assessment of the performance standard) | (1 week) | |

**Code Book Legend**

**Sample: STEM_GP12GLT-IIi-73**

| LEGEND | | SAMPLE | |
|---|---|---|---|
| **First Entry** | Learning Area and Strand/ Subject or Specialization | Science, Technology, Engineering and Mathematics General Physics | **STEM_GP12GLT** |
| | Grade Level | Grade 12 | |
| **Uppercase Letter/s** | Domain/Content/ Component/ Topic | Ideal Gases and Laws of Thermodynamics | |
| | | | **-** |
| **Roman Numeral** **Zero if no specific quarter* | Quarter | Second Quarter | **II** |
| **Lowercase Letter/s** **Put a hyphen (-) in between letters to indicate more than a specific week* | Week | Week 9 | **i** |
| | | | **-** |
| **Arabic Number** | Competency | State Carnot's theorem and use it to calculate the maximum possible efficiency of a heat engine | **73** |

| DOMAIN/ COMPONENT | CODE |
|---|---|
| Units and Measurement | EU |
| Vectors | V |
| Kinematics | KIN |
| Newton's Laws | N |
| Work and Energy | WE |
| Center of Mass, Momentum, Impulse and Collisions | MMIC |
| Rotational Equilibrium and Rotational Dynamics | RED |
| Gravity | G |
| Periodic Motion | PM |
| Mechanical Waves and Sounds | MWS |
| Fluid Mechanics | FM |
| Temperature and Heat | TH |
| Ideal Gases and Laws of Thermodynamics | GLT |

**References:**

Cummings, Karen; Laws, Priscilla; Redish, Edward; and Cooney, Patrick. *Understanding Physics.* New Jersey: John Wiley and Sons, 2004. (Reprinted in the Philippines, MG Reprographics for Global Learning Media)

Hewitt, Paul G. *Conceptual Physics, 11th Edition.* San Francisco: Pearson, 2010.

Resnick, Robert; Halliday, David; and Krane, Kenneth. *Physics Vol.2, 5th Edition.* New Jersey: John Wiley and Sons, 2002. (Reprinted in the Philippines by C & E Publishing)

Resnick, Robert; Halliday; David; and Krane, Kenneth. *Physics Vol.1, 5th Edition.* New Jersey: John Wiley and Sons, 2002. (Reprinted in the Philippines by C & E Publishing)

Serway, Raymond, and Belchner, Robert. *Physics for Scientists and Engineers with Modern Physics, 5th Edition.* Orlando: Harcourt College Publishing, 2000.

Tipler, Paul. *Physics for Scientists and Engineers, 4th Edition.* New York: W.H. Freeman and Company, 1999.

Tsokos, K.A. *Physics for the IB Diploma*, *5th Edition.* Cambridge: Cambridge University Press, 2010.

Young, Hugh D., and Freedman, Roger A. *Sears and Zemansky's University with Modern Physics, 11th Edition.* San Francisco: Pearson, 2004.

**180 MINS**

# Units, Physical Quantities, Measurement, Errors and Uncertainties, Graphical Presentation, and Linear Fitting of Data

## Content Standards

The learners demonstrate an understanding of:

- the effect of instruments on measurements;
- uncertainties and deviations in measurement;
- sources and types of error; accuracy versus precision;
- uncertainty of derived quantities;
- error bars; and, graphical analysis: linear fitting and transformation of functional dependence to linear form.

## Performance Standards

The learners shall be able to solve using experimental and theoretical approaches, multi-concept and rich-context problems involving measurement.

## Learning Competencies

At the end of the lesson, the learners:

1. Solve measurement problems involving conversion of units, expression of measurements in scientific notation **(STEM_GP12EU-Ia-1)**
2. Differentiate accuracy from precision **(STEM_GP12EU-Ia-2)**
3. Differentiate random errors from systematic errors **(STEM_GP12EU-Ia-3)**
4. 4. Use the least count concept to estimate errors associated with single measurements **(STEM_GP12EU-Ia-4)**
5. Estimate errors from multiple measurements of a physical quantity using variance **(STEM_GP12EU-Ia-5)**
6. Estimate the uncertainty of a derived quantity from the estimated values and uncertainties of directly measured quantities (**STEM_GP12EU-Ia-6)**
7. Estimate intercepts and slopes—and their uncertainties—in experimental data with linear dependence using the "eyeball method" and/or linear regression formula (**STEM_GP12EU-Ia-7)**

## Specific Learning Objectives:

The learners will be able to solve measurement problems involving conversion of units, expression of measurements in scientific notation; differentiate accuracy from precision; differentiate random errors from systematic errors; use the least count concept to estimate errors associated with single measurements; estimate errors from multiple measurements of a physical quantity using variance; estimate the uncertainty of a derived quantity from the estimated values and uncertainties of directly measured quantities; and estimate intercepts and slopes—and their uncertainties—in experimental data with linear dependence using the "eyeball method" and/or linear regression formula.

## Materials

Ruler, Meterstick, Tape measure, Weighing scale, Timer (or watch)

## Resources


- Resnick, D., Halliday, R., & Krane, K. S. (1991). Physics (4th ed.). Hoboken, NJ: John Wiley & Sons.
- Young, H. D., & Freedman, R. A. (2007). University Physics with modern Physics (12th ed.). Boston, MA: Addison-Wesley.

# INTRODUCTION (10 MINS)

1. Introduce the discipline of Physics:

- Invite learners to give the first idea that come to their minds whenever they hear "Physics".
- Let some learners explain why they have such impressions of the field.
- Emphasize that just as any other scholarly field, Physics helped in shaping the modern world.

2. Steer the discussion towards the notable contributions of Physics to humanity:

- The laws of motion(providing fundamental definitions and concepts to describe motion and derive the origins of interactions between objects in the universe)
- Understanding of light, matter, and physical processes
- Quantum mechanics (towards inventions leading to the components in a cell phone)

3. Physics is science. Physics is fun. It is an exciting adventure in the quest to find out patterns in nature and find means of understanding phenomena through careful deductions based on experimental verification. Explain that in order to study Physics, one requires a sense of discipline. That is, one needs to plan how to study by:

- Understanding how one learns. Explain that everyone is capable of learning Physics especially if one takes advantage of one's unique way of learning. (Those who learn by listening are good in sitting down and taking notes during lectures; those who learn more by engaging others and questioning can take advantage of discussion sessions in class or group study outside classes. )
- Finding time to study. Explain that learning requires time. Easy concepts require less time to learn compared to more difficult ones. Therefore, one has to invest more time in topics one finds more difficult. (Do learners study Physics every day? Does one need to prepare before attending a class? What are the difficult topics one finds?)

# PART 1: PHYSICAL QUANTITIES

# INSTRUCTION/DELIVERY (30 MINS)

**Units**

Explain that Physics is an experimental science. Physicists perform experiments to test hypotheses. Conclusions in experiment are derived from measurements. And physicists use numbers to describe measurements. Such a number is called a physical quantity. However, a physical quantity would make sense to everyone when compared to a reference standard. For example, when one says, that his or her height is 1.5 m, this means that one's height is 1.5 times a meter stick (or a tape measure that is 1-m long). The meter stick is here considered to be the reference standard. Thus, stating that one's height is 1.5 is not as informative.

Since 1960 the system of units used by scientists and engineers is the "metric system", which is officially known as the "International System" or SI units (abbreviation for its French term, Système International).

To make sure that scientists from different parts of the world understand the same thing when referring to a measurement, standards have been defined for measurements of length, time, and mass.

*Length* – 1 m is defined as the distance travelled by light in a vacuum in 1/299,792,458 second. Based on the definition that the speed of light is exactly 299,792,458 m/s.

*Time* – 1 second is defined as 9,192,631,770 cycles of the microwave radiation due to the transition between the two lowest energy states of the Cesium atom. This is measured from an atomic clock using this transition.

Mass – 1 kg is defined to be the mass of a cylinder of platinum-iridium alloy at the International Bureau of Weights and Measures (Sèvres, France).

**Conversion of units**

Discuss that a few countries continue to use the British system of units (e.g., the United States). However, the conversion between the British system of units and SI units have been defined exactly as follows:

*Length: 1 in = 2.54 cm*

*Force: 1 lb = 4.448221615260 newtons*

- The second is exactly the same in both the British and the SI system of units.
- How many inches are there in 3 m?
- How much time would it take for light to travel 10,000 ft?
- How many inches would light travel in 10 fs? (Refer to Table 1 for the unit prefix related to factors of 10).
- How many newtons of force do you need to lift a 34-lb bag? (Intuitively, just assume that you need exactly the same amount of force as the weight of the bag).

**Rounding off numbers**

Ask the learners why one needs to round off numbers. Possible answers may include reference to estimating a measurement, simplifying a report of a measurement, etc.

Discuss the rules of rounding off numbers:

- Know which last digit to keep.
- This last digit remains the same if the next digit is less than 5.
- Increase this last digit if the next digit is 5 or more.

In nuclear physics, atomic nuclei with a magic number of protons or neutrons are very stable. The seven most widely recognized magic numbers as of 2007 are 2, 8, 20, 28, 50, 82, and 126 – round the magic numbers to the nearest 10.

Round off to the nearest 10:

314234, 343, 5567, 245, 7891

Round off to the nearest tenths:

3.1416, 745.1324, 8.345, 67.47

| **Prefix** | **Symbol** | **Factor** | | **Prefix** | **Symbol** | **Factor** |
|---|---|---|---|---|---|---|
| atto | a | 10-18 | | deka | da | $10^{1}$ |
| femto | f | 10-15 | | hecto | h | $10^{2}$ |
| pico | p | 10-12 | | kilo | k | $10^{3}$ |
| nano | n | $10^{-9}$ | | mega | M | $10^{6}$ |
| micro | μ | $10^{-6}$ | | giga | G | $10^{9}$ |
| milli | m | $10^{-3}$ | | tera | T | $10^{12}$ |
| centi | c | $10^{-2}$ | | peta | P | $10^{15}$ |
| deci | d | $10^{-1}$ | | exa | E | $10^{18}$ |

*Système International (SI) prefixes*


4

## EVALUATION AND DISCUSSION (20 MINS)

Conversion of units:

A snail moves 1.0 cm every 20 seconds. What is this in inches per second? Decide how to report the answer (that is, let the learners round off their answers according to their preference).

$$\frac{1.0\,\cancel{cm}}{20s} \times \frac{1\,in}{2.54\,\cancel{cm}} = 0.0196850393700787401574803149606\,3\frac{in}{s}$$

$$\frac{1.0\ cm}{20\ s} = 0.05\frac{cm}{s} = 5.0\times10^{-2}\frac{cm}{s} = 0.020\frac{in}{s} = 2.0\times10^{-2}\frac{in}{s}$$

In the first line, 1.0 cm/20 s was multiplied by the ratio of 1 in to 2.54 cm (which is equal to one). By strategically putting the unit of cm in the denominator, we are able to remove this unit and retain inches. However, based on the calculator, the conversion involves several digits.

In the second line, we divided 1.0 by 20 and retained two digits and rewrote in terms of a factor $10^{-2}$. The final answer is then rounded off to retain two figures.

In performing the conversion, we did two things. We identified the number of *significant figures* and then rounded off the final answer to retain this number of figures. For convenience, the final answer is rewritten in *scientific notation.*

*The number of significant figures refers to all digits to the left of the decimal point (except zeroes after the last non-zero digit) and all digits to the right of the decimal point (including all zeroes).

*Scientific notation is also called the "powers-of-ten notation". This allows one to write only the significant figures multiplied to 10 with the appropriate power. As a shorthand notation, we therefore use only one digit before the decimal point with the rest of the significant figures written after the decimal point.

How many significant figures do the following numbers have?

$1.2343\text{x}10^{10}$

035

23.004

23.000

$2.3\text{x}10^{4}$

Perform the following conversions using the correct number of significant figures in scientific notation:

1. A jeepney tried to overtake a car. The jeepney moves at 40 km/hour: convert this to the British system (feet per second)?
2. It takes about 8.0 minutes for light to travel from the sun to the earth. How far is the sun from the earth (in meters, in feet)?
3. Let learners perform the calculations in groups (two to four people per group). Let volunteers show their answer on the board.

## PART 2: MEASUREMENT UNCERTAINTIES

## MOTIVATION (15 MINS)

1. Measurement and experimentation is fundamental to Physics. To test whether the recognized patterns are consistent, physicists perform experiments, leading to new ways of understanding observable phenomena in nature.
2. Thus, measurement is a primary skill for all scientists. To illustrate issues surrounding this skill, the following measurement activities can be performed by volunteer pairs:

- Body size: weight, height, waistline
- From a volunteer pair, ask one to measure the suggested dimensions of the other person with three trials using a weighing scale and a tape measure.
- Ask the class to express opinions on what the effect of the measurement tool might have on the true value of a measured physical quantity. What about the skill of the one measuring?
- Pulse rate (http://www.webmd.com/heart-disease/pulse-measurement)
- Measure the pulse rate five times on a single person. Is the measurement repeatable?

## INSTRUCTION (30 MINS)

**Scientific notation and significant figures**

Discuss that in reporting a measurement value, one often performs several trials and calculates the average of the measurements to report a representative value. The repeated measurements have a range of values due to several possible sources. For instance, with the use of a tape measure, a length measurement may vary due to the fact that the tape measure is not stretched straight in the same manner in all trials.

So what is the height of a table? A volunteer uses a tape measure to estimate the height of the teacher's table. Should this be reported in millimeters? Centimeters? Meters? Kilometers?

The choice of units can be settled by agreement. However, there are times when the unit chosen is considered most applicable when the choice allows easy access to a mental estimate. Thus, a pencil is measured in centimeters and roads are measured in kilometers.

How high is Mount Apo? How many Filipinos are there in the world? How many children are born every hour in the world?

**Discuss the following:**

- When the length of a table is 1.51 ± 0.02 m, this means that the true value is unlikely to be less than 1.49 m or more than 1.53 m. This is how we report the accuracy of a measurement. The maximum and minimum provides upper and lower bounds to the true value. The shorthand notation is reported as 1.51(2) m. The number enclosed in parentheses indicates the uncertainty in the final digits of the number.
- The measurement can also be presented or expressed in terms of the maximum likely fractional or percent error. Thus, 52 s ± 10% means that the maximum time is not more than 52 s plus 10% of 52 s (which is 57 s, when we round off 5.2 s to 5 s). Here, the fractional error is (5 s)/52 s.
- Discuss that the uncertainty can then be expressed by the number of meaningful digits included in the reported measurement. For instance, in measuring the area of a rectangle, one may proceed by measuring the length of its two sides and the area is calculated by the product of these measurements.

Side 1 = 5.25 cm
Side 2 = 3.15 cm

Note that since the meterstick gives you a *precision* down to a single millimeter, there is uncertainty in the measurement within a millimeter. The side that is a little above 5.2 cm or a little below 5.3 cm is then reported as 5.25 ± 0.05 cm. However, for this example only we will use 5.25 cm.

Area = 5.25 cm × 3.15 cm = 16.5375 $cm^2$ or 16.54 $cm^2$

Since the precision of the meterstick is only down to a millimeter, the uncertainty is assumed to be half a millimeter. The area cannot be reported with a precision lower than half a millimeter and is then rounded off to the nearest 100th.

- Review of significant figures

Convert 45.1 $cm^3$ to $in^3$. Note that since the original number has three significant figures, the conversion to in3 should retain this number of significant figures:

$$45.1\ cm^3 \times \left(\frac{1\ in}{2.54\ cm}\right)^3 = 45.1\ \cancel{cm^3} \times \frac{1\ in^3}{16.387064\ \cancel{cm^3}} = 2.75217085\ldots in^3$$

$$45.1\ cm^3 = 2.75\ in^3$$

Show other examples.

**Review of scientific notation**

Convert 234 km to mm:

$$234\ \cancel{km} \times \frac{1000\ \cancel{m}}{1\ \cancel{km}} \times \frac{100\ cm}{1\ \cancel{m}} = 23400000\ cm$$

$$234\ km = 2.34 \times 10^7\ cm$$

**Reporting a measurement value**

A measurement is limited by the tools used to derive the number to be reported in the correct units as illustrated in the example above (on determining the area of a rectangle).

Now, consider a table with the following sides:

$25.23 \pm 0.02$ cm and $35.13 \pm 0.02$ cm or
25.23(2) cm and 35.13(2) cm

$$25.23\ cm \times 35.13\ cm = 886.3299\ cm^2$$

$$886.3\ cm^2 = 8.863 \times 10^2\ cm^2$$

What about the resulting measurement *error* in determining the area?

Note: The associated *error* in a measurement is not to be attributed to *human error*. Here, we use the term to refer to the associated *uncertainty* in obtaining a representative value for the measurement due to undetermined factors. A *bias* in a measurement can be associated to *systematic errors* that could be due to several factors consistently contributing a predictable direction for the overall error. We will deal with random uncertainties that do not contribute towards a predictable *bias* in a measurement

**Propagation of error**

A measurement x or y is reported as:

$$x \pm \Delta x$$
$$y \pm \Delta y$$

The above indicates that the best estimate of the true value for *x* is found between *x* – Δx and *x* + Δx (the same goes for y).

The central problem in error propagation or uncertainty propagation is best conveyed in the question *"How does one report the result when a derived quantity is dependent on other quantities that can be measured or estimated only with a finite level of precision (i.e. with non-zero uncertainty)?"* It turns out that the rules for error propagation are straightforward when the derived quantity can be expressed as a sum, difference, quotient or product of other quantitites; or when a derived quantity has a power law dependence on  a measured or estimated quantity.

Addition or subtraction: Suppose we want to calculate  the uncertainty or error , Δz, associated with either the sum, z = x+y, or difference,  z = x – y - it is assumed that the quantities *x* and *y*  have uncertainties  Δ*x* and Δ*y*, respectively.

To be more specific, suppose we want to calculate the total mass of two objects. Suppose the mass of Object 1 is x and is estimated to be 79 ± 1 g while the mass of Object 2 is y and estimated to be 65 ± 2 g.

How should the total mass , z = x+y be reported?
Answer: The total mass of the objects is approximately 79g  + 65g = 144 g. But the total mass  can be as high as 80 g + 67 g = 147 g or as low as 78 g + 63 g = 141 g.  The total mass should therefore be reported as 144 ± 3 *g.*

How should the difference in mass, z = x-y, be reported? (Note that the symbol z now denotes the difference instead of the sum of two measurements )

Answer: The mass difference is approximately 79 g – 65 g = 14 g. But that mass difference can be as low as 78 g – 67 g = 11 g or as high as 80 g – 63 g. The mass difference should therefore be reported as 144 ± 3 *g.*

Hence, if $z = x + y$ or $z = x - y$, then the uncertainty of z is just the sum of the uncertainties of x and y: Δz = Δ*x* and Δ*y.*

**Multiplication or division**

Suppose we want to calculate the uncertainty or error , Δz, associated with either the sum, z = xy, or quotient, z = x/ y - it is, again, assumed that the quantities x and y have uncertainties Δx and Δy, respectively. In this case the resulting error is the sum of the fractional errors multiplied by the original measurement.

The fractional uncertainty Δz/z can be calculated through the formula: $\frac{\Delta z}{z} = \frac{\Delta x}{x} + \frac{\Delta y}{y}$

Hence the uncertainty of z is given by: $\Delta z = z\left(\frac{\Delta x}{x} + \frac{\Delta y}{y}\right)$

If the measured quantities are *x* ± Δ*x*, and +Δ*y*, then the if derived quantity is the quotient $z = x/y$. The uncertainty Δz can also be calculated

through the formula $\frac{\Delta z}{z} = \frac{\Delta x}{x} + \frac{\Delta y}{y}$ or equivalently, $\Delta z = z\left(\frac{\Delta x}{x} + \frac{\Delta y}{y}\right)$.

The estimate for the compounded error is conservatively calculated. Hence, the resultant error is taken as the sum of the corresponding errors or fractional errors.

Example: The length and width of a rectangle are measured to be 19 ± 0.5 *cm* and 15 ± 0.5 *cm*. How should the area, A, of the rectangle be reported?

Answer: The area of the rectangle is approximately A = 19 x 15 $cm^2$=285 $cm^2$. The fractional uncertainty is $\frac{\Delta A}{A} = \left(\frac{0.5}{19}\right) + \left(\frac{0.5}{15}\right)$.

Hence $\Delta A = 285\left[\left(\frac{0.5}{19}\right) + \left(\frac{0.5}{15}\right)\right] cm^2 = 17\ cm^2$. The area should therefore be reported as 285 ± 17 $cm^2$

Power law dependence: Suppose the derived quantity z is related to the measure quantity x through the relation $z = x^n$ , then the uncertainty $\Delta z$ can be calculated as follows:

$$z = x^n \rightarrow \frac{\Delta z}{z} = n\frac{\Delta x}{x} \rightarrow \ \Delta z = nz\frac{\Delta x}{x} = nx^{n-1}\Delta x$$

The above prescriptions for estimating the error or uncertainty provide conservative error estimates, the maximum possible error is assumed. However, when the calculated or derived quantity is calculated based on a large number of other quantities a less conservative error estimate is warranted:

For addition or subtraction: $$\Delta z = \sqrt{(\Delta x)^2 + (\Delta y)^2 + \ldots + (\Delta p)^2 + (\Delta q)^2}$$

For multiplication or division: $$\Delta z = z\sqrt{\left(\frac{\Delta x}{x}\right)^2 + \left(\frac{\Delta y}{y}\right)^2 + \ldots + \left(\frac{\Delta p}{p}\right)^2 + \left(\frac{\Delta q}{q}\right)^2}$$

**Statistical treatment**

The arithmetic average of the repeated measurements of a physical quantity is the best representative value of this quantity provided the errors involved is random. Systematic errors cannot be treated statistically.

Mean: $$x_m = \frac{1}{N}\sum_{i=1}^{N} x_i$$

Standard deviation: $$sd = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - x_m)^2}$$

For measurements with associated random uncertainties, the reported value is: mean plus-or-minus standard deviation. Provided many measurements will exhibit a normal distribution, 50% of these measurements would fall within plus-or-minus 0.6745(*sd*) of the mean. Alternatively, 32% of the measurements would lie outside the mean plus-or-minus twice the standard deviation.

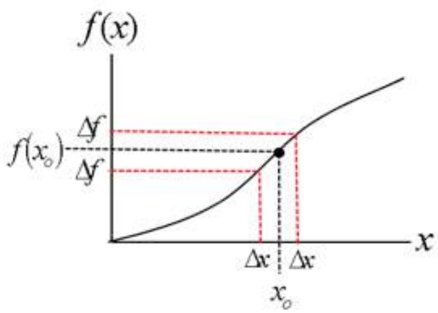
The standard error can be taken as the standard deviation of the means. Upon repeated measurement of the mean for different sets of random samples taken from a population, the standard error is estimated as:

Standard error:

$$sd_{mean} = \frac{sd}{\sqrt{N}}$$

## ENRICHMENT (15 MINS)

If a derived quantity *y* is related to a measured quantity x through the relation *y = f (x)* , the uncertainty, Δ*y* or Δ*f*, in the derived quantity can be obtained as follows:




$$\frac{df}{dx} \approx \frac{\Delta f}{\Delta x}$$

$$\Delta f \approx \Delta x \left( \left. \frac{df}{dx} \right|_{x=x_o} \right)$$

*Figure: Function of one variable and its error Δf. Given a function f(x), the local slope at $x_o$ is calculated as the first derivative at $x_o$.*

Example:

Suppose the measured quantity is reported as $x = x_0 \pm \Delta x$, and the derived quantity is given by

$$y = \sin(x)$$

The uncertainty $\Delta y$ is calculated as follows:

$$\Delta y \approx \Delta x \left( \frac{d}{dx} [\sin(x)] \right) \Big|_{x=x_0} = \Delta x \cos(x_0)$$

Alternatively, the following approach can be used:

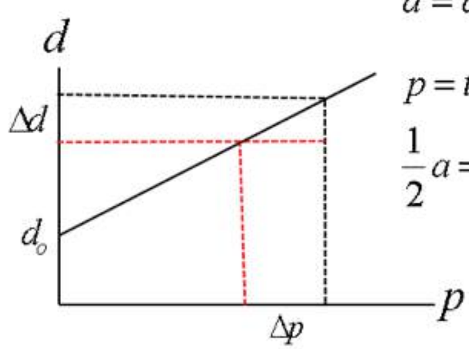
y = sin (x)

$y \pm \Delta y = \sin(x_0 \pm \Delta x) = \sin(x_0)\cos(\Delta x) \pm \cos(x_0)\sin(\Delta x)$

When the uncertainty is small, i.e. $|\Delta x| \ll 1$, one can use the approximations $\sin(\Delta x) \approx \Delta x$ and $\cos(\Delta x) \approx 1$. Hence $y \pm \Delta y \approx \sin(x_0) \pm \Delta x \cos(x_0)$ , and it follows that $\Delta y \approx \cos(x_0)$.

## PART 3: GRAPHING (60 MINUTES)

1. Graphing relations between physical quantities.




$$d = d_o + \frac{1}{2}ap$$

$$p = t^2$$

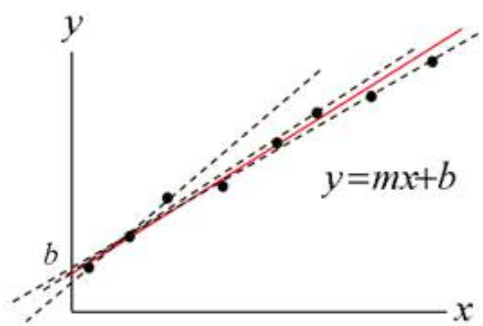
$$\frac{1}{2}a = \frac{\Delta d}{\Delta p}$$

*Figure: Distance related to the square of time (for motions with constant acceleration): the acceleration a can be calculated from the slope of the line, and the intercept at the vertical axis $d_o$ is determined from the graph*

The simplest relation between physical quantities is linear. A smart choice of physical quantities (or a mathematical manipulation) allows one to simplify the study of the relation between these quantities. Figure 3 shows that the relation between the displacement magnitude *d* and the square of the time exhibits a linear relation (implicitly having a constant acceleration; and having no initial velocity). Another example is the simple pendulum, where the frequency of oscillation $f_o$ is proportional to the square-root of the acceleration due to gravity divided by the length of the pendulum *L*. The relation between the frequency of oscillation and the root of the multiplicative inverse of the pendulum length can be explored by repeated measurements or by varying the length *L*. And from the slope, the acceleration due to gravity can be determined.

$$f_0 = \frac{1}{2\pi}\sqrt{g/L} = \left(\frac{1}{2\pi}\sqrt{g}\right)\sqrt{1/L}$$

2. The previous examples showed that the equation of the line can be determined from two parameters, its slope and the constant *y*-intercept. The line can be determined from a set of points by plotting and finding the slope and the y-intercept by finding the best fitting straight line.




*Fitting a line relating y to x, with slope m and y-intercept b. By visual inspection, the solid line (colored red in the online version) has the best fit through all the points compared with the other trials (dashed lines)*

3. The slope and the y-intercept can be determined analytically. The assumption here is that the best fitting line has the least distance from all the points at once. Legendre stated the criterion for the best fitting curve to a set of points. The best fitting curve is the one which has the least sum of deviations from the given set of data points (the Method of Least Squares). More precisely, the curve with the least sum of squared deviations from a set of points has the best fit. From this principle the slope and the y-intercept are determined as follows:

$$y = mx + b$$

$$m = \frac{N\sum_{i=1}^{N}(x_i y_i) - \left(\sum_{i=1}^{N} x_i\right)\left(\sum_{i=1}^{N} y_i\right)}{N\sum_{i=1}^{N} x_i^2 - \left(\sum_{i=1}^{N} x_i\right)^2}$$

$$b = \frac{\left(\sum_{i=1}^{N} x_i^2\right)\left(\sum_{i=1}^{N} y_i\right) - \left(\sum_{i=1}^{N} x_i\right)\left(\sum_{i=1}^{N} x_i y_i\right)}{N\sum_{i=1}^{N} x_i^2 - \left(\sum_{i=1}^{N} x_i\right)^2}$$

The standard deviation of the slope $s_m$ and the y-intercept $s_b$ are as follows:

$$s_m = s_y\sqrt{\frac{n}{n\sum x_i^2 - \left(\sum x_i\right)^2}} \qquad s_b = s_y\sqrt{\frac{\sum x_i^2}{n\sum x_i^2 - \left(\sum x_i\right)^2}}$$

4. The Lab Report

Explain that in performing experiments one has to consider that the findings found can be verified by other scientists. Thus, documenting one's experiments through a Laboratory Report is an essential skill to a future scientist. The sections normally found in a Lab Report  are listed below. For senior high school a maximum length  of  four pages for the lab report is reasonable for a 1 hour experiment.

**Introduction**

- A concise description of the entire experiment (purpose, relevance, methods, significant results and conclusions).

**Objectives**

- A concise and summarized list of what needs to be accomplished in the experiment.

**Background**

- An account of the experiment intended to familiarize the reader with the theory, related research that are relevant to the experiment itself.

**Methods**

- A description of what was performed, which may include a list of equipment and materials used in order to pursue the objectives of the experiment.

**Results**

- A presentation of relevant measurements convincing the reader that the objectives have been performed and accomplished.

**Discussion of Results**

- The interpretation of results directing the reader back to the objectives

**Conclusions**

- Could be part of the previous section but is not intended solely as a summary of results. This section could highlight the novelty of the experiment in relation to other studies performed before.

# Vectors

### Content Standard
The learners demonstrate an understanding of: (1) vectors and vector addition; (2) components of vectors; and (3) unit vectors.

### Performance Standards
The learners shall be able to solve using experimental and theoretical approaches, multiconcept, rich context problems involving vectors.

### Learning Competencies
The learners shall be able to:

1. Differentiate vector and scalar quantities **(STEM_GP12EU-Ia-8)**
2. Perform addition of vectors **(STEM_GP12EU-Ia-9)**
3. Rewrite a vector in component form **(STEM_GP12EU-Ia-10)**
4. Calculate directions and magnitudes of vectors **(STEM_GP12EU-Ia-11)**

### Specific Learning Outcomes
At the end of the lesson, the learners will be able to differentiate vector and scalar quantities; perform addition of vectors; rewrite a vector in component form; and calculate directions and magnitudes of vectors.

**60 MINS**

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction** | Quick review of the previous lessons on physical quantities, and a mathematical refresher on right triangle relations (SOH-CAH-TOA) and the distinction between vectors and scalars | 5 |
| **Motivation** | Exercise illustrating vectors. Options include: paddling on a flowing river, tension game, random walk | 5 |
| **Instruction** | Discussion on the geometric representation of vectors, unit vectors, vector components, and vector addition | 30 |
| **Enrichment** | Seatwork exercises on vectors | 10 |
| **Evaluation** | If the learners have mastered learning competencies for the lesson, and there is time left for an in-class activity, make the class go through an exercise on the components of a rotating vector and introduce rotation matrix. | 10 |

### Materials
For Learners: graphing paper, protractor, ruler

For Teachers: two pcs nylon cord (about 0.5 -m long), meter stick or tape measure

### Resources

1. Resnick, D., Halliday, R., & Krane, K.S. (1991). *Physics* (4th ed.) Hoboken, NJ: John Wiley & Sons.
2. Young, H.D., & Freedman, R. A. (2007). *University Physics with Modern Physics* (12th ed.). Boston, MA: Addison-Wesley.

## INTRODUCTION (5 MINS)

1. Do a quick review of the previous lesson involving physical quantities.
2. Give a mathematical refresher on right triangle relations, SOH-CAH-TOA, and basic properties involving parallelogram .
3. Give several examples and ask which of these quantities are *scalars* or *vectors*. Then ask the learners to give examples of *vectors* and *scalars*.
4. Mention that **vectors** are physical quantities that have both *magnitude* and *direction* while **scalars** are physical quantities that can be represented by a single number

## MOTIVATION (5 MINS)

1. *Option 1*: Discuss with learners scenarios involving paddling upstream, downstream, or across a flowing river. Allow the learners to strategize how should one paddle across the river to traverse the least possible distance?
2. *Option 2*: String tension game (perform with careful supervision)
   -Ask for two volunteers
   -One learner would hold a nylon cord at length across two hands
   -The second learner loops his nylon cord onto the other learner's cord
   -The second learner pulls slowly on the cord; if the loop is closer to the other learner's hand, ask the class how the learner would feel the pull on each hand, and why
3. *Option 3*: Total displacement in a *random walk*
   -Ask for six volunteers
   -Blindfold the first volunteer about a meter away from the board, let the volunteer turn around two to three times to give a little spatial disorientation, then ask this learner to walk towards the board and draw a dot on the board. Do the same for the next volunteer then draw an arrow connecting the two subsequent dots with the previous one as starting point and the current dot with the arrow head. Do the same for the rest of the volunteers.

After the exercise, indicate the vector of displacement (thick, gray arrow) by connecting the first position with the last position.  This vector is the sum of all the drawn vectors by connecting the endpoint to the starting point of the next.

**Teacher tip**

*For Option 1* – In paddling across the running river, you may introduce an initial angle or velocity or let the students discuss their relation.

*For Option 2*: If necessary, you may provide the hint that a stronger force, in this case the tension, must be represented by a longer vector.

An intuition on tension and length relation can be discussed if necessary. Vectors can be drawn separately before making their origins coincident in illustrating geometric addition.

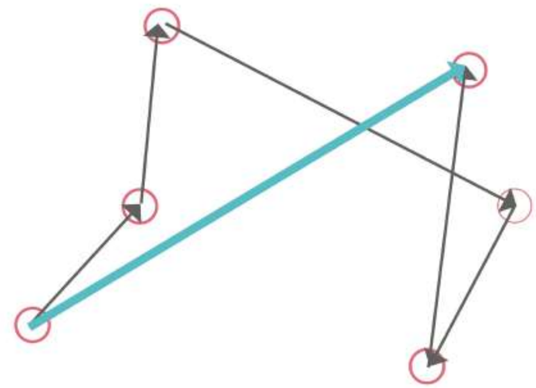


Figure: Summing vectors by sequential connecting of dots based on the random walk exercise

## INSTRUCTION (30 MINS)

**Part 1: Geometric representation of vectors**

1. If Option 3 above was performed, use the resulting diagram to introduce displacement as a vector. Otherwise, illustrate on the board the magnitude and direction of a vector using displacement (with a starting point and an ending point, where the arrow head is at the ending point).

$$\vec{R} = \vec{r}_1 + \vec{r}_2 + \vec{r}_3 + \vec{r}_4 + \vec{r}_5$$

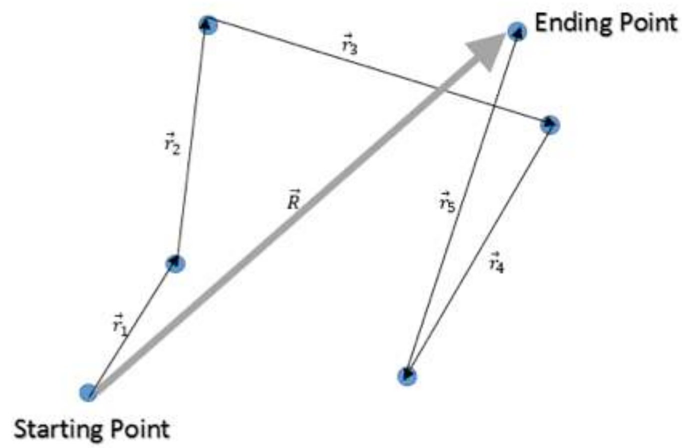



*Figure 2: Geometric sum of vectors example. The sum is independent of the actual path but is subtended between the starting and ending points of the displacement steps*

2. Discuss the following notational conventions:
A vector is usually represented by either a letter with an arrow above the letter: $\vec{A}, \vec{B},\ \vec{a}, \vec{b},$ etc or a bold-face letter: **A, B, a, b** etc.

The magnitude of a vector is represented by either a lightface letter without an arrow on top or the vector symbol with vertical bars on both sides. The magnitude of vector $\vec{A}$ can be written as $A$ or $\vec{A}$ or **A.**

3. Illustrate the addition of vectors using perpendicular displacements as shown below (where the thick gray arrow represent the sum of the vectors $\vec{A}$ and *B):*

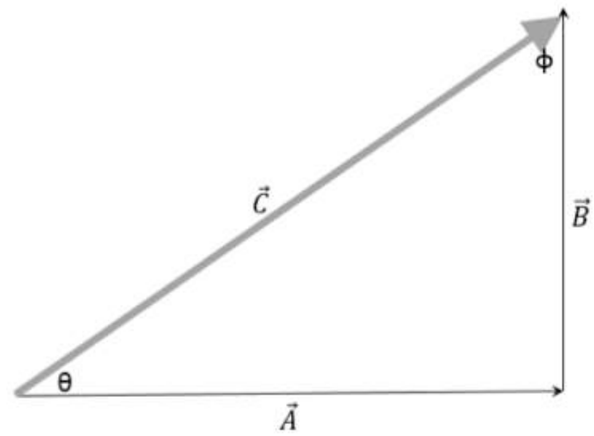



*Figure: Vector addition illustrated in a right triangle configuration*

Explain how the magnitude of vector **C** can be expressed in terms of the magnitude of vector **A** and the magnitude of vector **B** by using the Pythagorean theorem.

The final equation should be $|\vec{C}| = \sqrt{|\vec{A}|^2 + |\vec{B}|^2}.$

4. Explain how the components of vector **C** in the direction parallel to the vectors **A** and **B** can be expressed in terms of the magnitude of vector **C** and the cosines or sines of the angles ∅ and *Ø*.

The component of vector **C** in the direction parallel to **A** is |**C**| cos ( ∅ )

The component of vector **C** in the direction parallel to **B** is |**C**| cos ( *Ø )*

5. Use the *parallelogram method* to illustrate the sum of two vectors. Give more examples for learners to work with on the board.

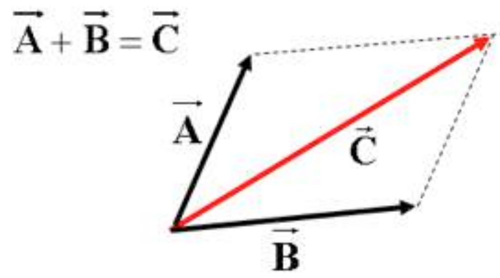



*Figure: Vector addition using the parallelogram method*

6. Illustrate vector subtraction by adding a vector to the negative direction of another vector. Compare the direction of the difference and the sum of vectors **A** and **B**. Indicate that vectors of the same magnitude but opposite directions are *anti-parallel* vectors.

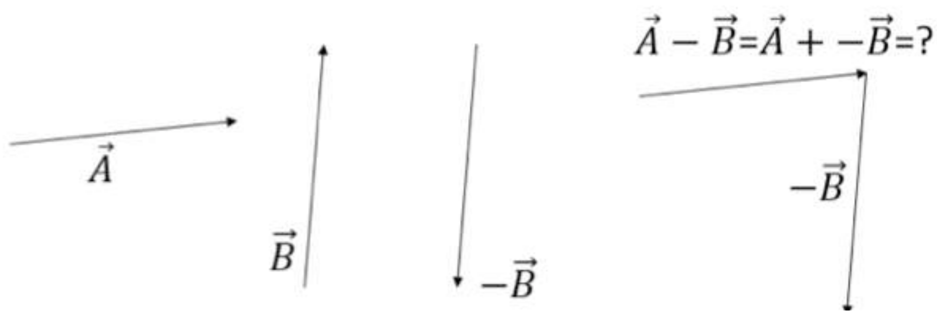
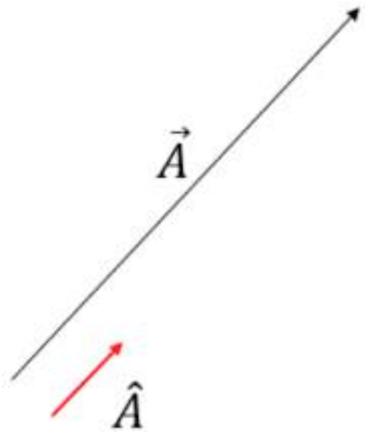



*Figure: Subtraction of vectors. Geometrically, vector subtraction is done by adding the vector minuend to the anti-parallel vector of the subtrahend. Note: the subtrahend is the quantity subtracted from the minuend.*

7. Discuss when vectors are *parallel* and when they are *equal*.

**Part 2: The Unit Vector**

1. Explain that the direction of a vector can be represented by a unit vector that is parallel to that vector.
2. Using the algebraic representation of a vector, calculate the components of the *unit vector* parallel to that vector.




$$\hat{A} = \vec{A}/|\vec{A}|$$

Figure: Unit vector

3. Indicate how to write a unit vector by using a caret or a hat: $\hat{\mathbf{A}}$

**Part 3: Vector components**

1. Discuss that vectors can be represented in terms of *components* of the vectors and unit vectors. For example, a vector with no z-component, can be represented as:

$$\vec{\mathbf{A}} = A_x\hat{\mathbf{i}} + A_y\hat{\mathbf{j}}$$

2. Discuss vectors and their addition using the *quadrant plane* to illustrate how the signs of the components vary depending on the location on the *quadrant plane* as sections in the two-dimensional Cartesian coordinate system.
3. Extend discussion to include vectors in three dimensions.

$$\vec{\mathbf{A}} = A_x\hat{\mathbf{i}} + A_y\hat{\mathbf{j}} + A_z\hat{\mathbf{k}}$$

4. Discuss how to sum (or subtract vectors) algebraically using the vector components.

$$\vec{\mathbf{A}} = A_x\hat{\mathbf{i}} + A_y\hat{\mathbf{j}} + A_z\hat{\mathbf{k}}$$
$$\vec{\mathbf{B}} = B_x\hat{\mathbf{i}} + B_y\hat{\mathbf{j}} + B_z\hat{\mathbf{k}}$$
$$\vec{\mathbf{C}} = \vec{\mathbf{A}} \pm \vec{\mathbf{B}} = (A_x \pm B_x)\hat{\mathbf{i}} + (A_y \pm B_y)\hat{\mathbf{j}} + (A_z \pm B_z)\hat{\mathbf{k}}$$

## ENRICHMENT (10 OR 15 MINUTES)

Ask the learners to do the seatwork exercises of the following type (no calculators allowed):

Calculation of vector magnitudes: Calculate the magnitude of the vector $\vec{A} = \hat{\imath} + 3\hat{\jmath} - 5\hat{k}$

Addition of vectors using components: Add the vectors $\vec{A} = \hat{\imath} + 3\hat{\jmath} - 5\hat{k}$ and $\vec{B} = 2\hat{\imath} - 4\hat{\jmath} + 3\hat{k}$

Determination of vector components using triangles : Determine the x-component and y-component of a vector with magnitude 20.0 that is directed at a 30° angle as measured counterclockwise from the positive x direction.

## EVALUATION (10 OR 15 MINUTES)

For group discussions or for advanced learners or for homework

1. Illustrate on the board how the components of a uniformly rotating unit vector changes with time. Note that this magnitude varies as the cosine and sine of the rotation angle (*the angular velocity magnitude multiplied with time, ø = ωt)*

**Teacher tip**

Some learners may benefit if you continually rotate a stick while explaining how the components of the vector change with time.

2. Calculate the components of a rotated unit vector and introduce the *rotation matrix*. This can be extended to vectors with arbitrary magnitude.

Draw a vector, $\vec{A}$ that is ø degrees from the horizontal or x-axis. This vector is then rotated by ø degrees. Refer to the following figure.

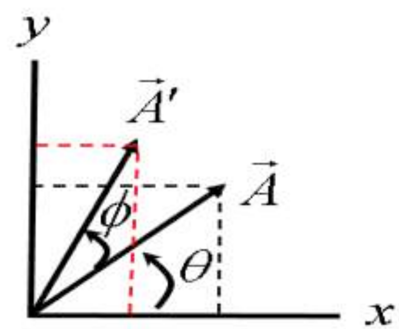



*Figure: Rotating a vector using a matrix multiplication*

Calculate the components of the new vector that is ø + ø degrees from the horizontal by using trigonometric identities as shown below.

The two equations can then be re-written using *matrix notation* where the 2 × 2 (two rows by two columns) matrix is called the *rotation matrix.*

For now, it can simply be agreed that this way of writing simultaneous equations is convenient. That is, a way to separate vector components (into a column) and the 2 × 2 matrix that operates on this column of numbers to yield a rotated vector, also written as a column of components.

The other column matrices are the rotated unit vector (ø + ø degrees from the horizontal) and the original vector (ø degrees from the horizontal) with the indicated components. This can be generalized by multiplying both sides with the same arbitrary length. Thus, the components of the rotated vector (on 2D) can be calculated using the rotation matrix.

$$cos(\theta + \phi) = cos\theta cos\phi - sin\theta sin\phi = cos\phi cos\theta - sin\phi sin\theta$$
$$sin(\theta + \phi) = sin\theta cos\phi + cos\theta sin\phi = sin\phi cos\theta + cos\phi sin\theta$$

$$\begin{bmatrix} cos(\theta + \phi) \\ sin(\theta + \phi) \end{bmatrix} = \begin{bmatrix} cos\phi & -sin\phi \\ sin\phi & cos\phi \end{bmatrix} \begin{bmatrix} cos\theta \\ sin\theta \end{bmatrix}$$

$$A \begin{bmatrix} cos(\theta + \phi) \\ sin(\theta + \phi) \end{bmatrix} = A \begin{bmatrix} cos\phi & -sin\phi \\ sin\phi & cos\phi \end{bmatrix} \begin{bmatrix} cos\theta \\ sin\theta \end{bmatrix}$$

$$\begin{bmatrix} A\ cos(\theta + \phi) \\ A\ sin(\theta + \phi) \end{bmatrix} = \begin{bmatrix} cos\phi & -sin\phi \\ sin\phi & cos\phi \end{bmatrix} \begin{bmatrix} A\ cos\theta \\ A\ sin\theta \end{bmatrix}$$

$$\begin{bmatrix} A'_x \\ A'_y \end{bmatrix} = \begin{bmatrix} cos\phi & -sin\phi \\ sin\phi & cos\phi \end{bmatrix} \begin{bmatrix} A_x \\ A_y \end{bmatrix}$$

$$A'_x = A_x cos\phi - A_y sin\phi$$

$$A'_y = A_x sin\phi + A_y cos\phi$$

60 MINS

# Displacement, Time, Average Velocity, Instantaneous Velocity

**Content Standard**
The learners demonstrate an understanding of position, time, distance, displacement, speed, average velocity, and instantaneous velocity.

**Performance Standards**
The learners shall be able to solve using experimental and theoretical approaches, multi-concept and rich-context problems involving displacement, time, average velocity, and instantaneous velocity.

**Learning Competencies**
The learners shall be able to:

1. Convert a verbal description of a physical situation involving uniform acceleration in one dimension into a mathematical description **(STEM_GP12KIN-Ib-12)**
2. Differentiate average velocity from instantaneous velocity
3. Recognize whether or not a physical situation involves constant velocity or constant acceleration **(STEM_GP12KIN-Ib-13)**

Interpret displacement and velocity , respectively, as areas under velocity-versus-time and acceleration-versus-time curves **(STEM_GP12KIN-Ib-14)**

**Specific Learning Outcomes**
The learners should be able to convert a verbal description of a physical situation involving uniform acceleration in one dimension into a mathematical description; differentiate average velocity from instantaneous velocity; introduce acceleration; recognize whether or not a physical situation involves constant velocity or constant acceleration; and interpret displacement and velocity , respectively, as areas under velocity-versus-time and acceleration-versus-time curves.

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction/ Motivation** | Review the previous lesson on vectors with some emphasis on the definition of displacement. Explain how the use of vectors leads to more precise descriptions of motion. Conduct a walking activity. Ask the learners to differentiate speed and velocity. | 15 |
| **Instruction** | Discussion on the aspects of motion along a straight line | 25 |
| **Enrichment** | Seatwork exercises on vectors | 20 |

**Materials**
Timer (or watch)

Meter stick (or tape measure)

**Resources**

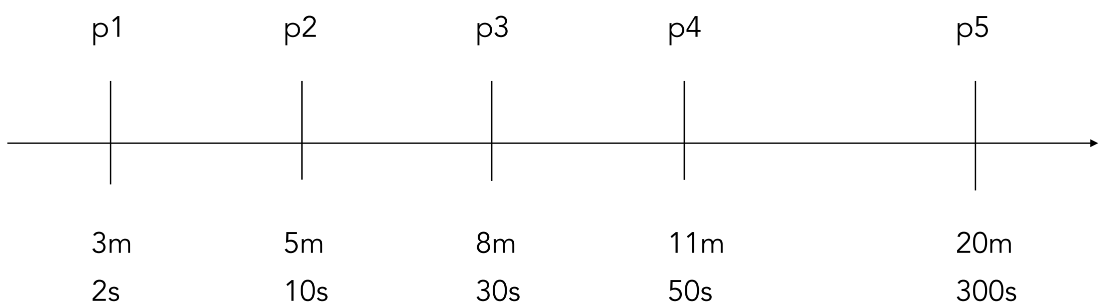
1. Resnick, D., Halliday, R., & Krane, K.S. (1991). *Physics* (4th ed.) Hoboken, NJ: John Wiley & Sons.
2. Young, H.D., & Freedman, R. A. (2007). *University Physics with Modern Physics* (12th ed.). Boston, MA: Addison-Wesley.

## INTRODUCTION (15 MINS)

1. Do a quick review of the previous lesson on vectors with some emphasis on the definition of displacement.
2. In describing how objects move introduce how the use of distance and time leads to the more precise use by physicists of vectors to quantify motion with velocity and acceleration (here, defined only as requiring change in velocity)
3. Ask for two volunteers. Instruct one to walk fast in a straight line from one end of the classroom to another as the other records the duration time (using his or her watch or timer). The covered distance is measured using the meter stick (or tape measure). Repeat the activity but this time let the volunteers switch tasks and ask the other volunteer to walk as fast as the first volunteer from the same ends of the classroom. Is the second volunteer able to walk as fast as the first? Another pair of volunteers might do better than the first pair.
4. Ask the class what the difference is between speed and velocity.

## INSTRUCTION (25 MINS)

1. Discuss how to calculate the average velocity using positions on a number line, with recorded arrival time and covered distance (p1, p2, …, p5). For instance at p1, $x_1$ = 3m, $t_1$ = 2s, etc.




The average velocity is calculated as the ratio between the displacement and the time interval during the displacement. Thus, the average velocity between p1 and p2 can be calculated as:

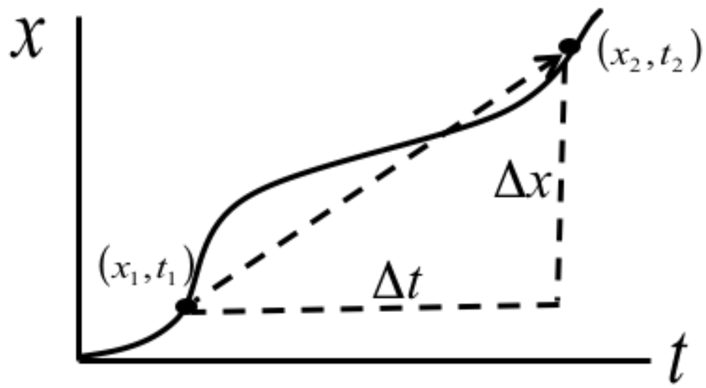
$$v_{av} = \frac{\Delta x}{\Delta t} = \frac{x_2 - x_1}{t_2 - t_1} = \frac{5\ m - 3\ m}{10\ s - 2\ s} = 0.25\ m/s$$

What is the average velocity from position p2 to p5?

Note that although the positive direction is often taken to be the rightward, upward, or eastward, we are free to assign any other direction as a positive direction. However, after the positive direction has been assigned, the opposite direction has to be towards the negative.

2. Emphasize that the average velocity between the given coordinates above vary (e.g., between p1 to p2 and p1 to p4). The displacement along the coordinate x can be graphed as a function of time *t*.

*Figure: Average velocity.*




Discuss that the average velocity from a coordinate $x_1$ to $x_2$ is taken as if the motion is along a straight line between said positions at the given time duration. Hence, the average velocity is geometrically the slope between these positions.

Is the average velocity the same as the average speed?

3. Now, discuss the notion of *instantaneous velocity v* as the slope of the tangential line at a given point. Mathematically, this is the **derivative** of *x* with respect to *t*.

$$\lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} = \frac{dx}{dt} = v$$

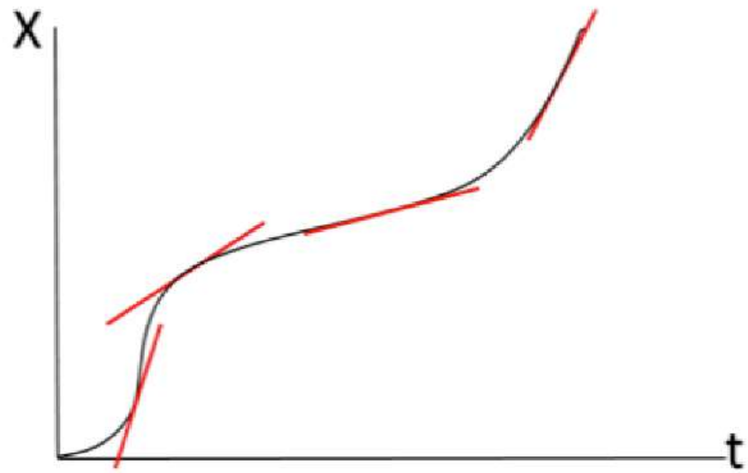



*Figure 2: Tangential lines*

4. Discuss which time points in Figure 3 (left) correspond to motion with constant or non-constant velocity, negative or positive constant velocity.

(Answers: The velocity is non-constant in the time intervals from $t_0$ to $t_1$, and from $t_2$ to $t_3$. The velocity is constant in the time intervals from $t_1$ to $t_2$, and from $t_3$ to $t_4$. The velocity is constant and positive in the time interval from $t_1$ to $t_2$. The velocity is constant and negative in the time interval from $t_3$ to $t_4$ )

Figure 3 (right) shows instantaneous velocities as slopes at specific time points. Discuss how the values of the instantaneous velocity vary as you move from $v_1$ to $v_6$.

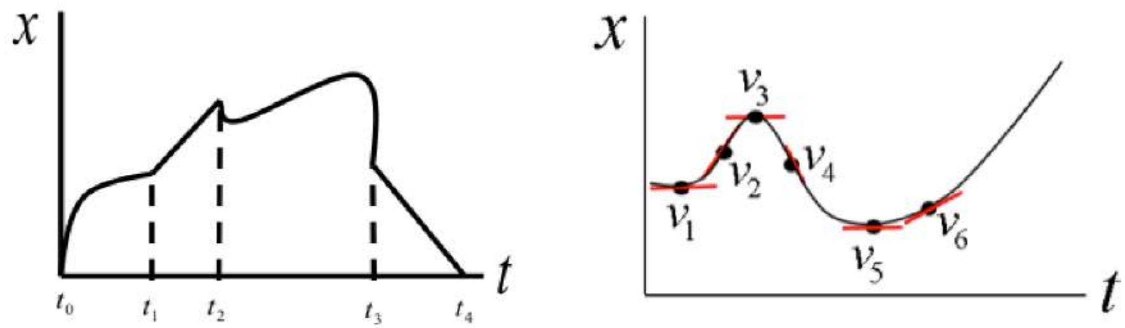



*Figure 3: x-t graph*

5. Show how one can derive the displacement based on the expression for the average velocity:

$$v_{av} = \frac{\Delta x}{\Delta t} \rightarrow \Delta x = v_{av}\Delta t$$

Note that when the velocity is constant, so is the average velocity between any two separate time points. Thus, the total displacement magnitude is the rectangular area under the velocity-versus-time graph (subtended by the change in time).

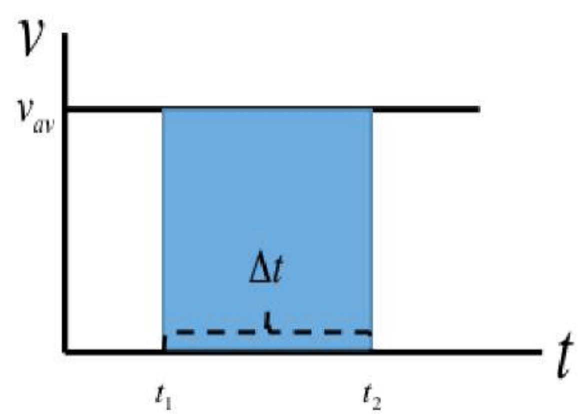



*Figure 4: Constant velocity*

6. Show that for a time varying velocity, the total displacement can be calculated in a similar manner by summing the rectangular areas defined by small intervals in time and the local average velocity. The local average velocity is then approximately the value of the velocity at a given number of time intervals. Say, there are *n* time intervals between time $t_1$ and $t_2$, the total displacement *x* is obtained by summing the displacements from the small time intervals as follows:

$$x = \sum_{i=1}^{N} \Delta x_i = \sum_{i=1}^{N} v_i \Delta t$$

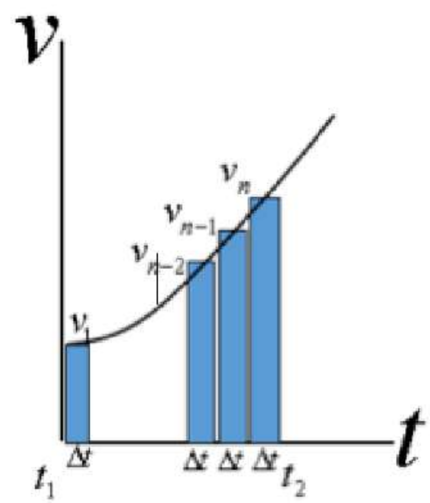



*Figure 5: Sum of discrete areas under the velocity-versus-time graph*

7. Discuss that as the time interval becomes infinitesimally small, the summation becomes an integral. Thus, the total displacement is the area under the curve of the velocity as a function of time between the time points in question.

$$x = \lim_{N\to\infty,\Delta t\to 0} \sum_{i=1}^{N} v_i \Delta t = \int_{t_1}^{t_2} v(t)dt$$

8. Introduce average acceleration as the change in velocity divided by the elapsed time (in preparation for the next lesson).

## ENRICHMENT (20 MINS)

Ask the learners to do seat work exercises of the following type:

Calculation of average velocities given initial and final position and time:

The x-coordinates of an object at time t = 1.00 s and t = 4.00 s are 3.00 m and 5.00 m respectively. Calculate the average velocity of the object on the time interval t = 1.00 s to 4.00 s.

Calculation of the instantaneous velocity at a specific time, given x as a function of time: The position of an object is $x(t)$ = 1.00 + 2.00 t - 3.00 $t^2$, where x is in meters and t is in seconds. Calculate the instantaneous velocity of the object at time t =3.00 s.

Calculate the total displacement over a time interval, given the velocity as a function of time:

The velocity of an object is $v(t)$ = 1.00 - 3.00 $t^2$, where v is in meters per second and t is in seconds. Calculate the displacement of the object in the time interval from t = 1.00 s to t =2.00 s.

60 MINS

# Average and Instantaneous Acceleration

**Content Standard**
The learners shall be able to solve, using experimental and theoretical approaches, multi-concept and rich-context problems involving the use of average and instantaneous accelerations.

**Performance Standards**
The learners shall be able to solve using experimental and theoretical approaches, multi-concept and rich-context problems involving displacement, time, average velocity, and instantaneous velocity.

**Learning Competencies**
The learners shall be able to:

1. Convert a verbal description of a physical situation involving uniform acceleration in one dimension into a mathematical description **(STEM_GP12KIN-Ib-12)**
2. Recognize whether or not a physical situation involves constant velocity or constant acceleration **(STEM_GP12KIN-Ib-13)**
3. Interpret velocity and acceleration, respectively, as slopes of position versus time and velocity versus time curves (**STEM_GP12KIN-Ib-15)**
4. Construct velocity versus time and acceleration versus time graphs, respectively, corresponding to a given position versus time-graph and velocity versus time graph and vice versa **(STEM_GP12KIN-Ib-16)**

**Specific Learning Outcomes**
The learners should be able to recognize whether or not a physical situation involves constant velocity or constant acceleration; convert a verbal description of a physical situation involving uniform acceleration in one dimension into a mathematical description; interpret velocity and acceleration, respectively, as slopes of position versus time and velocity versus time curves; Construct velocity versus time and acceleration versus time graphs, respectively, corresponding to a given position versus time-graph and velocity versus time graph and vice versa

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction/ Motivation** | Review the previous lesson on displacement, average velocity and instantaneous velocity | 5 |
| **Instruction** | Discussion on the aspects of 1D - motion | 20 |
| **Delivery** | Series of exercises on the interpretation and construction of position vs. time, velocity vs. time, and acceleration vs. time curves. | 20 |
| **Enrichment** | Written exercise involving the interpretation of a sinusoidal displacement versus time graph | 15 |

**Materials**
Graphing papers, protractor, ruler

**Resources**

1. Resnick, D., Halliday, R., & Krane, K.S. (1991). *Physics* (4th ed.) Hoboken, NJ: John Wiley & Sons.
2. Young, H.D., & Freedman, R. A. (2007). *University Physics with Modern Physics* (12th ed.). Boston, MA: Addison-Wesley.

## INTRODUCTION/MOTIVATION (5 MINS)

Do a quick review of the previous lesson on displacement, average velocity and instantaneous velocity.

## INSTRUCTION (20MINS)

The acceleration of a moving object is a measure of its change in velocity. Discuss how to calculate the average acceleration from the ratio of the change in velocity to the time elapsed during this change.

$$a_{av} = \frac{\Delta v}{\Delta t} = \frac{v_2 - v_1}{t_2 - t_1}$$

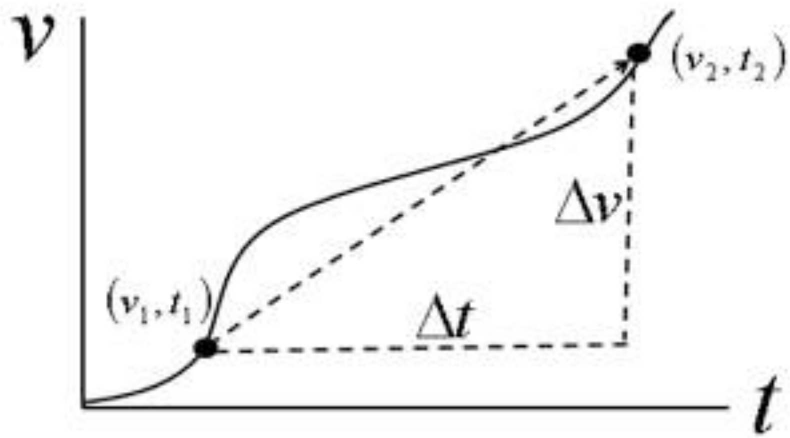



*Figure 1: Average acceleration*

Recall that the first derivative of the displacement with respect to time is the instantaneous velocity. Discuss that the instantaneous acceleration is the first derivative of the velocity with respect to time:

$$a = \lim_{\Delta t \to 0} \frac{\Delta v}{\Delta t} = \frac{dv}{dt}$$

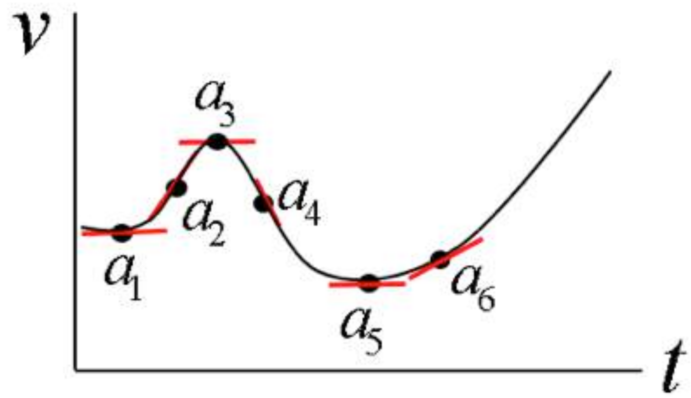



*Figure 2: Instantaneous acceleration*

Thus, given the displacement as a function of time, the acceleration can be calculated as a function of time by successive applications of the time derivative:

$$a = \frac{dv}{dt} = \frac{d}{dt}\frac{dx}{dt} = \frac{d^2x}{dt^2}$$

Given a constant acceleration, the change in velocity (from an initial velocity) can be calculated from the constant average velocity multiplied by the time interval.

$$a_{av} = \frac{\Delta v}{\Delta t} \rightarrow \Delta v = a_{av}\Delta t$$

$$v_2 - v_1 = a_{av}\Delta t$$

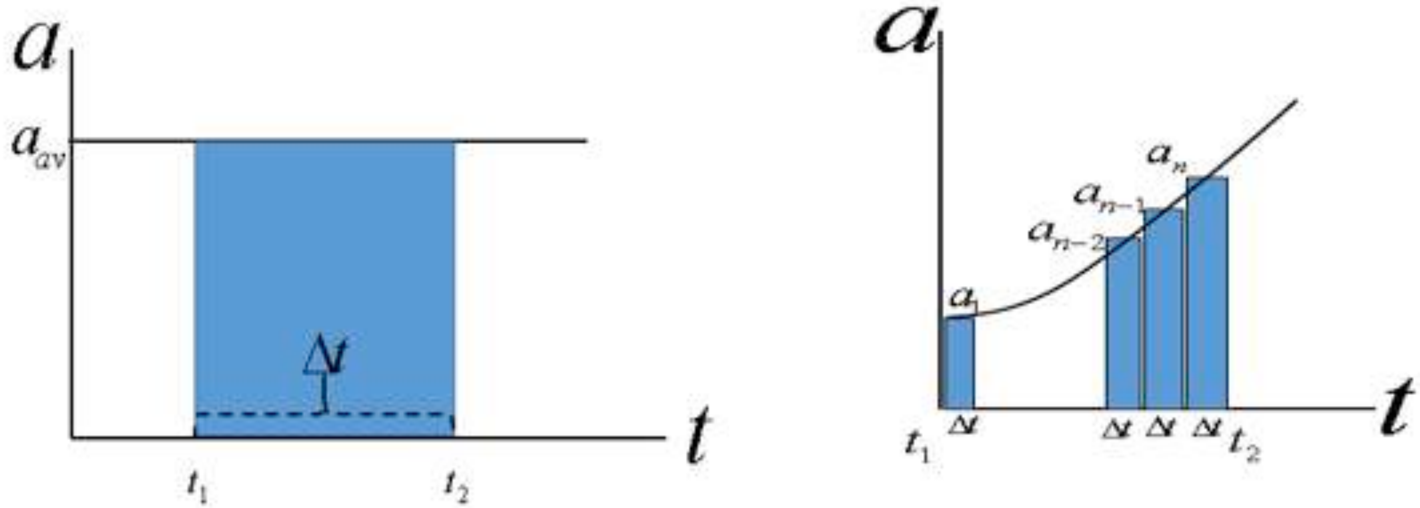



*Figure 3: Velocity as area under the acceleration versus time curve*

**Special case: motion with constant acceleration**

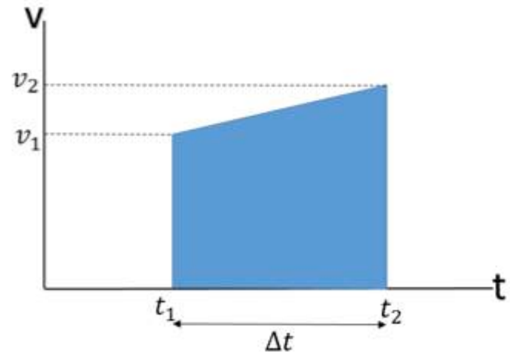
Derive the following relations (for constant acceleration):

Based on the definition of the average acceleration, we can derive an equation relating the final velocity to the initial velocity, acceleration, and time elapsed.

$$a_{av} = a = \frac{\Delta v}{\Delta t} \rightarrow \Delta v = a_{av}\Delta t = a\Delta t$$

$$\text{Eq.1: } v_2 - v_1 = a\Delta t \rightarrow v_2 = v_1 + a\Delta t$$

Use the definition of average velocity and the notion that the displacement is an area under the velocity vs. time curve to derive an equation relating the average velocity to the initial and final velocities. The relevant area for calculating the displacement from time $t^1$ to time $t^2$ is that of the blue trapezoid on the right.




$$\Delta x = \frac{1}{2}(v_1 + v_2)\Delta t$$

Eq.2: $v_{av} = \frac{\Delta x}{\Delta t} = \frac{1}{2}(v_1 + v_2)$

Use Eq.1 and the relation between displacement, initial velocity, and final velocity to derive an equation relating the displacement to the initial velocity, acceleration, and time elapsed (Eq.3); and another equation relating the displacement to the acceleration, and the initial and final velocities (Eq.4).

$$\Delta x = \frac{1}{2}(v_1 + v_2)\Delta t = \frac{1}{2}(v_1 + v_1 + a\Delta t)\Delta t$$

or

Eq.3: $\Delta x = v_1\,\Delta t + \frac{1}{2}a(\Delta t)^2$

$$\Delta x = \frac{1}{2}(v_1 + v_2)\Delta t = \frac{1}{2}(v_1 + v_2)\frac{v_2 - v_1}{a}$$

or

Eq.4: $\Delta x = \frac{{v_2}^2 - {v_1}^2}{2a}$

Discuss that with a time-varying acceleration, the total change in velocity (from an initial velocity) can be calculated as the area under the acceleration versus time curve (for a given time duration). Given a constant acceleration (Figure 3), the velocity change is defined by the rectangular area under the acceleration versus time curve subtended by the initial and final time. Thus, with a continuously time-varying acceleration, the area under the curve is approximated by the sum of the small rectangular areas defined by the product of small time intervals and the local average acceleration. This summation becomes an integral when the time duration increments become infinitesimally small.

$$v - v_0 = \lim_{\substack{\Delta t \to 0 \\ N \to \infty}} \sum_{i=1}^{N} a_i \Delta t = \int_{t_1}^{t_2} a(t)dt$$

## DELIVERY (20 MINS)

Lead the learners through a series of exercises on the interpretation and construction of position vs. time, velocity vs. time, and acceleration vs. time curves. Review the relations between displacement and velocity, velocity expressed as time derivatives and area under the curve within a time interval. Next, discuss how one can identify whether a velocity is constant (zero, positive or negative), or time varying (decreasing or increasing) using Figure 4.

Warning: the non-linear parts of the graph were strategically chosen as sections of a parabola—hence, the corresponding first derivate of these sections is either a negatively sloping line (for a downward opening parabola) or a positively sloping line (for an upward opening parabola)

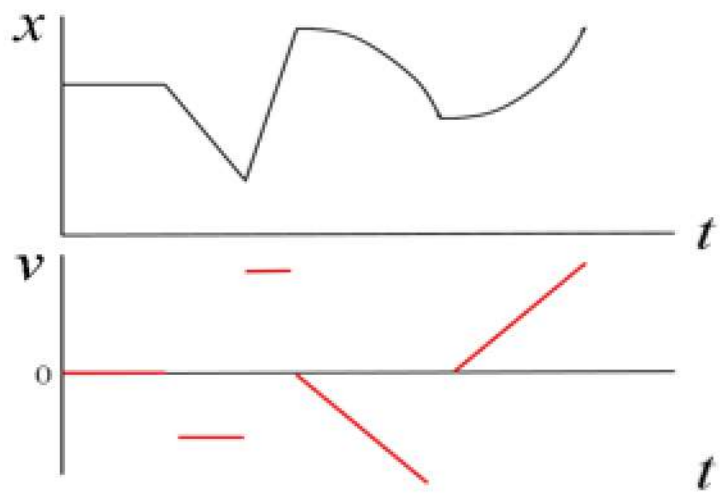



*Figure 4: Displacement versus time and the corresponding velocity graphs*

Replace the displacement variable with velocity in Figure 4 (which now becomes Figure 5) and discuss what the related acceleration becomes (constant or time varying).

Warning: the non-linear part of the graph were strategically chosen as sections of a parabola—hence, the corresponding first derivate of these sections is either a negatively sloping line (for a downward opening parabola) or a positively sloping line (for an upward opening parabola)

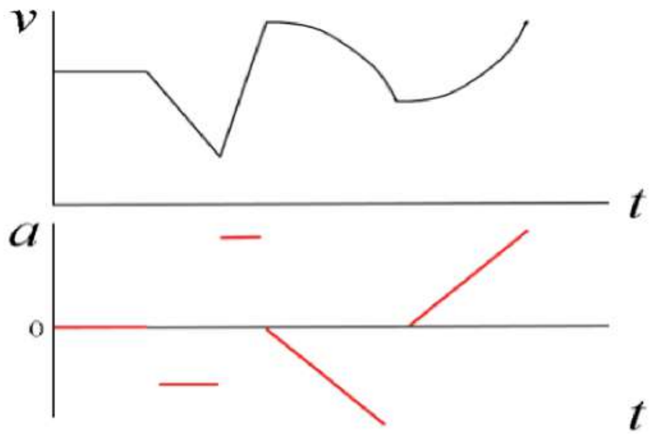



*Figure 5: Velocity versus time and the corresponding acceleration graphs.*

**Summary:**

*Displacement versus time:*

- Graph of a line with positive/negative slope ⟶ positive/negative constant velocity
- Graph with monotonically or constantly increasing slope ⟶ increasing velocity
- Graph with monotonically or constantly decreasing slope ⟶ decreasing velocity

*Velocity versus time:*

- Graph of a line with positive/negative slope ⟶ positive/negative constant acceleration
- Graph with monotonically or constantly increasing slope ⟶ increasing acceleration
- Graph with monotonically or constantly decreasing slope ⟶ decreasing acceleration

## ENRICHMENT (15 MINS)

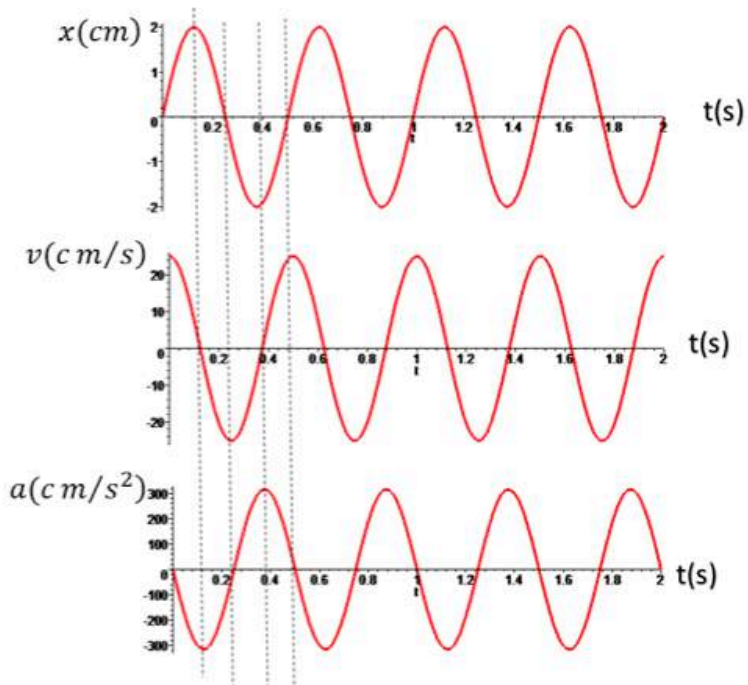
Ask the learners to solve a problem of the following type:

1. Given a sinusoidal displacement vs. time graph (displacement = A sin*(bt)*; *b* = 4π/*s*, A = 2 cm), ask the class to graph the corresponding velocity vs. time and acceleration vs. time graphs. (Recall that the velocity is the first derivative of the displacement with respect to time and that the acceleration is the first derivative with respect to time.)

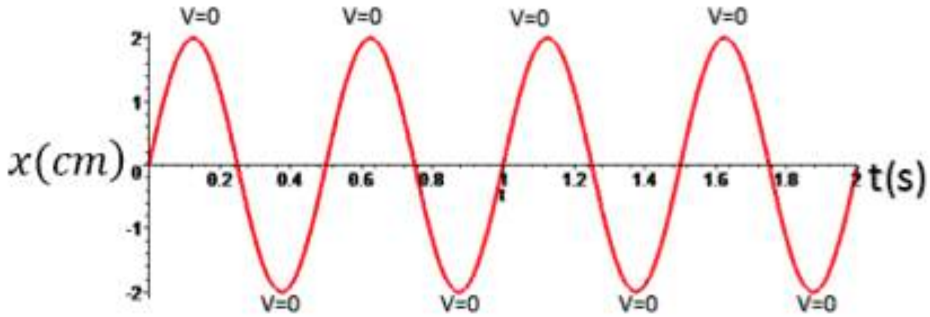
- At which parts of the displacement vs. time graph is the velocity zero? maximum? minimum?
- At which parts of the displacement vs time graph is the acceleration zero? maximum? minimum?
- What happens to the velocity and acceleration at the positions where the displacement is zero?

## APPENDIX: ANSWERS TO ENRICHMENT/EVALUATION EXERCISE

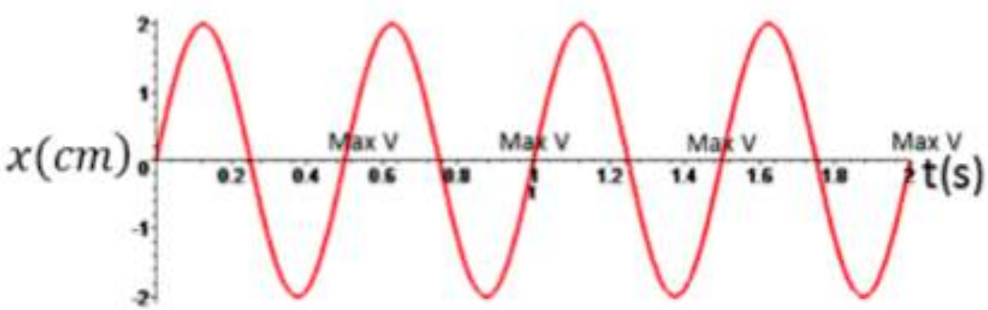
a) After taking time derivatives, the resulting expressions for the velocity and acceleration are shown to be $v(t) = bA\cos(bt)$ and by $a(t) = -b^2A\sin(bt)$. The velocity vs. time graph and acceleration vs. time graph are shown below. (The dashed lines are guides for the eye.)



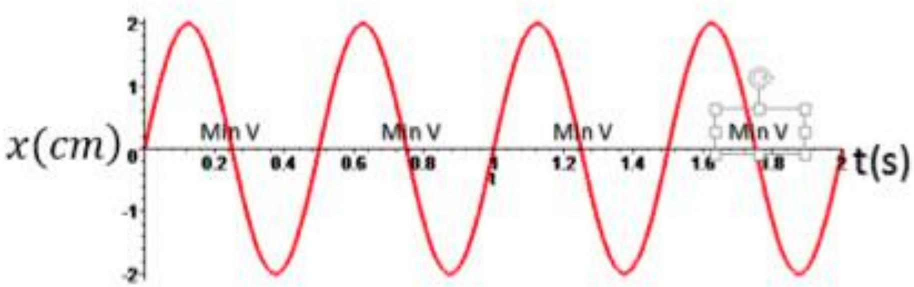
b. The velocity is zero at points where the displacement is either maximum or minimum:



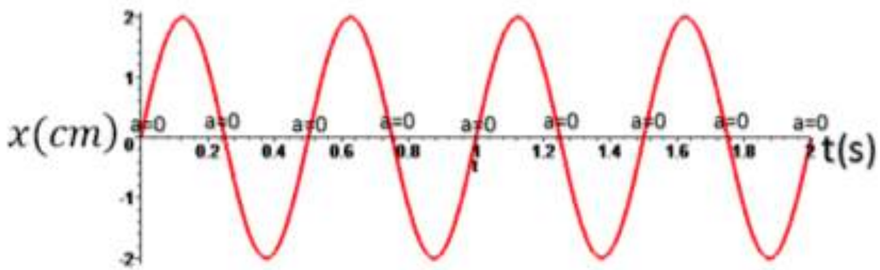

The velocity is maximum at points where the displacement vs. time graph is steepest and increasing from left to right:



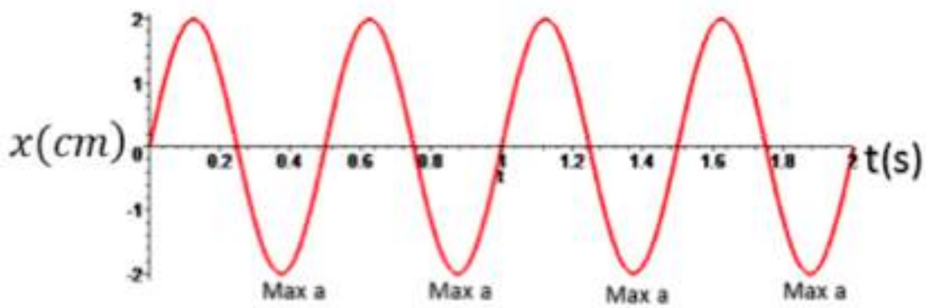

The velocity is minimum at points where the displacement vs. time graph is steepest and decreasing from left to right:



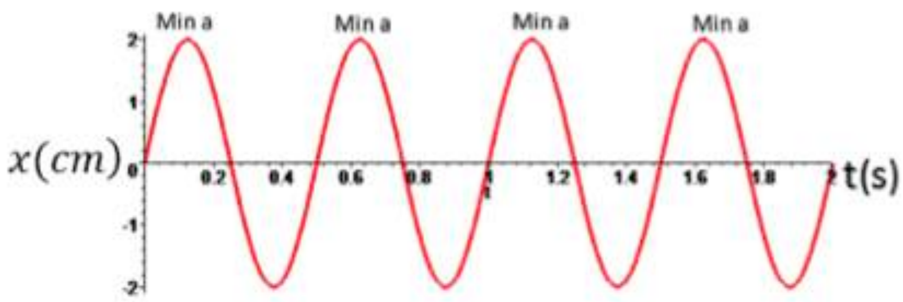
c) The acceleration is zero at points on the displacement vs. time graph where there is no concavity:




The acceleration is maximum at points on the displacement vs. time curve which are concave upward and where the slope is changing most rapidly:



The acceleration is minimum at points on the displacement vs. time curve which are concave downward and where the slope is changing most rapidly:




d) The acceleration is zero at points where the displacement is zero.

The velocity is either maximum or minimum at points where the displacement is zero.

60 MINS

# Standing waves on a string

**Content Standard**
The learners shall be able to learn about (1) interference and beats, and (2) standing waves.

**Learning Competency**
The learners shall be able to apply the condition for standing waves on a string (**STEM_GP12MWS-IIe-36)**

**Specific Learning Outcomes**
At the end of the unit, the learners must be able to:

1. Identify the condition for standing waves to form on a string.
2. Determine the wave function for a standing wave using the principle of superposition.
3. Locate nodes and antinodes in a standing wave.
4. Visualize normal modes on a string.
5. Identify the frequency of the normal modes of a string.

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction** | Review of the principle of superposition. | 5 |
| **Motivation** | Describe the kind of waves that form on the strings of a guitar and distinguish it from a travelling wave | 5 |
| **Instruction/ Delivery** | Discussion on the following:<br>-Qualitative description of a standing wave<br>-Condition for standing wave<br>-Nodes and anti-nodes<br>-Normal modes on a string | 30 |
| **Practice** | Plug-and-play problem | 5 |
| **Enrichment** | Actual or video demonstration on how to form harmonics on a guitar | 5 |
| **Evaluation** | Problem solving exercise | 10 |

**Materials**
Guitar (optional)l slinky toy

**Resource**

Young, Hugh D., Freedman, Roger A. (2008). *University Physics* (12th ed.). San Francisco, CA: Pearson Education, Inc.

## INTRODUCTION (5MINS)

Review the principle of superposition. Emphasize how the wave function of the resulting interference is just the sum of the individual wave functions.

## MOTIVATION (5MINS)

Describe a travelling wave in a string. Then describe the kind of wave that happens on a guitar string. Show this either by using a guitar or just the image below. Ask the class if they could spot the differences between the two. Emphasize that since the guitar string is fixed at both ends, the wave cannot travel. Instead, it is standing.

## INSTRUCTION/DELIVERY (30MINS)

1. Give a qualitative description of a standing wave. If possible, show an animation.

2. Cite the condition for standing waves to occur: *A wave must interfere with another wave of equal amplitude but opposite in direction of propagation.* Cite the simplest example of how this condition is satisfied: a string fixed at one end and wiggled at the other end. Incident waves will travel toward the fixed end. These waves will reflect from the fixed end. The interference of the incident and the reflected waves form a standing wave. If possible, show an animation.

3. Write down the wave function corresponding to the incident and reflected waves:

$$y_1(x,t) = A\cos(kx + \omega t)$$
$$y_2(x,t) = -A\cos(kx - \omega t)$$

Tell the class that the negative sign comes from the fact that waves invert when they reflect from a fixed end. Write down the wave function of the resulting interference by principle of superposition. You will need to use a trigonometric identity.

$$y(x,t) = y_1(x,t) + y_2(x,t)$$
$$y(x,t) = A\cos(kx + \omega t) - A\cos(kx - \omega t)$$
$$y(x,t) = 2A \sin \omega t \sin kx$$

Tell the class that this can be interpreted as a sine function in position with an amplitude that oscillates in time.

4. Distinguish between nodes and antinodes: *Nodes are points in the standing wave that do not move and antinodes are points in the standing wave that moves the greatest.* Show the figure below, or if possible, an animation. Derive the positions of the nodes by setting $y(x,t) = 2A \sin \omega t \sin kx = 0$ and solving for $x$:

$$x = \frac{n\pi}{k} = \frac{n\lambda}{2}, \qquad n = 0,1,2,\ldots$$

Emphasize that, from the above equation, it follows that consecutive nodes are half a wavelength apart.

5. Underline that fixed ends must be nodes, which restrict the possible wavelengths that can occur on a string fixed at both its ends (the previous figure can serve as a visual reinforcement). Draw a string of length $L$ fixed on both ends on the board. Have the class imagine a standing wave occurring on this string. Tell them that there are many possible answers. Then show the class the figure below. Define these patterns as *normal modes.*

6. Call on a student to hold one end of a slinky. Hold the other end and wiggle it to form the first, second, and third normal modes. Mention that that you need a faster wiggle, and therefore a larger frequency, to get higher frequencies. You can also let the student wiggle his end while your end stays in place.

7. Have some students count the number of cycles that occur in each normal mode. Argue then that for the first situation to occur, $L = \frac{\lambda}{2};$ for the second situation to occur, $L = \frac{2\lambda}{2};$ and so on, which, in general, leads to the expression below:

$$L = \frac{n\lambda}{2}, \qquad n = 1,2,\ldots$$

Solve for λ to get the wavelength of the normal modes: $\lambda = \frac{2L}{n}$

Using the relation $v = \lambda f,$ derive the expression for the frequency of the normal mode: $f = n\frac{v}{2L}, \qquad n = 1,2,\ldots$

Define the $n = 1$ frequency as the fundamental frequency, the $n = 2$ frequency as the second harmonic, the $n = 3$ frequency as the third harmonic, and so on.

Note: It is important for the teacher to practice this before coming to class. Standing waves will only form for specific wiggle frequencies.

## PRACTICE (5 MINS)

Give a specific length of a string, and let students identify the wavelengths of the fourth and fifth normal mode ($n$ = 4). Give a specific wave speed, and let the students identify the fourth harmonic. Use up all the time to go around the class and make sure everyone gets the correct answer with the correct solution.

## ENRICHMENT (5 MINS)

1. Establish the fact that amplitude and frequency are perceived by humans as volume and pitch, respectively.
2. Show a video or an actual demonstration on how to produce harmonics on a guitar:

a. Tell the class that when you pluck a guitar string, it produces all possible normal modes, but the loudest frequency is the fundamental frequency, followed by the first harmonic, then the second harmonic, and so on. Let a guitar string ring.

**Teacher tip**
The midpoint of the string lies between the 12th and 13th fret of the guitar.

b. Tell the class that you can mute the fundamental frequency by lightly pressing the midpoint of the string, thereby making the first harmonic the loudest mode. Explain why this works while using the previous figure of the normal modes as visual reinforcement: *The midpoint of the string is an antinode for the first normal mode. By lightly pressing on that point, you force it to be a node, thereby not allowing the string to produce the first mode.* Lightly press on the midpoint of a guitar string and let it ring.

c. Tell the class that you can mute the fundamental frequency and the first harmonic by lightly pressing a point a third of the way from one end of the string, thereby making the second harmonic the loudest mode. Explain why this works while using the previous figure of the normal modes as visual reinforcement: *The point a third of a way through one end of the string is an antinode for the second normal mode. By lightly pressing on that point, you force it to be a node, thereby not allowing the string to produce the second mode.* Lightly press on the point a third of a way through one end of a guitar string and let it ring.

**Teacher tip**
The point a third of the way through the fret end of the string lies between the 7th and 8th fret of the guitar.

## EVALUATION (10MINS)

1. Let the students answer the following problem: The A-string of a guitar has a fundamental frequency of 110. Hz.

- Which of the following is NOT a frequency of a normal mode of the string?
  - 110. Hz
  - 930. Hz
  - 1210 Hz
  - 1430 Hz

ANSWER: 1430 Hz. From the equation for the frequencies, it follows that the higher harmonics are multiples of the fundamental frequency. 930 Hz is not a multiple of 110 Hz, and hence is not a frequency of a normal mode.

- If the wavelength of the third normal mode is 45 cm, what is the length of the string?

ANSWER: for *n* = 3

$$L = \frac{n\lambda}{2} = \frac{3(42\ \text{cm})}{2} = 63\ \text{cm}$$

# Doppler Effect for Sound

**60 MINS**

**Content Standard**
The learners shall be able to learn about (1) sound, and (2) doppler effect.

**Learning Competency**
The learners shall be able to relate the frequency (source dependent) and wavelength of sound with the motion of the source and the listener **(STEM_GP12MWS-IIe-37)**

**Specific Learning Outcomes**
At the end of the unit, the learners must be able to:

1. Describe Doppler effect.
2. Solve for the frequency of a sound wave from a source as perceived by the listener for the cases when the source is moving, the listener is moving, or both the source and listener are moving.

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction** | Review of the kinds of waves. | 5 |
| **Motivation** | Emulating what they hear when an ambulance passes by them. | 5 |
| **Instruction/ Delivery** | Discussion on the following:<br>-Speed of sound in air<br>-Derivation of the Doppler effect for a moving source<br>-Derivation of the Doppler effect for a moving listener<br>Derivation of the Doppler effect for a moving source and moving listener | 35 |
| **Practice** | Simple exercise on selecting the correct signs in the Doppler effect equation. | 5 |
| **Enrichment** | Describing a sonic boom and explain it using Doppler effect. | 5 |
| **Evaluation** | Problem solving exercise | 5 |

**Materials**
Identical balls

**Resource**

Young, Hugh D., Freedman, Roger A. (2008). *University Physics* (12th ed.). San Francisco, CA: Pearson Education, Inc.

## INTRODUCTION (5MINS)

Review the kinds of waves (transverse, longitudinal, combination). Establish that sound waves are longitudinal waves. Review the fact that amplitude and frequency are perceived by humans as volume and pitch, respectively.

## MOTIVATION (5MINS)

Ask the students to emulate what they hear when an ambulance passes by them. They should be able to identify the increase then decrease in volume and pitch.

Recall in class that the intensity of sound waves is larger when the source is closer and cite this as the reason for the change in volume.

Tell the class that the variation in pitch is due to the motion of the ambulance. Ask the students to identify when the pitch increases and decreases. They should be able to identify that the pitch increases when the ambulance approaches them and decreases when it recedes from them.

Emphasize that the frequency of the source does not change; only the frequency as perceived by the listener changes. Tell the class that this also happens when the listener is moving. Define this dependence of the perceived frequency to the motion of the source and/or listener as the *Doppler effect.*

## INSTRUCTION/DELIVERY (35MINS)

**Speed of sound in air**

Tell the class that the speed of sound in a fluid depends on the bulk modulus and density of the fluid.

Mention that in room temperature, the speed of sound is $v = 340.\frac{\text{m}}{\text{s}}$.

**Derivation of the Doppler effect for a moving source**

Roll balls at regular intervals while you are stationary, like how wave fronts are "thrown" periodically in a travelling wave. Tell the class to think of the stream of balls as a wave wherein you are the source, and each ball as a wave front of the wave. Establish the fact that the distance between two balls represents the wavelength of the wave.

**Teacher tip**

Practice this before coming in to class. The balls must roll with the same speed.

Now roll balls at regular intervals, this time while you are moving forward. Ask the class if they noticed a change in the wavelength. They should notice a decrease in wavelength. Again, roll balls at regular intervals, this time while you are moving backward. Ask the class if they noticed a change in the wavelength. They should notice an increase in wavelength. Argue that this change in wavelength, from the expression $v = \lambda f$, leads to a change in frequency, i.e. Doppler effect.

Define variables to be used in the succeeding derivations:

- Let $v$ be the wave speed in air.
- Let $v_s$ be the speed of the source.
- Let primed variables (e.g. $\lambda'$, $f'$) be quantities perceived by the listener.

From the previous demonstration, argue that the wavelength perceived by the listener is different from the wavelength of the source by an amount $v_sT$ (speed of the source times the period): $\lambda' = \lambda \pm v_sT$ where where the plus sign is for when the source moves away from the listener and the minus sign is for when the source moves towards the listener.

By using the expression $v = \lambda f$ in the previous equation, derive the equation: $f' = \left(\frac{v}{v \pm v_S}\right) f$

Do a simple check on how the value of changes when the source is moving toward and away from the listener. Reinforce the results with the observations from the demonstration and/or the ambulance scenario.

Give this simple example: A guitarist plucks a C-note (523 Hz) while moving at a speed of 20.0 m/s towards a fangirl. What frequency does the fangirl hear?

Ans.

$$f' = \frac{v}{v - v_S} f = \frac{340.\frac{\text{m}}{\text{s}}}{340.\frac{\text{m}}{\text{s}} - 20\frac{\text{m}}{\text{s}}}(523\text{ Hz})$$
$$= 557\text{ Hz}$$

**Derivation of the Doppler effect for a moving listener**

Do the previous demonstration but this time ask a student to stand some distance in front of where the balls will roll. Tell the student to pick up each ball when it reaches his/her feet. Tell the class that the rate at which the student receives the balls represents the perceived frequency of the listener.

Roll balls again, but this time while the student is moving towards you. Ask the class if they noticed a change in the rate at which the student picks up the balls, i.e. the perceived frequency. They should notice an increase in the perceived frequency. Roll balls again, but this time while the student is moving away from you. Ask the class if they noticed a change in the perceived frequency. They should notice a decrease in the perceived frequency. Emphasize that the wavelength of the wave did not change; it was the relative motion of the listener with the wave that caused the change in frequency.

Define variables to be used in the succeeding derivations:

- Let *v* be the wave speed in air.
- Let $v_L$ be the speed of the listener.
- Let primed variables (e.g. λ', *f'* ) be quantities perceived by the listener.

From the previous demonstration, argue that the perceived wave speed of the listener is equal to the relative speed of the wave with respect to the listener: $v' = v \pm v_L$ where the plus sign is for when the listener is moving toward the source and the minus sign is when the listener is moving away from the source. Argue that since the wavelength is unchanged, using $v = \lambda f$, the perceived wave speed corresponds to the perceived frequency

$$f' = \frac{v'}{\lambda} = \frac{v \pm v_L}{\lambda}$$

Using $v = \lambda f$ once more, derive the equation

$$f' = \left(\frac{v \pm v_L}{v}\right) f$$

Do a simple check on how the value of *f* changes when the source is moving toward and away from the listener. Reinforce the results with the observations from the demonstration and/or the water waves analogy.

Give this simple example: A guitarist plucks a C-note (523 Hz) while a fangirl moves at a speed of 20.0 m/s towards him. What frequency does the fangirl hear?

Ans:

$$f' = \frac{v + v_L}{v} f = \frac{340.\frac{\text{m}}{\text{s}} + 20\frac{\text{m}}{\text{s}}}{340.\frac{\text{m}}{\text{s}}}(523\text{ Hz})$$
$$= 554\text{ Hz}$$

**Derivation of the Doppler effect for a moving source and a moving listener**

Argue that for the case wherein both the source and the listener are moving, the perceived frequency is given by

$$f' = \left(\frac{v \pm v_L}{v \pm v_S}\right) f$$

Emphasize that the previous equations can be obtained by setting either $v_L = 0$ or $v_s = 0$, or , and hence they only need to remember this single equation for all Doppler effect problems.

Summarize the sign conventions. Emphasize that to decide for the correct signs, they can just think of what should happen to the frequency (increase or decrease) in real life, and base the signs from that. One moving toward the other should result to a frequency increase, and one moving away from the other should result to a frequency decrease.

**Teacher tip**

"For example, if both the source and the listener are moving to the right, then the source is moving toward the listener, and the listener is moving away from the source. The former should result to an increase in frequency, so it must be $v - v_s$ in the expression (so that the denominator decreases and the fraction increases). The latter should result to a decrease in frequency, so it must be $v - v_L$ in the expression (so that the numerator decreases and the fraction decreases)."

## PRACTICE (5 MINS)

Give this exercise: The figure indicates the directions of motion of a sound source and a detector for six situations in stationary air. For each situation, is the detected frequency greater than or less than the emitted frequency, or can't we tell without more information about the actual speeds?

| | Source | Detector | | Source | Detector |
|---|---|---|---|---|---|
| (a) | → | • 0 speed | (d) | ← | ← |
| (b) | ← | • 0 speed | (e) | → | ← |
| (c) | → | → | (f) | ← | → |

ANSWER: (a) increase; (b) decrease; (c) can't tell; (d) can't tell; (e) increase; (f) can't tell. Everything can be figured out from what is observed in real life, except (c) and (d). For (c) and (d), we must look at the equation for the perceived frequency. For (c), the equation becomes

$$f' = \left(\frac{v - v_L}{v - v_S}\right) f$$

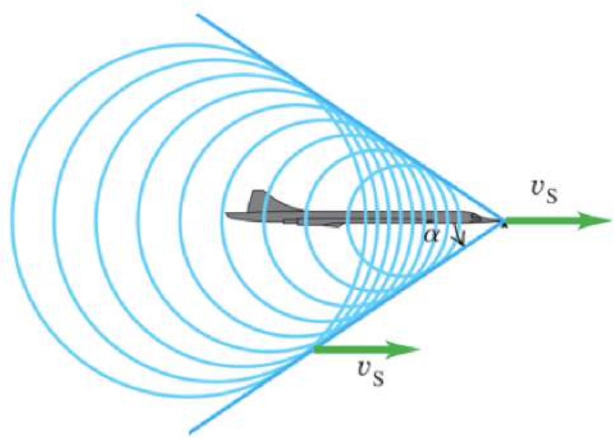
and for (d), the equation becomes

$$f' = \left(\frac{v + v_L}{v + v_S}\right) f$$

In both cases, the answer will depend on the source and listener speeds. In fact, if they are equal, then the numerator cancels out the denominator, and there won't be a change in the perceived frequency.

## ENRICHMENT (5 MINS)

1. Describe a sonic boom in an airplane.
2. Explain how it is created, using the figure below as a visual aid: When the source is as fast or faster than the speed of sound in air, the wave fronts pile up in front of the source. These piled up waves correspond to a loud sound that we hear as the sonic boom.



3. Tell the class that the crack of a bullet and a whip are also sonic booms.

## EVALUATION (5MINS)

Give the class this problem: A truck and an ambulance move at the same rate of 13 m/s toward each other but on different lanes. If the ambulance siren emits sound of frequency 1200 Hz, what is the frequency of the sound that the truck driver hears?

ANSWER:

Since the truck driver and the ambulance are both moving toward each other, then the signs of the numerator and the denominator must be set in such a way that they increase the frequency heard by the listener. So it should be a plus in the numerator and a minus in the denominator.

$$f' = \left(\frac{v + v_L}{v - v_S}\right) f = \left(\frac{340\,\frac{\mathrm{m}}{\mathrm{s}} + 13\,\frac{\mathrm{m}}{\mathrm{s}}}{340\,\frac{\mathrm{m}}{\mathrm{s}} - 13\,\frac{\mathrm{m}}{\mathrm{s}}}\right)(1200\ \mathrm{Hz})$$
$$= 1300\ \mathrm{Hz}$$

60 MINS

# Context rich problems involving sound and mechanical waves

**Content Standard**
The learners shall be able to learn about
(1) Sound
(2) Wave Intensity
(3) Interference and beats
(4) Standing waves

**Learning Competency**
Solve problems involving sound and mechanical waves in contexts such as, but not limited to, echolocation, musical instruments, ambulance sounds **(STEM_GP12MWS-IIe-38)**

**Specific Learning Outcomes**
At the end of the unit, the learners must be able to solve multi-step, multi-concept problems involving the topics of sound, wave intensity, interference and beats, standing waves, and Doppler effect.

## LESSON OUTLINE

| | | |
|---|---|---|
| **Problem-solving Session** | Group activity | 40 |
| **Presentation of Solutions** | Group demonstration | 20 |

**Materials**
Pen and paper

**Resource**

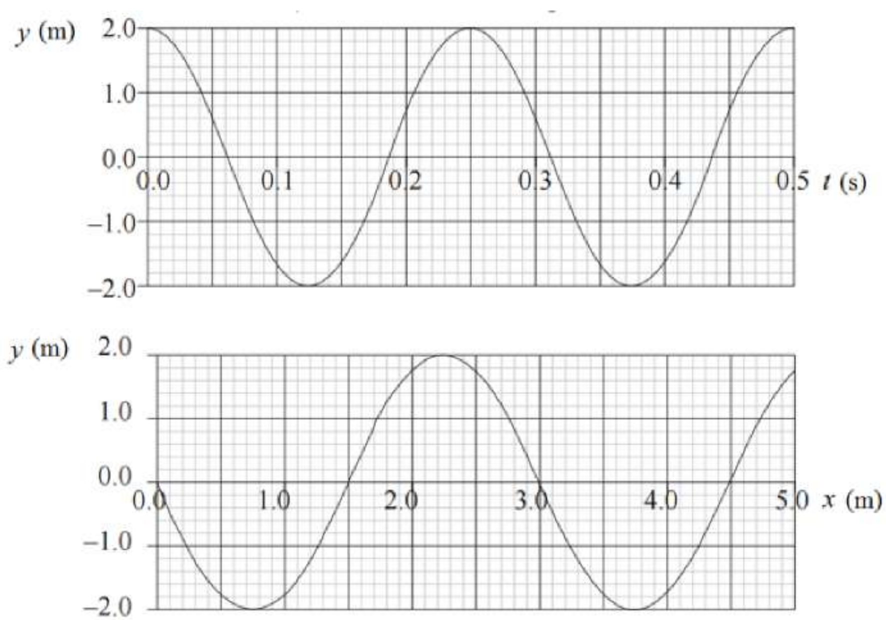
Young, Hugh D., Freedman, Roger A. (2008). *University Physics* (12th ed.). San Francisco, CA: Pearson Education, Inc.

# PROBLEM-SOLVING SESSION (40 MINS)

**Teacher tip**
The formula for the Doppler effect in electromagnetic waves is different. But when the speed of the source/listener is very small compared to the speed of the wave, such as in this problem, then the Doppler effect for sound still holds.

Ask the class to form groups of four to five members. Make sure that everyone contributes to the discussions. Tell the class that you will ask a member of a group to present the solution to a question, so that everyone will be encouraged to participate. Answer the following problems:

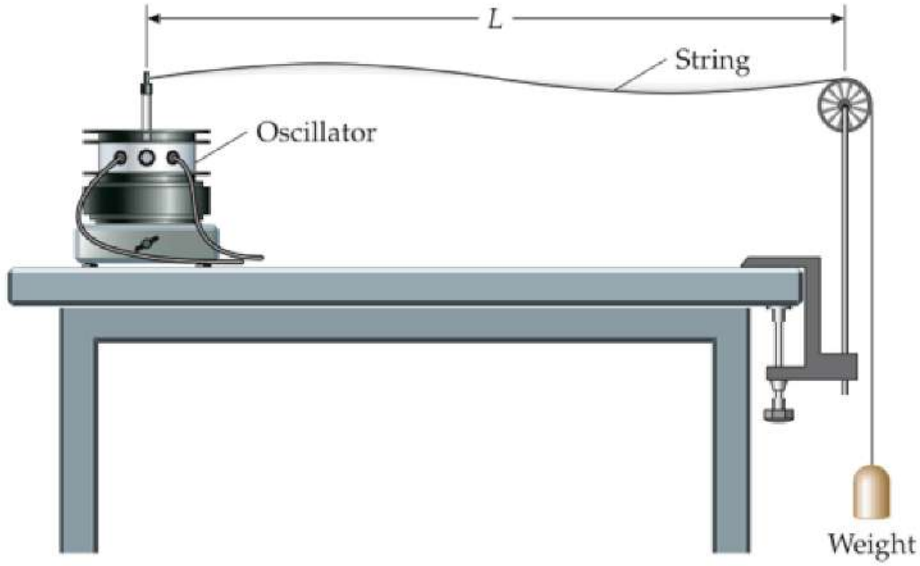
1. Travelling waves occur on a certain string. The displacement of a point on the string varies with time according to the first graph. The second graph shows a snapshot of the string at time $t$ = 0




a. Write down the corresponding wave equation.

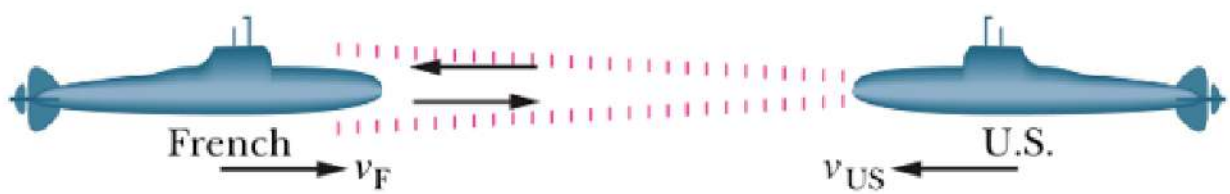
b. Draw a snapshot of the string at a time equal to half the period $T$ of the wave.

2. A 20-N weight is attached to the end of a string draped over a pulley; the other end of the string is attached to a mechanical oscillator that moves up and down at a tunable frequency. The length between the oscillator and the pulley is 1m. You slowly increase the frequency from zero until a standing wave formed at 60 Hz. What is the linear mass density of the string?




3. A tuning fork that plays a G-note (384-Hz) was detuned due to improper handling. You try to identify its frequency by playing it side by side with another G tuning fork that is still in tune. After simultaneously striking the forks, you heard a pitch slightly lower than G. You also heard beats at 0.100-s intervals. What is the frequency of the detuned fork?

4. A French submarine move toward an essentially motionless U.S. submarine in motionless water. The French sub moves at speed $v_F$ = 50.00 km/h. The U.S. sub sends out a sonar signal (sound wave in water) at $1.000 \times 10^3$ Hz. Sound waves travel at 5470 km/h in water, hitting the French sub and reflecting back to the U.S. sub at $1.018 \times 10^3$ Hz. What is the speed of the French sub?



## PRESENTATION OF SOLUTIONS (20MINS)

Select a random member from each group and let them present a problem. In case there are more groups than problems, divide the problems into sections and assign groups to those sections, so that all groups are able to discuss in class.

60 MINS

# Experiment involving mechanical waves or sound

**Content Standard**
The learners demonstrate an understanding of: (1) Sound, and (2) Sound waves

**Performance Standards**
The learners shall be able to identify the speed of sound through an experiment involving standing sound waves on a tube.

**Learning Competency**
The learners shall be able to perform an experiment investigating the properties of sound waves and analyze the data appropriately—identifying deviations from theoretical expectations when appropriate **(STEM_GP12MWS-IIe-39)**

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction/ Review/ Motivation** | Review sound waves and standing waves on a string. Blow on the opening of different glass bottles (e.g. soft drink bottles) at some angle such that a sound of constant pitch can be heard. Ask the students how the sound waves are formed, and why does the pitch differ from one bottle to another. | 5 |
| **Instruction/ Delivery** | Discuss how standing sound waves are formed in a tube that with one open end. Prepare the materials. Demonstrate the experiment. Distribute the materials to the students. | 15 |
| **Practice/ Enrichment** | Let the students perform the experiment, gather data, and answer the guide questions in the worksheet. Assist the students throughout the experiment. | 40 |

**Materials**
open tube(preferably transparent), tuning fork, pail filled with water, ruler

**Resources**
1. Young, Hugh D., Freedman, Roger A. (2008). *University Physics* (12th ed.). San Francisco, CA: Pearson Education, Inc.

2. Tube resonance experiment (https://www.youtube.com/watch?v=bHdHaYNX4Tk

## INTRODUCTION/MOTIVATION (5 MINS)

Review sound waves and standing waves on a string, specifically the concept of node/antinode. Emphasize that for a string, the fixed ends must be nodes. Mention the speed of sound in air.

Blow on the opening of different glass bottles (e.g. soft drink bottles) at some angle such that a sound of constant pitch can be heard. Ask the students how the sound waves are formed, and why does the pitch differ from one bottle to another.

## INSTRUCTION/DELIVERY (15 MINS)

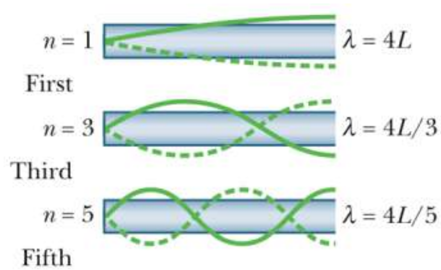
Answer the previously posed question: *The sound that we hear from blowing the opening of a glass bottle comes from the standing waves that form inside the bottle. The pitch depends on the dimensions of the bottle, in the same way that the normal modes on a string depends on the length of the string.*

Discuss how standing sound waves are formed in a tube. Start with the fact that since air cannot move freely on the closed end of a tube, it must be a node of a standing sound wave. Point out the analogy with the fixed ends of a string. Proceed with the fact that since air can move freely on an open end of a tube, it must be an antinode of a standing sound wave*. Describe the different standing waves that can form on a tube with one closed end and one open end, using the figure below as visual reinforcement.

**Teacher tip**

*The more accurate explanation for why the open end of the tube must be an antinode can be found in Section 16.4 of the University Physics by Young and Freedman (12th edition).*

*Students might get confused with this figure, since it depicts transverse amplitudes rather than the longitudinal ones that occur for sound waves. If they look confused upon seeing the figure, clear this up with them.*




Prepare the materials. Demonstrate the experiment as detailed in the manual. Then distribute the materials to the students.

## PRACTICE/ENRICHMENT (40 MINS)

**Teacher tip**
Assist the students in filling up water. Make sure that valuables, especially electronic gadgets, are far from the experimental set-up.

Let the students perform the experiment, gather data, and answer the guide questions in the worksheet. Assist the students throughout the experiment. The students would need to pass a worksheet containing the data and their answers to guide questions.

**Determining the speed of sound through standing waves on a tube**

**Objective:** In this experiment, the students are expected to

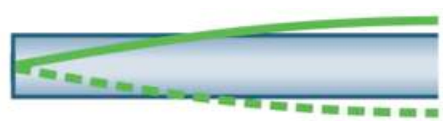
- produce a standing wave on a tube using a tuning fork and a pail filled with water
- obtain the wavelength of the standing wave
- and calculate the speed of sound using the obtained value of the wavelength and the known frequency of the tuning fork

**Materials:**

- open tube (preferably transparent)
- tuning fork
- pail filled with water
- ruler

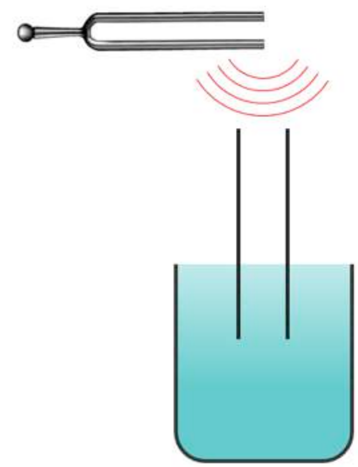
**Background:**

Standing sound waves can form on a tube, much like how standing transverse waves can form on a string. Since air cannot move freely on the closed end of a tube, it must be a node of a standing sound wave. On the other hand, since air can move freely on an open end of a tube, it must be an antinode of a standing sound wave. There are many possible standing waves of different wavelengths that can fit these criteria, but the standing wave with the largest wavelength, called the first normal mode, occurs when the node and antinode of the open and closed ends are adjacent in the wave:



A node and its adjacent antinode are a quarter of a wavelength apart. Hence the first normal mode occurs when the length of the string is a quarter of a wavelength. In this experiment, a tube with both ends open will be used. One end will then be dipped in water. The surface of the water acts as a closed end. It follows that the effective length of the tube wherein standing waves form is only the fraction that is not dipped in water.

**Procedure:**



- Fill a pail with water. Dip one end of the pipe to the water.
- Read and record the label value of the frequency of the tuning fork. Strike the tuning fork on your palm (Caution: striking the tuning fork to a hard surface may cause damage to the tuning fork.), then place it near the open end of the tube.
- While the tuning fork still rings, hold the tube and slowly move it up and down. You should notice a height wherein you hear the loudest sound. This is the height wherein the first normal mode form. Measure the length of the tube that is not submerged in water. Record this as the effective length of the tube.
- Calculate the wavelength corresponding to this length.
- Calculate the speed of sound from the measured wavelength of the standing wave and the label value of the frequency of the tuning fork, using the formula $v = \lambda f$
- Compare this with the theoretical value of the speed of sound. Calculate the percent deviation.

**Data:**

Table 1: Data for calculating the speed of sound in air.

| | |
|---|---|
| Frequency of the tuning fork (Hz) | |
| Effective length of the tube (m) | |
| Calculated wavelength of the standing wave (m) | |
| Calculated speed of sound (m/s) | |
| Percent deviation (%) | |

**Calculations:**

**Questions: (Use extra sheets if necessary)**

- What was the purpose of the water? Is it possible to form standing waves without it?
- Using the same set-up, is it possible to hear the second normal mode? Explain.
- What are the possible sources of error in the experiment?

60 MINS

# Fluid Statics Part 1

**Content Standards**
The learners shall be able to learn about (1) fluid density, and (2) pressure

**Performance Standards**
The learners shall be able to solve multi-concept, rich context problems using concepts from rotational motion, fluids, oscillations, gravity, and thermodynamics

**Learning Competency**
The learners shall be able to:

Relate density, specific gravity, mass, and volume to each other **(STEM_GP12FM-IIf-40)**

Relate pressure to area and force **(STEM_GP12FM-IIf-41)**

Relate pressure to fluid density and depth **(STEM_GP12FM-IIf-42)**
Solve problems involving fluids **(STEM_GP12FM-IIf-47)**

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction/ Review** | Review prerequisite concepts such as mass, volume, force, area, and acceleration due to gravity | 5 |
| **Motivation** | Show the regular and diet soft drink demo | 10 |
| **Instruction/ Delivery** | • Discuss density and specific gravity<br>Discuss the concept of sinking and floating<br>• Discuss pressure as force per unit area<br>• Define gauge pressure and absolute pressure | 15 |
| **Practice** | Discuss sample problems on density and pressure | 10 |
| **Enrichment** | Conceptual questions | 10 |
| **Evaluation** | Conceptual questions on density and pressure | 10 |

**Materials**
aquarium or any transparent water container, unopened Regular coke in can, unopened Coke Light in can, water

**Resource**

Cassidy, D. C., Holton, G., & Rutherford, F. J. (2002). Understanding physics. Springer Science & Business Media.

Hewitt, P. G. (2007). Conceptual physics (Vol. 8). Addison-Wesley, Massachusets.

*(Additional resources at the end of lesson)*

# INTRODUCTION (5MINS)

**Show the outline of the chapter.**

Fluid Mechanics have two branches. Fluid statics deals with the study of fluids at rest. Fluid dynamics deals with the study of fluids in motion.

- Density
- Fluid Statistics
    - Pressure in a Fluid
        - Pressure, depth and Pascal's Law
        - Absolute pressure, gauge pressure and pressure gauges
    - Buoyancy
- Fluid Dynamics
    - Fluid Flow
    - Continuity Equation
    - Bernoulli's Equation

**Discuss Fluids**

A fluid is a collection of molecules that are randomly arranged and held together by weak cohesive forces and by forces exerted by the walls of a container. It is any substance that does not have definite shape and exhibits the phenomenon of flow. It includes liquids and gases.

Liquids flow under gravity until they occupy the lowest possible regions of their container. Gasses expand to fill their containers regardless of its shape.

# MOTIVATION (10MINS)

1. Show the class the two cans of soft drink. (Any regular soft drink and its diet counterpart will do)
2. Ask the students to predict what will happen to the two cans if you put it in the aquarium that is filled with water.
3. Have a show of hands on the following choices:

- Both cans will float.
- Regular coke will float; Coke light will sink.
- Regular coke will sink; Coke light will float.

- Both cans will sink.

4. Emphasize the difference of the content of the two cans. They have the same volume but different mass. This difference is due to the formulation of the fluid inside the can. They have different density.

## INSTRUCTION/DELIVERY (15MINS)

1. Discuss density.

**Density** is mass per unit volume. The Greek letter ρ (rho) is usually used to denote density $\rho = \frac{m}{V}$

2. Show a table of density of common substances. Emphasize that density is unique for each substance.

| Material | Density $(kg/m^3)$* | Material | Density $(kg/m^3)$* |
|---|---|---|---|
| Air (1 atm, 20° C) | 1.20 | Iron, steel | $7.8 \times 10^3$ |
| Ethanol | $0.81 \times 10^3$ | Brass | $8.6 \times 10^3$ |
| Benzene | $0.90 \times 10^3$ | Copper | $8.9 \times 10^3$ |
| Ice | $0.92 \times 10^3$ | Silver | $10.5 \times 10^3$ |
| Water | $1.00 \times 10^3$ | Lead | $11.3 \times 10^3$ |
| Seawater | $1.03 \times 10^3$ | Mercury | $13.6 \times 10^3$ |
| Blood | $1.06 \times 10^3$ | Gold | $19.3 \times 10^3$ |
| Glycerin | $1.26 \times 10^3$ | Platinum | $21.4 \times 10^3$ |
| Concrete | $2 \times 10^3$ | White dwarf star | $10^{10}$ |
| Aluminum | $2.7 \times 10^3$ | Neutron star | $10^{18}$ |

*To obtain the densities in grams per cubic centimeter, simply divide by $10^3$.

3. Discuss the concept of sinking and floating.

When an object's density is greater than that of water it will sink in water. When its density is less it will float. For floating object, the fraction of the volume of an object that is submerged in any liquid equals the ratio of the density of the object to that of the liquid.

Example, the density of ice is 0.92 $g/cm^3$. This means 92 percent of the volume of ice is submerged in water.

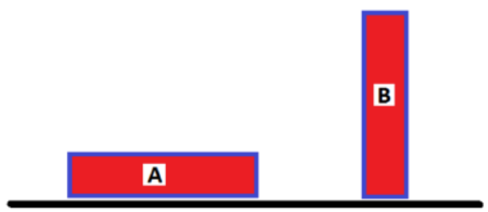
4. Discuss specific gravity and the standards for liquids and gases.

Specific gravity is the ratio of the density of a material to a standard density. It is a unitless quantity.

The standard density for liquids is the density of water at 4°C: 1 g/cm$^3$ or 1000 kg/m$^3$. For gases, the standard is the density of oxygen at 0°C and pressure of 1 atm: 1.43 kg/m$^3$.

## PRACTICE (10 MINS)

1. Consider two identical blocks.




a. Which block exerts greater force on the surface?

(ANSWER: They exert the same amount of force on the surface. This force is equal to the weight of the blocks.)

b. Which block exerts greater pressure?

(ANSWER: Block B exerts greater pressure.)

**Teacher tip**

The students might be confused with the difference of pressure and force. In everyday language the words ''pressure'' and "force" may mean the same thing. However, in Physics these words describe different quantities. Fluid pressure acts perpendicular to any surface in the fluid, no matter how that surface is oriented. Therefore pressure has no intrinsic direction of its own; it's a scalar. Force, on the other hand, is a vector with a definite direction.

2. Discuss pressure

Pressure is force per unit area. The unit of pressure is Pascal (Pa).

$$P = \frac{F}{A}$$

$$1\ Pa = 1\frac{N}{m^2}$$

4. Discuss liquid pressure. Emphasize its dependence on the liquid density and that pressure is depth dependent, not volume dependent.

The pressure at depth h in a liquid is given by P = $P_0$ + *pgh*

The pressure *P* at a depth *h* is greater than the pressure $P_0$ at the surface by an amount *pgh*. Pressure in a liquid at any location is exerted in equal amount in all direction. Note that the pressure is the same at any two points at the same level in the fluid. The shape of the container does not matter. Pressure is also not volume dependent

As expected, P = $P_0$ at the surface, where *h* = 0.Pressure $P_0$ is often due to the air or other gas above the liquid. $P_0$ = 1 *atm* = 1.013 x $10^5$ *Pa* for a liquid that is open to the air.

However, $P_0$ can also be the pressure due to a piston or a closed surface pushing down on the top of the liquid.

5. Differentiate gauge pressure and absolute pressure.

If the pressure inside a car tire is equal to atmospheric pressure, the tire is flat. The pressure has to be greater than atmospheric to support the car. When we say that the pressure in a car tire is "32 pounds" (actually 32 lb/$in^2$, equal to 220 kPa or 2.2x105 Pa), we mean that it is greater than atmospheric pressure (14.7 lb/$in^2$ or 1.01x$10^5$ Pa) by this amount. The total pressure in the tire is then 47 lb/$in^2$ or 320 kPa. The excess pressure above atmospheric pressure is called gauge pressure, and the total pressure is called absolute pressure.

## ENRICHMENT (10 MINS)

1. A nurse administers medication in a saline solution to a patient by infusion into the patient's arm. The density of the solution is 1 x $10^3$ kg/$m^3$. And the pressure inside the vein is 2.4 x $10^3$ Pa. How high must the container be hung?

For the solution to enter the vein, the liquid pressure should be equal to the pressure inside the vein

$$P_{liquid} = P_{vein}$$
$$\rho g h = P_{vein}$$

solving for *h*:

$$h = \frac{P_{vein}}{\rho g}$$
$$h = \frac{2.4x10^3 Pa}{\left(1x10^3 \frac{kg}{m^3}\right)\left(9.8 \frac{m}{s^2}\right)}$$
$$h = 0.24m$$

2. Lake Pinatubo is the deepest lake in the Philippines. Find the pressure at a depth of 10 m below the surface of Lake Pinatubo if the pressure at the surface is 1 atm. Assume that the water in the lake is pure water with a density of $1.00x10^3$ kg/$m^3$.

$$P = P_0 + \rho g h$$
$$P = 1.013x10^5 Pa + \left(1.00x10^3 \frac{kg}{m^3}\right)\left(9.8 \frac{m}{s^2}\right)(10m)$$
$$P = 1.99x10^5 Pa$$

## EVALUATION (10MINS)

1. The sphere on the right has twice the mass and twice the radius of the sphere on the left. Compared to the sphere on the left, the larger sphere on the right has

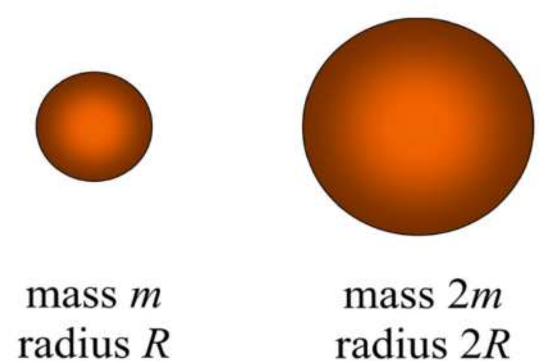
A. twice the density

B. the same density

C. 1/2 the density

D. 1/4 the density

E. 1/8 the density




ANSWER: C 1/2 the density

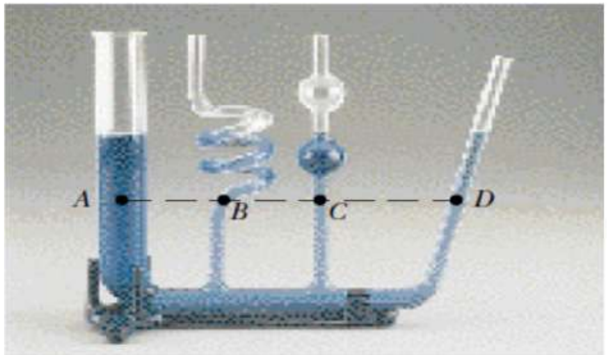
2. At what depth is the pressure twice the atmospheric pressure?

Consider four containers of varying shape. In which point is the pressure greatest?

$$P = P_0 + \rho g h$$
$$h = \frac{P - P_0}{\rho g}$$
$$h = \frac{2P_0 - P_0}{\rho g}$$
$$h = \frac{P_0}{\rho g}$$

$$h = \frac{1.013x10^5 Pa}{\left(1.00x10^3 \frac{kg}{m^3}\right)\left(9.8 \frac{m}{s^2}\right)}$$
$$h = \frac{1.013x10^5 Pa}{\left(1.00x10^3 \frac{kg}{m^3}\right)\left(9.8 \frac{m}{s^2}\right)}$$
$$h = 10.3\ m$$

A. A
B. B
C. C
D. D
E. Pressure is the same at all points




ANSWER: E

## ADDITIONAL RESOURCES

Knight, R. (2007). Physics for Scientists and Engineers: A Strategic Approach with

Modern Physics [and Mastering Physics TM]. Pearson Education.

Tipler, P. A., & Mosca, G. (2007). Physics for scientists and engineers. Macmillan. Young, H. & Freedman, R.(2008). University Physics with modern physics 12th ed.

60 MINS

# Fluid Statics Part 2

**Content Standards**
The learners shall be able to learn about (1) Pascal's principle, Buoyancy, and (2) Archimedes' Principle

**Performance Standards**
The learners shall be able to solve multi-concept, rich context problems using concepts from rotational motion, fluids, oscillations, gravity, and thermodynamics

**Learning Competencies**
The learners shall be able to  Apply Pascal's principle in analyzing fluids in various systems (**STEM_GP12FM-IIf-43)**; apply the concept of buoyancy and Archimedes' principle **(STEM_GP12FM-IIf-44)**; Solve problems involving fluids **(STEM_GP12FM-IIf-47)**

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction/ Motivation** | Ask students some preliminary questions to determine whether they have heard of Pascal's law or Archimedes' principle or any of the physics concepts behind them. | 10 |
| **Instruction** | Discussion Proper | 30 |
| **Practice** | Discuss sample problems on Pascal's Law and buoyancy | 20 |
| **Evaluation** | Conceptual questions on Pascal's Law and buoyancy | 5 |

**Resource**

Cassidy, D. C., Holton, G., & Rutherford, F. J. (2002). Understanding physics. Springer Science & Business Media.

Hewitt, P. G. (2007). Conceptual physics (Vol. 8). Addison-Wesley, Massachusets.

Knight, R. (2007). Physics for Scientists and Engineers: A Strategic Approach with Modern Physics [and Mastering Physics TM]. Pearson Education.

Tipler, P. A., & Mosca, G. (2007). Physics for scientists and engineers. Macmillan. Young, H. & Freedman, R.(2008). University Physics with modern physics 12th ed.

## INTRODUCTION/MOTIVATION (10MINS)

Ask students some preliminary questions to determine whether they have heard of Pascal's law or Archimedes' principle or any of the physics concepts behind them.

a. Who knows why ships float?
b. When you are swimming in a pool, do you feel lighter or heavier than when you are walking on the ground? How much lighter are you?
c. How do hydraulic jacks work?

## INSTRUCTION (15 MINS)

1. Discuss Pascal's principle.
   *Pressure applied to an enclosed fluid is transmitted undiminished to every portion of the fluid and the walls of the containing vessel.*
2. Discuss its application on hydraulic lifts.

   A common application of Pascal's Principle is a hydraulic lift used to raise a car off the ground so it can be repaired. A small force applied to a small-area piston is transformed to a large force at a large-area piston. If a car sits on top of the large piston, it can be lifted by applying a relatively small force to the smaller piston.

## PRACTICE (10 MINS)

1. A hydraulic lift was made by fitting a piston attached to a handle into a 3-cm-diameter cylinder, which is connected to a larger cylinder of 24-cm diameter. If a 50 kg woman puts all her weight on the handle of the smaller piston, how much weight can be lifted by the hydraulic lift?

ANSWER:

$$F_b = \frac{A_b}{A_a} F_a$$

$$F_b = \frac{\pi r_a^2}{\pi r_b^2} F_a$$

$$F_b = \left(\frac{0.12m}{0.015m}\right)^2 (50kg)\left(9.8\frac{m}{s^2}\right)$$

$$F_b = 3.14\ x\ 10^4\ N$$

$$\sim 3{,}200\ kg$$

## INSTRUCTION (15 MINS)

1. Discuss Archimedes's Principle.

   *When a body is completely or partially immersed in a fluid, the fluid exerts an upward force on the body equal to the weight of the fluid displaced by the body.*

2. Discuss buoyancy.

   The upward force exerted by the fluid is called buoyant force. As stated by Archimedes' Principle this force is equal to the weight of the fluid displaced by the body.

$$F_B = w_f = m_f g = \rho_f V_f g$$

where $F_B$ is the buoyant force
$P_f$ is the density of the displaced fluid
$V_f$ is the volume of the displaced fluid
g is the acceleration due to gravity

If the weight of the submerged object is greater than the buoyant force, it will SINK. If the weight of the submerged object is less than the buoyant force, it will FLOAT.

3. Cite some examples of buoyancy.

a. Fish use volume change as a means of altering buoyancy. A fish has an internal swim bladder, which is filled with gas. When it needs to rise or descend, it changes the volume in its swim bladder, which then changes its density.
b. Swimming in fresh water and salt water shows that buoyant force also depends on the density of the fluid. Fresh water has a density of $1.00 \times 10^3$ kg/m$^3$ while that of salt water is $1.03 \times 10^3$ kg/m $^3$. Thus, salt water provides more buoyant force than fresh water.
c. Boats float, even though it weighs a lot, because it displaces a huge amount of water that weighs even more.

## PRACTICE (10 MINS)

A 15.0-kg solid gold statue is being raised from a sunken ship. What is the tension in the hoisting cable when the statue is at rest and

a. completely immersed?
b. out of the water?

We are given the mass of the gold statue $m$ = 15.0 $kg$, the density of gold $P_g$ = 1.93 x $10^4$ kg/$m^3$),and the density of salt water $P_f$ = 1.03 x $10^3$ kg/$m^3$,

Drawing the free-body diagram for the first case (a),


$$T + F_b - w = 0$$
$$T = w - F_b$$
$$T = mg - \rho_f V_f g$$

Since the statue is completely immersed, the volume of displaced fluid is equal to the volume of the statue.

$$T = mg - \rho_f \left(\frac{m}{\rho_g}\right) g$$
$$T = (15.0\,kg)\left(9.8\frac{m}{s^2}\right) - \left(1.03\,x\,10^3\frac{kg}{m^3}\right)\left(\frac{15.0\,kg}{1.93\,x\,10^4\frac{kg}{m^3}}\right)\left(9.8\frac{m}{s^2}\right)$$
$$T = (15.0\,kg)\left(9.8\frac{m}{s^2}\right) - \left(1.03\,x\,10^3\frac{kg}{m^3}\right)\left(\frac{15.0\,kg}{1.93\,x\,10^4\frac{kg}{m^3}}\right)\left(9.8\frac{m}{s^2}\right)$$
$$T = 147N - 7.85N$$
$$T = 139N$$

## EVALUATION (5 MINS)

This can be given as a graded quiz or a quick assessment (show of hands)

A container is filled with oil and fitted on both ends with pistons. The area of the left piston is 10 $mm^2$; that of the right piston 10,000 $mm^2$. What force must be exerted on the left piston to keep the 10,000-N car on the right at the same height?

A. 10N

B. 100N

C. 10,000N

D. 106N

E. insufficient information

Answer: A

$$F_l = \frac{A_l}{A_r} F_r$$

$$F_b = \frac{10\ mm^2}{10000\ mm^2}(10000\ N)$$

$$F_b = 10N$$

60 MINS

# Fluid Dynamics

**Content Standards**
The learners shall be able to learn about (1) continuity, and (2) Bernoulli's principle

**Performance Standards**
The learners shall be able to solve multi-concept, rich context problems using concepts from rotational motion, fluids, oscillations, gravity, and thermodynamics.

**Learning Competencies**
The learners shall be able to explain the limitations of and the assumptions underlying Bernoulli's principle and the continuity equation **(STEM_GP12FM-IIf-45)**; apply Bernoulli's principle and continuity equation, whenever appropriate, to infer relations involving pressure, elevation, speed, and flux **(STEM_GP12FM-IIf-46)**; and solve problems involving fluids **(STEM_GP12FM-IIf-47)**

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction/ Motivation** | Ask the students to hold one sheet of paper close to their bottom lip and blow hard across the upper surface; let them observe. | 5 |
| **Instruction** | Discussion Proper | 20 |
| **Practice** | Discuss sample problems on Continuity equation and Bernoulli's principle | 20 |
| **Enrichment** | Show that Torricelli's Theorem is a special case of Bernoulli's Equation | 10 |
| **Evaluation** | Conceptual questions on Continuity equation and Bernoulli's principle | 5 |
| **Materials** | 2 sheets of paper | |

**Resource**


- Hewitt, P. G. (2007). Conceptual physics (Vol. 8). Addison-Wesley, Massachusets.
- Knight, R. (2007). Physics for Scientists and Engineers: A Strategic Approach with Modern Physics [and Mastering Physics TM]. Pearson Education.
- Tipler, P. A., & Mosca, G. (2007). Physics for scientists and engineers. Macmillan.
- Young, H. & Freedman, R.(2008). University Physics with modern physics 12th ed.
- https://phet.colorado.edu/en/simulation/fluid-pressure-and-flow
- Dynamics of Flight: https://www.grc.nasa.gov/www/k- 12/UEET/StudentSite/dynamicsofflight.html

## INTRODUCTION/MOTIVATION (5 MINS)

1. Ask the students to get 2 sheets of paper and follow the instructions below.
   a. Hold one of the sheets of paper close to your bottom lip and blow hard across the upper surface. What happens?
   b. b.Hold the two sheets of paper upright, a few inches apart in front of your face. Again, blow hard and watch what happens.
2. Ask some students their observation. Tell the students that the same principle can explain how airplanes fly.
3. Introduce today's topic which deals with fluid flow.

## INSTRUCTION (10 MINS)

State the assumption that we are considering IDEAL fluids, i.e. fluids exhibiting the following characteristics:

A. Non-turbulent flows. Turbulent flow is irregular flow characterized by small whirlpool-like regions.
B. Steady-state flow. In steady (laminar) flow, the velocity of the fluid at each point remains constant.
C. Non-viscous fluid. Internal friction is neglected. An object moving through the fluid experiences no viscous force.
D. Incompressible fluids. Density is constant throughout the fluid.

Discuss the continuity equation.

$A_1v_1 = A_2v_2$
where A is the pipe cross-sectional area and v is the fluid speed.

The product of Av is the volume flow rate.

Emphasize the implication of the continuity equation. If the pipe cross-section area decreases, the flow velocity will increase. We can relate it to everyday activities such as watering the plants using a garden hose. If you your finger to close a part of the hole, the waters' speed increases as it come out of the hose.

## PRACTICE (10 MINS)

A horizontal pipe of 25 $cm^2$ cross-section carries water at a velocity of 3.0 m/s. The pipe feeds into a smaller pipe with a cross section of only 15 $cm^2$. What is the velocity in the smaller pipe?

ANSWER:
$v_2 = (v_1 A_1)/A_2$
$v_2 = (3.0\ m/s)(25\ cm^2)/(15\ cm^2)$
$v_2 = 5.0\ m/s$

## INSTRUCTION (10 MINS)

Discuss how Bernoulli's Equation relates pressure, flow velocity, and height for flow of an ideal fluid.

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2$$

Emphasize the similarity of Bernoulli's equation to the conservation of energy equation so that the students can easily remember it.

Explain how airplanes fly. *Lower pressure is caused by the increased speed of the air over the wing. Since the pressure is higher beneath the wing, the wing is pushed upwards.*

Airplane wings are shaped to make air move faster over the top of the wing. When air moves faster, the pressure of the air decreases. So the pressure on the top of the wing is less than the pressure on the bottom of the wing. The difference in pressure creates a force on the wing that lifts the wing up into the air.

## PRACTICE (10 MINS)

Water enters a house through a pipe with an inside diameter of 2.0 cm at an absolute pressure of $4.0x10^5$ Pa (about 4 atm). A 1.0 cm diameter pipe leads to the second floor of the bathroom 5.0 m above. When the flow speed at the inlet pipe is 1.5 m/s. Find the flow speed, pressure and volume flow rate in the bathroom.

We are given the diameter of the inlet ($d_1$ = 2.0*cm*) and outlet ($d_2$= 1.0cm) pipe. To calculate for the flow speed at the outlet pipe, we first need to calculate the cross-sectional area of each pipe.

Using the equation $A = \frac{\pi d^2}{4}$, the calculated cross-sectional area of the inlet pipe is $A_1 = 3.14 \times 10^{-4}\ m^2$ and that for the outlet pipe is $A_2$ = 7.85 x $10\text{-}^5\ m^{2.}$

To calculate the flow speed in the bathroom, we use the continuity equation:

$$A_1 v_1 = A_2 v_2$$

$$v_2 = \frac{A_1 v_1}{A_2}$$

$$v_2 = \frac{(3.14\ x\ 10^{-4} m^2)\left(1.5\frac{m}{s}\right)}{7.85\ x\ 10^{-5} m^2}$$

$$v_2 = 6.0\frac{m}{s}$$

The volume flow rate is given by

$$\frac{dV}{dt} = A_1 v_1 = (3.14\ x\ 10^{-4} m^2)\left(1.5\frac{m}{s}\right) = 4.7\ x\ 10^{-4}\frac{m^3}{s}$$

This is also equal to

$$\frac{dV}{dt} = A_2 v_2 = (7.85\ x\ 10^{-5} m^2)\left(6.0\frac{m}{s}\right) = 4.7\ x\ 10^{-4}\frac{m^3}{s}$$

To calculate for the pressure at the bathroom pipe, we will use Bernoulli's principle:

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2$$

We set the height of the inlet pipe $y_1$ = 0 and the bathroom pipe is at a height $y_2$ = 5.0 *m*.

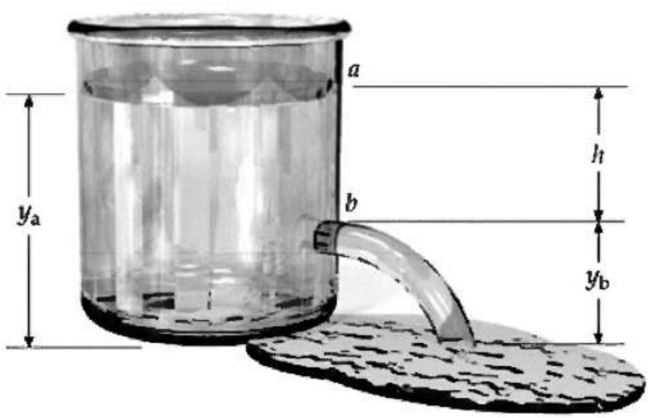
$$P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2$$
$$P_2 = P_1 + \frac{1}{2}\rho(v_1^2 - v_2^2) - \rho g y_2$$
$$P_2 = 4.0\ x\ 10^5 Pa + \frac{1}{2}\left(1x10^3\,\frac{kg}{m^3}\right)((1.5\ m)^2 - (6.0\ m)^2) - \left(1x10^3\,\frac{kg}{m^3}\right)\left(9.8\,\frac{m}{s^2}\right)(5.0\ m)$$
$$P_2 = 4.0\ x\ 10^5 Pa - 1.7\ x\ 10^4 Pa - 4.9\ x\ 10^4 Pa$$
$$P_2 = 3.3\ x\ 10^5 Pa$$

## ENRICHMENT (10 MINS)

Show that Torricelli's Theorem is a special case of Bernoulli's Equation.

Torricelli's Theorem states that the speed of efflux of a liquid from an opening in a reservoir equals the speed that the liquid would acquire if allowed to fall from rest from the surface of the reservoir to the opening.

Consider a large tank of water which has a small hole a distance h below the water surface.



We apply Bernoulli's equation to points a and b.

$$P_a + \frac{1}{2}\rho v_a^2 + \rho g y_a = P_b + \frac{1}{2}\rho v_b^2 + \rho g y_b$$

Since the diameter of the hole is much smaller than the diameter of the tank, we can neglect the velocity of the water at the top (point a).

$$P_a + 0 + \rho g y_a = P_b + \frac{1}{2}\rho v_b^2 + \rho g y_b$$

The pressure at point a and point b is the same, $P_{atm}$, since both points are open to the air:

$$P_{atm} + 0 + \rho g y_a = P_{atm} + \frac{1}{2}\rho v_b^2 + \rho g y_b$$

We can cancel $P_{atm}$

$$\rho g y_a = \frac{1}{2}\rho v_b^2 + \rho g y_b$$

and $\rho$

$$g y_a = \frac{1}{2} v_b^2 + g y_b$$

Solving for $v_b$

$$v_b^2 = 2g(y_a - y_b)$$
$$v_b = \sqrt{2g(y_a - y_b)}$$

In the figure, $(y_a - y_b) = h$, the distance of the hole below the water surface.

$$v_b = \sqrt{2gh}$$

This equation is the same as the velocity of an object freely- falling from a height h.

## EVALUATION (5 MINS)

Concept Tests. This can be given as a graded quiz or a quick assessment (show of hands)

1. An incompressible fluid flows through a pipe of varying radius (shown in cross-section). Compared to the fluid at point P, the fluid at point Q has
   A. greater pressure and greater volume flow rate.
   B. greater pressure and the same volume flow rate.
   C. the same pressure and greater volume flow rate.
   D. lower pressure and the same volume flow rate.

   ANSWER: D. lower pressure and the same volume flow rate.

2. An incompressible fluid flows through a pipe of varying radius (shown in cross-section). Compared to the fluid at point P, the fluid at point Q has
   A. 4 times the fluid speed.
   B. 2 times the fluid speed.
   C. the same fluid speed.
   D. 1/2 the fluid speed.

   ANSWER: A. 4 times the fluid speed.

# Fluid Experiment

**Content Standards**
The learners shall be able to learn about buoyancy and Archimedes' principle

**Performance Standards**
The learners shall be able to solve, using experimental and theoretical approaches, multiconcept, rich-context problems involving measurement, vectors, motions in 1D, 2D, and 3D, Newton's Laws, work, energy, center of mass, momentum, impulse, and collisions

**Learning Competencies**
The learners shall be able to perform an experiment involving buoyancy **(STEM_GP12FM-IIf-48)**; and identify discrepancies between theoretical expectations and experimental results **(STEM_GP12FM-IIf-48)**

**60 MINS**

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction/ Review** | Review on buoyant force | 2 |
| **Motivation** | Tell the story of Archimedes' *eureka moment* | 5 |
| **Instruction** | Discussion of Objectives | 3 |
| **Practice** | Experiment with the students | 30 |
| **Enrichment** | If time permits, let the students predict and observe what will happen if all liquids are combined | 5 |
| **Evaluation** | Reporting of the results of experiment | 15 |
| **Materials** | Graduated cylinder, distilled water, oil, kerosine, string, metallic cylinder (or any object that can fit in the graduated cylinder), weighing scale | |

**Resource**


- Hewitt, P.G. (2007). Conceptual Physics (Vol 8). Addison-Wesley, Massachusetts.
- Knight, R. (2007). Physics for Scientists and Engineers: A Strategic Approach with Modern Physics [and Mastering Physics TM]. Pearson Education.
- Tipler, P.A. & Mosca, G. (2007). Physics for Scientists and Engineers. Macmillan.
- Young, H., & Freedman, R. (2008). University Physics with Modern Physics 12th Edition.
- Physics 81 Laboratory Manual, University of the Philippines Los Baños.

## INTRODUCTION (2 MINS)

Review Archimedes' Principle.

Archimedes' Principle states that when a body is wholly or partially immersed in a fluid, the fluid exerts an upward force on the body equal to the weight of the fluid displaced. The weight loss of the body when immersed in a fluid is equal to the weight of the fluid dispersed.

## MOTIVATION (5 MINS)

Tell the story about how Archimedes determine the density of a crown without damaging it.

## INSTRUCTION/DELIVERY (3 MINS)

1. Discuss the objectives of the experiment.
2. Show the materials to be used.
3. Distribute the materials to the students.

## PRACTICE (30 MINS)

Let the students conduct the experiment.

## ENRICHMENT (5 MINS)

If time permits, let the students predict and observe what will happen if all liquids were combined.

## EVALUATION (15 MINS)

The students will report to class the results of the experiment. The students will submit the data sheet and answers to questions.

**Teacher tip**
There are different (some longer, some shorter) versions of this story on the internet and in science books/textbooks. Make sure that the version of the story to be told comes from credible academic sources.

**Teacher tip**
You may use any three liquids with known density.

For the metallic cylinder, you may use any object which can fit in the graduated cylinder.

**Teacher tip**

Density of water ($\rho_{H2O}$) = 1000 kg/$m^3$

Density of oil ($\rho_{oil}$) = 920 kg/$m^3$

Density of kerosene ($\rho_k$) = 810 kg/$m^3$

# FLUID MECHANICS

# LABORATORY MANUAL BUOYANT FORCE IN DIFFERENT FLUIDS

## OBJECTIVES

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

1. determine the buoyant force exerted by the different fluids;
2. relate the buoyant force to the density of the fluid; and
3. compare the experimental values of buoyant force with the theoretical values.

## MATERIALS

- graduated cylinder
- distilled water
- oil
- kerosene
- string
- metallic cylinder (or any object which can fit in the graduated cylinder)
- beaker
- weighing scale

## PROCEDURE

1. Fill a graduated cylinder with 100-ml water.
2. Tie a string on the metal cylinder. Submerge the metal cylinder and observe the rise in the water level.

3. Pour into an initially weighed beaker the water in excess of the initial volume. Record the volume of the displaced fluid in Table 1.
4. Weigh the beaker. Record the weight in Table 2.

   *NOTE: The weight that you will be recording in Table 2 is the weight of the displaced fluid, not the total weight of the beaker+fluid.*

5. Make 2 more trials, repeating steps 1-4.
6. Repeat steps 1-5 using oil instead of water. Wipe the graduated cylinder and metal cylinder with tissue paper to avoid contamination of fluid.
7. Repeat steps 1-5 using kerosene instead of oil. Wipe the graduated cylinder and metal cylinder with tissue paper to avoid contamination of fluid.

## DATA SHEET

Weight of the beaker: ________ kg

**Table 1. Volume of the displaced fluid ($m^3$).**

| Fluid | Trial 1 | Trial 2 | Trial 3 | Average |
|---|---|---|---|---|
| Water | | | | |
| Oil | | | | |
| Kerosene | | | | |

**Table 2. Weight of the displaced fluid (N).**

| Fluid | Trial 1 | Trial 2 | Trial 3 | Average |
|---|---|---|---|---|
| Water | | | | |
| Oil | | | | |
| Kerosene | | | | |

**Table 3. Comparison of experimental and theoretical value of the buoyant force.**

| Fluid | Average weight of displaced fluid (N) | Calculated buoyant force | Percent Difference |
|---|---|---|---|
| Water | | | |
| Oil | | | |
| Kerosene | | | |

## GUIDE FOR ANALYSIS

1. Archimedes' Principle states that when a body is wholly or partially immersed in a fluid, the fluid exerts an upward force on the body equal to the weight of the fluid displaced. Derive an expression for the buoyant force in terms of the density $\rho_f$ and volume $V_f$ of the displaced fluid. Use this equation in determining the calculated buoyant force in Table 3.
2. Compare the experimental and theoretical values of the buoyant force. Are the corresponding values of the buoyant forces for each liquids in good agreement? Justify your answer.
3. Which fluid exerted the greatest buoyant force on the submerged object? Why?

## ENRICHMENT ACTIVITY

1. Predict what will happen if you will combine all three liquids in one beaker.
2. To verify if your prediction is correct, pour all three liquids in one beaker. Use a big beaker so that it will not spill over. Discuss your observation.

60 MINS

# Zeroth Law of Thermodynamics and Temperature Measurement; Thermal Expansion

**Content Standards**
The learners shall be able to acquire knowledge and applications of:

- Zeroth Law of Thermodynamics and Temperature
- Thermal expansion
- Heat and heat capacity
- Calorimetry

**Performance Standards**
The learners shall be able to

- Explain the difference and relationship of temperature and heat as well as the mechanisms involved in heat transformation and transfer;
- Relate the concepts of heat to the concepts of energy, basic kinetic molecular theory, and states of matter;
- Apply the mechanisms of heat and its transfer to various phenomena; and,
- Analyze and solve problems in both the theoretical and practical sense.

**Learning Competencies**
The learners shall be able to explain the connection between the zeroth law of thermodynamics, temperature, thermal equilibrium, and temperature scales **(STEM_GP12TH-IIg-49)**; Convert temperatures and temperature differences in the following scales: Fahrenheit, Celsius, Kelvin **(STEM_GP12TH-IIg-50)**; Define coefficient of thermal expansion and coefficient of volume expansion **(STEM_GP12TH-IIg-51)**; and, Calculate volume or length changes of solids due to changes in temperature **(STEM_GP12TH-IIg-52)**.

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction/ Review** | Review of the knowledge on volume and density; review of the students' skills in using laboratory equipment | 5 |
| **Motivation** | Brief discussion on understanding of temperature | 5 |
| **Instruction** | Small observation experiment | 5 |
| **Discussion** | Discussion on Zeroth Law of Thermodynamics and Temperature Measurement and Thermal Expansion | 40 |
| **Enrichment** | Reading Assignment | 10 |
| **Materials** | Bowls of hot water, cold water, and room temperature water; and thermometers | |

**Resource**
Sears' and Zemansky's University Physics by Young and Freedman (13th Edition) Physics by Cutnell and Johnson (8th Edition)

## INTRODUCTION (5 MINS)

1. Make sure that students have prerequisite knowledge on volume and density.
2. Make sure that students have the following skills: use of thermometers, handling of glassware with liquids.
3. Ask how temperature is measured by a thermometer (recall what they may have learned from lessons in previous grades):
   a. The liquid inside the thermometer expands (rises) when the temperature increases.
   b. The thermometer has the same temperature as the object.

## MOTIVATION (5 MINS)

1. Ask students about their understanding of temperature and how it affects daily life (some examples given below):
   a. Hot and cold food
   b. Wearing appropriate clothes for the weather
   c. Effect of temperature in weather, etc.

2. Discuss the qualitative definition of temperature:
   a. The hotness or coldness of an object as a measure of its temperature
   b. The reliance of this measurement on the sense of touch
   c. The unreliability of the senses to make measurements

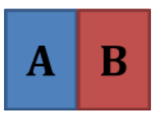
## INSTRUCTION/DELIVERY (5 MINS)

1. Have a student place one hand into the warm water and one hand in the cold water.
2. Wait about a minute and ask the student to close their eyes.
3. Have the student lift his hand out of the water and switch the bowl of warm water for the bowl of room temp water. (Make sure the student doesn't open his eyes while you do this.) Ask them if the water is hot or cold.
4. After he has answered, do the same thing for the cold water hand and ask the same question.

**Teacher tip**
If the hand is placed in a particular temperature (hot or cold) long enough, the nerve endings of the hand get used to the first temperature and "desensitizes" it. Putting the hand in water that is just a few degrees cooler or warmer, it feels the opposite. So the hand placed in warm water when placed in room temp water feels cold and the hand placed in the cold water when placed in the room temp water feels hot.
Alternatively, you can ask two different students to experience the warm and cold water.

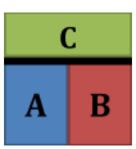
## DISCUSSION (40 MINS)

1. Discuss the"unreliability"of the senses as a standard for temperature measurement.
2. Place one glass each of hot and cold water on the table and show a thermometer to introduce the concept of thermal equilibrium:
    a. Hold the thermometer and ask why the reading is not zero (it's actually measuring room temperature)
    b. Ask students to observe what happens to the "liquid"inside the thermometer as you place the thermometer in the hot water (the liquid rises) and in the cold water (the liquid sinks)
    c. Ask students why the liquid in the thermometer stops rising or sinking (the temperature of the water and the thermometer are now the same)
    d. Define **thermal equilibrium**: (i) the thermometer and its surroundings now have the same temperature and (ii) no further change happens to both the thermometer and its surroundings.
    e. Ask: What does the thermometer measure? (The thermometer actually shows its own temperature. However, because it rapidly gains thermal equilibrium with its surroundings, then we can consider its temperature as the temperature of the object it is in contact with.)
3. Discuss the Zeroth Law:
    a. Introduce insulators (materials that did not allow interaction between substances) and conductors (materials that allowed materials to interact) and provide examples
    b. Two objects have temperatures A and B and are placed side-by- side. Both A and B are conductors. What will happen to their temperatures?

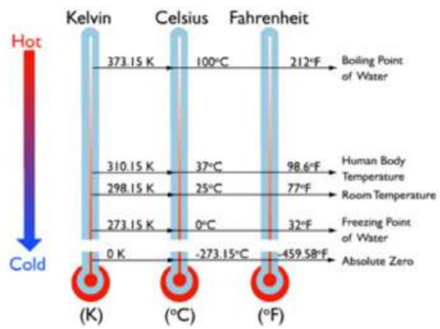



If temperatures A and B are the same, nothing changes. If temperature A is higher than B, then A will become cooler and B will become warmer. If temperature A is lower than B, then A will become warmer and B will become cooler.

    c. Discuss: If no change occurs to either A or B, then we know that their temperatures are the same. In this condition, if B is placed beside another object with temperature C and no change happens to both, then we know that B and C have the same temperature. What would happen if we then place C beside A? (The temperature of A is the same as C.)
    d. This is called the Zeroth Law (note that similarity to the transitive property in mathematics): If object A is in thermal equilibrium with object B and object B is in thermal equilibrium with object C, then objects A and C are in thermal equilibrium: *If* $T_A = T_B$ *and* $T_B = T_C$, *then* $T_A = T_C$



4. Discuss temperature scales
   a. To ensure that the measurement of temperature is objective, a standard is established. There are several standard temperature scales, three of which are shown in the diagram below:




   b. Discuss how to convert between Celsius and Fahrenheit scales:
      i. Note the freezing point (0°C and 32°F) and the boiling point (100°C and 212°F) of water in the scale
      ii. Note also the difference in the number of degrees between the temperature points (0 – 100 or 100 for Celsius and 32 – 212 or 180 for Fahrenheit)
      iii. Thus the proportion will be $T_C : T_V = 100 : 180$ *or* $T_C : T_F = 5 : 9$. Proportionally, these scales then: $\frac{T_C}{T_F} = \frac{5}{9}$. Considering that the Celsius scale is started at 0 and the Fahrenheit scale at 32, then we can write a conversion between scales as: $\frac{T_C}{T_F} = \frac{5}{9}$.
   c. Discuss how to convert between Celsius and Kelvin scales:
      i. Same number of degrees/calibrations for both scales but freezing point in the Kelvin scale is 273.15 K (note that Kelvin does not use "degree")
      ii. Thus, $T_K = T_C + 273.15$.
   d. Provide drill examples for conversion and discuss. Use familiar temperatures, such as weather temperatures, body temperatures, etc.
5. Introduce thermal expansion by asking students what happens to objects when temperature increases and to cite examples:
   a. Objects expand when temperature increases
   b. Some examples: jar cover can be removed by putting the cover in hot water, roads have gaps so they don't buckle during summer, sea levels rise because of warmer temperatures, etc.
6. Define thermal expansion as "the increase in the dimensions of an object as its temperature increases":

a. Linear expansion is expre$\Delta L = \alpha L_0 \Delta T$ and the new length can be expressed as $L = L_0 + \Delta L = L_0(1 + \alpha \Delta T)$

i. Expansion can be explained at the molecular level by the increased vibration in the connections between atoms

ii. All linear dimensions increase so an object with volume will expand volumetrically

iii. The coefficient of linear expansion $(\alpha)$ is constant for specific materials (see table of coefficients)

b. Volume expansion is expressed as $\Delta V = \beta V_0 \Delta T$, where the coefficient of volume expansion $(\beta)$ is constant for specific materials and are usually higher for liquids than for solids

7. Solve sample problems of thermal expansion:

a. Concept check: You are given four rectangular sheets.The dimensions of each are: (i) L x L, (ii) L x 2L, (iii) L X 3L, and 3L x 3L. They are all made from the same material and their temperature is increased to the same amount. Rank the plates according to the increase in their areas, greatest first. Explain your reasoning.

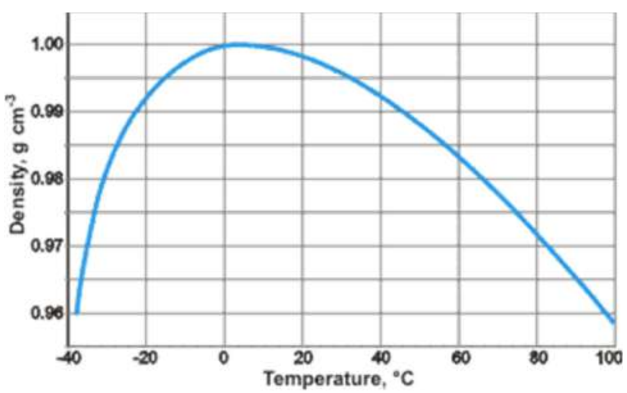
b. An aluminum baseball bat has a length of 0.86 m at a temperature of 17°C. When the temperature of the bat is raised, the bat lengthens by 0.00016 m. Determine the final temperature of the bat.

c. One rod is made from lead and another from quartz. The rods are heated and experience the same change in temperature. The change in length of each rod is the same. If the initial length of the lead rod is 0.10 m, what is the initial length of the quartz rod?

d. A test tube contains $2.54 \times 10^{-4}$ $m^3$ of liquid carbon tetrachloride at a temperature of 75.0°C. The test tube and the carbon tetrachloride are cooled to a temperature of – 13.0°C, which is above the freezing point of carbon tetrachloride. Find the volume of tetrachloride in the test tube at – 13.0°C.

8. Discuss the “anomalous” thermal expansion of water and how this favors life:

a. The temperature vs. density graph for water is shown below. Note that water is at its densest near 0° (actually, about 4°):



b. If mass remains constant, a decrease in density would mean an increase in volume (since $\rho = \frac{m}{V}$) ; note the decrease in density (thus increase in volume) as the temperature increa$(\Delta V \; \alpha \; \Delta T)$

c. Conversely, $-\Delta V \; \alpha - \Delta T$; as temperature decreases, volume should also decrease. Note the graph as temperature goes below 0°; water actually expands as it cools down (this is of course simultaneous with the change of phase from liquid water to solid ice)

d. Cite examples: ice floating in water, lakes freezing at the surface in winter but are water underneath (thereby allowing fish to survive even in winter), etc.

9. Discuss thermal stress:

a. Roads are built with gaps in between blocks. Why? These gaps are placed to cope with the changes in temperature that the road is exposed to. Figures below illustrates this:

| When temperature increases, the object expands and the gap closes | When temperature decreases, the object contracts and the gap increases |
|---|---|
|  |  |
| If the gap is not wide enough, the road "buckles" and the blocks are lifted upwards | If the gap is too wide, it poses a danger to motorists |
|  |  |

b. This is called "thermal stress"and can be related to the nature of the material. Derive the expression:

$$Young's\ Modulus\ (Y) = \frac{stress}{strain} = \frac{\frac{F}{A}}{\frac{\Delta L}{L_0}}$$

$$if\ \Delta L = \alpha L_0 \Delta T, then\ \frac{\Delta L}{L_0} = \alpha \Delta T\ and\ \frac{F}{A} = Y\alpha\Delta T$$

Discuss a sample problem: A steel wire whose length L is 130 cm and whose diameter is 1.1 mm is heated to an average temperature of 830°C and stretched taut between two rigid supports. What tension develops in the wire as it cools to 20°C?

## ENRICHMENT/READING ASSIGNMENT

1. Various kinds of thermometers and how they function (special attention to thermal properties)
2. The basis of each temperature scale: (Celsius,Fahrenheit,Kelvin)

## EVALUATION (5 MINS)

Ask students to explain their reasoning/answers:

a. A piece of square copper sheet with a hole in the middle was heated. Because of thermal expansion, the sheet itself will expand. Will the hole in the middle expand or shrink with the metal? Explain your answer.
b. Is there a relationship between the Young's modulus and the thermal linear coefficient of a material? If there is, what is this relationship?

60 MINS

# Heat and Capacity; Calorimetry

**Content Standards**
The learners shall be able to learn knowledge and application of:

1. Zeroth Law of Thermodynamics and Temperature
2. Thermal expansion
3. Heat and heat capacity
4. Calorimetry

**Performance Standards**
The learners shall be able to:

1. Explain the difference and relationship of temperature and heat as well as the mechanisms involved in heat transformation and transfer;
2. Relate the concepts of heat to the concepts of energy, basic kinetic molecular theory, and states of matter;
3. Apply the mechanisms of heat and its transfer to various phenomena; and,
4. Analyze and solve problems in both the theoretical and practical sense.

**Learning Competencies**
The learners shall be able to differentiate between temperature and heat; Define heat capacity and explain how it affects the increase and decrease in temperature of an object.; Solve problems involving temperature,thermal expansion, heat capacity, heat transfer, and thermal equilibrium in various contexts **(STEM_GP12TH-IIg-53)**; Perform an experiment investigating factors affecting thermal energy transfer **(STEM_GP12TH-IIg-54)**; Carry out measurements using thermometers **(STEM_GP12TH-IIg-55).**

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction/ Review** | Review on the prerequisite knowledge on temperature | 5 |
| **Motivation** | Discussion of previous lesson's assignment | 5 |
| **Instruction** | Experiment Activity | 15 |
| **Practice** | Presentation of Activity Results | 20 |
| **Enrichment** | Discussion of molar heat capacity | 5 |
| **Evaluation** | Pair-up discussion | 10 |
| **Materials** | (for each group) iron stand or tripod, alcohol lamp or burner, heat resistant beaker, 100g mass (metal) math, two thermometers, two Styrofoam cups (one with lid), stirrer, weighing scale | |

**Resource**

- Sears' and Zemanky's University Physics by Young and Freedman (13th Edition)
- Physics by Cutnell and Johnson (8th Edition).

## INTRODUCTION (5 MINS)

1. Make sure that students have prerequisite knowledge on temperature.
2. Make sure that students have the following skills: setting-up experiments, measuring quantities using appropriate tools, and handling hazardous (hot) materials; analyzing data
3. Define heat:
   a. Heat is **energy** that flows from an object of higher temperature to an object of lower temperature
   b. An object does **not** contain heat; an object has **internal energy** that can be converted to heat and transferred to another object
4. Discuss common conceptions of heat:
   a. A body with high temperature is said to be "hot"and to contain"heat" (the idea that "heat" is something that an object "possesses" and can pass to another)
   b. "*Isara ang pinto, lalabas ang aircon*" (the idea that it is cold air that moves outward, opposite the notion that heat moves from an object of higher temperature to one of lower temperature)
5. Discuss specific heat capacity:
   a. The heat that must be removed or added to an object depends on three factors: (i) the change in temperature, $\Delta T$; (ii) the mass of the object, $m$; and (iii) the specific heat capacity, $c$.
   b. These are combined in the equation: $Q = mc\Delta T$, *where* $Q$ = *heat lost or gained*
   c. From this, a definition of specific heat capacity can be obtained: $c = \frac{Q}{m\Delta T}$
   d. Thus, specific heat capacity can be defined as: "the amount of heat needed to raise the temperature of 1 kg of a substance by $1^0$C"
   e. The unit for heat is the Joule.
6. Discuss examples using table of specific heat capacities:
   a. metals have lower heat capacities so they heat up faster
   b. cheese and pie filling have higher heat capacities than the crust, etc.

**Teacher tip**

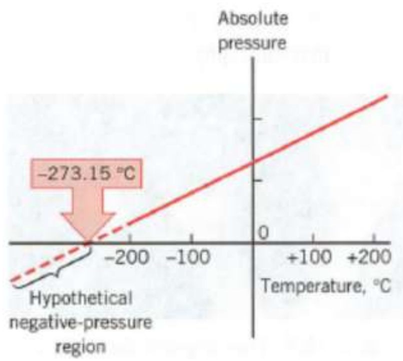
Alternatively for item 6, you may want to discuss hot pizza or any pie in which the crust may be cool enough to eat but not the filling or the cheese. Lead with the question, "Does the crust and the filling have the same temperature?" Or hot chocolate may also serve as a good example.

## MOTIVATION (5 MINS)

1. Discuss the previous lesson's assignment:
   a. Types of thermometers (emphasize the scientific principles applied)

b. The basis of temperature scales.

c. How the Kelvin scale was determined (Focus on the graph below)




2. Cite applications of thermal expansion:
    a. Tight-fitting metal rods
    b. Thermostatic switches

**Teacher tip**

You can sometimes procure a still-working thermostatic switch from a refrigerator repair shop.

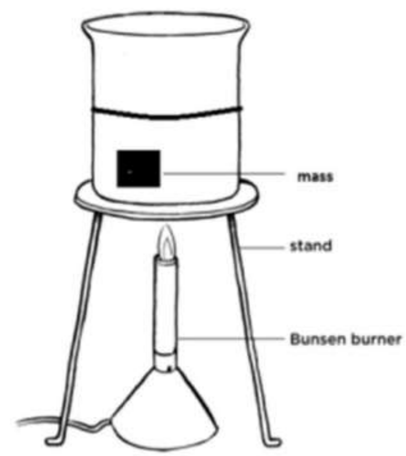
## INSTRUCTION/DELIVERY (15 MINS)

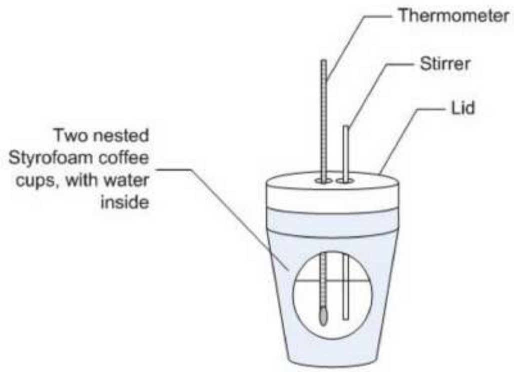
Remind students to: (1) read through the procedure before starting; (2) discuss the procedure first before proceeding; and (3) record all their data and prepare a short presentation of their results of the following experiment/activity.

1. Check that the mass of the object is indeed 100 g. Place it in a beaker of water so that it is completely submerged (but do NOT fill the beaker to the brim!).
2. Boil the mass and the water. Measure the temperature of the water. What does the temperature of the water tell you about the temperature of the mass? Why are we able to make this assumption?
3. Stack the two Styrofoam tops one on top of the other. Measure the mass of the two cups. Pour cold water into the topmost cup by approximating just enough to cover the mass. Measure the mass of the water. Describe how you measured the mass of the water.
4. Cover the cold water (the colder, the better) with the cup lid. Insert the thermometer through the straw-hole (see figure below) and measure the temperature of the cold water inside the cup. Why do we need to cover the cup? Also, what is the purpose of stacking the cups?

**Teacher tip**

To anticipate student questions as well as to have approximate results, the teacher should perform this activity beforehand using the mass that will be used by the students.






5. Using a pair of tongs, carefully remove the mass from the boiling water and transfer it to the cup with cold water. Take care that the thermometer in the lid is placed aside so that it does not come into contact with the mass.
6. Stir the water in the cup slowly about three times. What is the purpose of the stirring?
7. Replace the lid with the thermometer, taking care that the thermometer is not touching the mass. Measure the temperature of the water.
8. Fill the data below:

Mass of standard mass (in g) = ________________
Mass of cold water (in g) = ________________
Initial temperature of standard mass (in °C) = ________________
Initial temperature of water in cup, without mass (in °C) = ________________
Final temperature of water in cup, with mass (in °C) = ________________

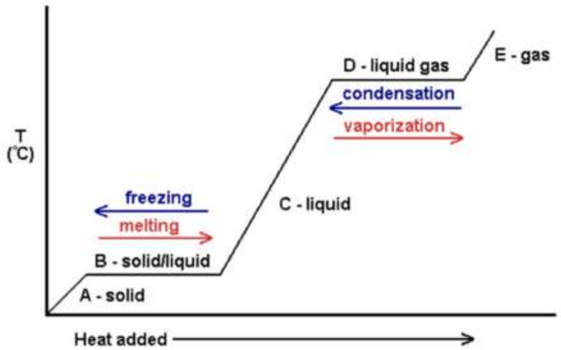
Using the available data, is it possible to approximate the specific heat capacity of the standard mass? If yes, how would you go about it? Show your analysis.

## PRACTICE (20 MINS)

1. Let students present and discuss the results of the activity:
    a. The boiling water and the standard mass are supposed to achieve thermal equilibrium (this should occur quickly since metals have low heat capacities)
    b. There must be a heat exchange between the standard mass (hotter) and the water in the cup (colder) so that the heat lost by the standard mass should be equal to the heat gained by the water, as described in $Q = mc\Delta T$
    c. It is possible to compute for an approximate of the specific heat capacity of the standard mass: $c_{sm} = \frac{m_{h2o}}{m_{sm}} c_{h2o}$

d. This measurement is an approximate because of the energy lost to the environment.

2. Define calorimetry: "measuring heat"or"  changes in energy of a system by measuring the heat exchanged with the surroundings"
3. Discuss heat exchange and phase change:
    a. Discuss the details of the graph below:




    b. The amount of heat transferred during a phase change is described by: *Q = ± mL ; where m is mass and L can be Lf (heat of fusion) or Lv (heat of vaporization)*
    c. When a substance undergoes a phase change directly to gas from a solid without passing through the liquid state, it undergoes **sublimation**
    d. A substance that is cooled to a temperature below its freezing point **without** changing from the liquid phase is **supercooled**.
4. Discuss examples of calorimetric calculations:
    a. Examples with no phase change involved
    b. Examples with phase changes involved

## ENRICHMENT (5 MINS)

1. If time is adequate, discuss **molar heat capacity** and the Dulong-Petitrule.
2. Provide additional reading on"calorie"as a heat measurement and the"food-calorie". Ask students to write a synthesis for extra credit. An article discussing the history of the calorie can be found in: **http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2238749/**

## EVALUATION (10 MINS)

1. Pair up students to discuss the following questions with the additional caution that their answers must consider the concepts discussed in the two succeeding lessons (55 & 56):

   a. A cool drink"sweats"at room temperature. Why is this so?
   b. Putting isopropyl alcohol in your skin makes it feel cold. Why?
   c. Why does it sometimes feel very warm right before a thunderstorm? Hint: Try to relate it to humidity and the processes of condensation and evaporation.
   d. If you put your hand inside an oven,your hand does not get burned as long as you don't touch any of the oven parts. The air temperature (inside the oven) and the oven temperature are supposed to be the same. Why would this be the case?

2. Ask pairs (select randomly) to discuss their answers. Discuss, explain, and correct whenever necessary. The students will report to class the results of the experiment. The students will submit the data sheet and answers to questions.

60 MINS

# Mechanisms of Heat Transfer with Stefan-Boltzmann Law and Applications of Heat Current Formula for Conduction

**Content Standards**
The learners shall be able to learn knowledge and application of:

1. Zeroth Law of Thermodynamics and Temperature
2. Thermal expansion
3. Heat and heat capacity
4. Calorimetry
5. Mechanisms of Heat Transfer

**Performance Standards**
The learners shall be able to:

1. Explain the difference and relationship of temperature and heat as well as the mechanisms involved in heat transformation and transfer;
2. Relate the concepts of heat to the concepts of energy, basic kinetic molecular theory, and states of matter;
3. Apply the mechanisms of heat and its transfer to various phenomena; and,
4. Analyze and solve problems in both the theoretical and practical sense.

**Learning Competencies**
The learners shall be able to describe the various modes of heat transfer; Solve problems involving temperature,thermal expansion, heat capacity, heat transfer, and thermal equilibrium in various contexts **(STEM_GP12TH-IIg-53)**; Solve problems using the Stefan-Boltzmann law and the heat current formula for radiation and conduction. **(STEM_GP12TH-IIh-56)**

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction/ Review** | Review on the prerequisite knowledge on temperature and heat capacity | 5 |
| **Motivation** | Simple observation activity | 5 |
| **Instruction** | Discussion on heat transfer, convection, conduction, and radiation | 30 |
| **Enrichment** | Discussion of Stefan-Boltzmann Law | 10 |
| **Evaluation** | Essay | 10 |
| **Materials** | Large beaker of cold water, small stoppered flask of coloured warm water (small enough to fit into the beaker) | |

**Resource**

- Sears' and Zemanky's University Physics by Young and Freedman (13th Edition)
- Physics by Cutnell and Johnson (8th Edition).

## INTRODUCTION (5 MINS)

1. Make sure that students have prerequisite knowledge on temperature and heat capacity.
2. Make sure that students have the following skills: mathematical problem solving, equation analysis.

## REVIEW

1. The following activity can be performed in groups or you may demonstrate and let students observe and explain:
    a. Pour cold water into a large beaker. Prepare a flask of hot water (about 500C) and color it with food dye. Close it with a stopper with two holes.
    b. Lower and immerse the flask into the beaker of cold water. If the hot water does not flow, you may need to prod one of the holes with a stirrer to start it.
2. List student observations and explanations (can be done in groups or dyads):
    a. Relate densities of cold and hot water to the observed behaviour
    b. Provide examples of common phenomena that exhibit the same behaviour (e.g. hot air rises, cold air sinks)
3. Review previous discussions
    a. Temperature and thermal expansion
    b. Heat capacities
4. Review conventions and definitions
    a. Heat moves from object of higher temperature to one of lower temperature
    b. Heat is not stored energy; the form that energy takes as it is transferred from one object to another object

## MOTIVATION (5 MINS)

1. Prepare a cup of hot water and ask students: How will I know if the water is hot or not without touching the water itself and without using a thermometer
2. The answer to the question is related to the fact that the skin is a "thermal sensor":

**Teacher tip**
If you have access to the internet, the following site provides good introduction of the three modes of heat transfer:

https://www.khanacademy.org/partner- content/mit-k12/mit-k12-physics/v/heat-transfer

a. Touch the cup (heat travels to your hand by conduction)
b. Put your hand above the cup of hot water (heat travels to your hand by convection)
c. Put your hand a certain distance from the warm cup (heat travels to your hand by a combination of radiation and convection)

## INSTRUCTION/DELIVERY (30 MINS)

1. Define heat transfer (the process by which energy from an object of higher temperature is transferred to an object of lower temperature through heat).
2. Discuss convection:
    a. Convection is the process of transferring heat through the movement of a fluid.
    b. Differentiate between natural and forced convection by citing examples and technological applications. (Refer to recommended references or search.)

3. Discuss conduction:
    a. Conduction is the process of transferring heat through the contact of two materials.
    b. Some materials are better at conducting heat (thermal conductors) than others (thermal insulators). Cite examples of objects that are conductors and those that are insulators.
    c. Find a table of thermal conductivities of different materials, like the one in the figure on the right. Which group of substances has high thermal conductivity? Which group of substances has low thermal conductivity? Based on your answers to the previous questions, speculate on what makes an object a thermal conductor.
    d. Consider a bar that is being heated as shown in the figure. What factors should we consider as heat transfers from the flame to the hand through the bar? How do these factors relate to each other?
    e. There are several factors that affect conduction:
        i. More heat flows for longer time: $Q \propto t$
        ii. The amount of heat that flows is proportional to the difference in temperature between two objects: $Q \propto \Delta T$

**Teacher tip**
How does conduction occur? Sample animation here: https://www.e- education.psu.edu/meteo003/sites/www.e-education.psu.edu.meteo003/files/image/Lesson%202/conduction0403_5.swf

Thermal Conductivity of Common Materials (at 25° C)

| Material | Conductivity (Watts/meter-°C) |
|---|---|
| Acrylic | 0.200 |
| Air | 0.024 |
| Aluminum | 250.000 |
| Copper | 401.000 |
| Carbon Steel | 54.000 |
| Concrete | 1.050 |
| Glass | 1.050 |
| Gold | 310.000 |
| Nickel | 91.000 |
| Paper | 0.050 |
| PTFE (Teflon®) | 0.250 |
| PVC | 0.190 |
| Silver | 429.000 |
| Steel | 46.000 |
| Water | 0.580 |
| Wood | 0.130 |

iii. A larger cross-sectional area will mean more heat flowing: $Q \propto A$

iv. A longer bar will mean longer length for heat to pass through and less heat conducted: $Q \propto \frac{1}{L}$

f. We summarize these factors: $Q \propto \frac{A(\Delta T)t}{L}$ and $Q = k\frac{(A\Delta T)t}{L}$

where $k$ is the thermal conductivity (dependent on the kind of material conducting the heat)

g. Provide worked mathematical examples:

i. Conduction through a single material

ii. Conduction through several materials

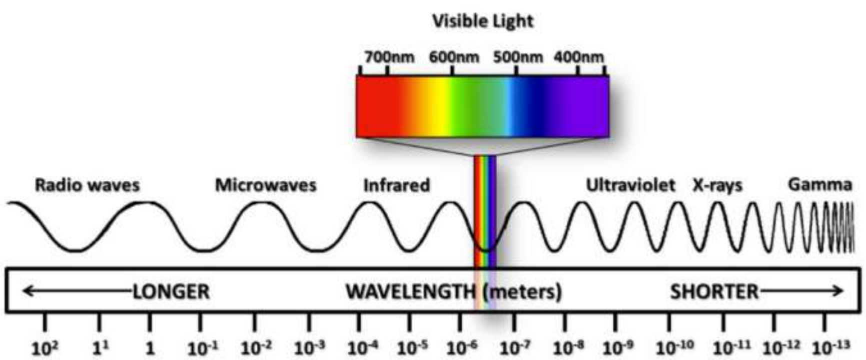
4. Discuss radiation

a. Radiation is the process of transferring heat through electromagnetic waves.

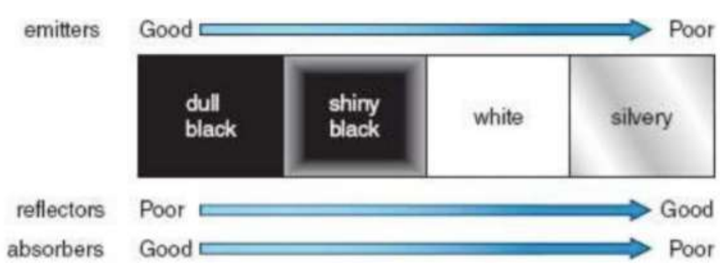
b. Radiation transfers heat even in the absence of a "medium" (i.e. through a vacuum), the way that sunlight travels through space to earth.

c. Briefly discuss EM radiation and how it relates to heat energy:

d. Discuss examples of emitters, absorbers, and reflectors and their various applications:




e. A perfect **blackbody** is both perfect emitter and a perfect absorber.



f. Discuss: Consider the sun as an emitter. What factors would affect the amount of heat that it emits?
   i. The amount of time it is radiating: $Q \propto t$
   ii. The area of the radiating surface: $Q \propto A$
   iii. (experimentally) The absolute temperature: $Q \propto T^4$
g. Discuss the implications of these factors:
   a. Thus we get the proportionality $Q = \sigma T^4 At$, and the equation $Q = \sigma T^4 At$, where $\sigma$ is the Stefan-Boltzmann constant $\sigma = 5.67 \times 10^{-8}$ $J/(s. m^2. K^4)$.
   b. The equation above is good only for a perfect emitter. For less-than-ideal emitters, an emissivity number e is included in the equation. The emissivity e is the ratio between the actual emission of the object and its projected emission if it were a perfect emitter. (Note that e is dimensionless number.)
   c. Thus, an object that is emitting 80% of its projected emission will have an emissivity of $e = 0.8$ and its heat emission will be $Q = (0.8)\ \sigma T^4 At$. The inclusion of emissivity in the equation is the Stefan-Boltzmann law of radiation: $Q = e\ \sigma T^4 At$.

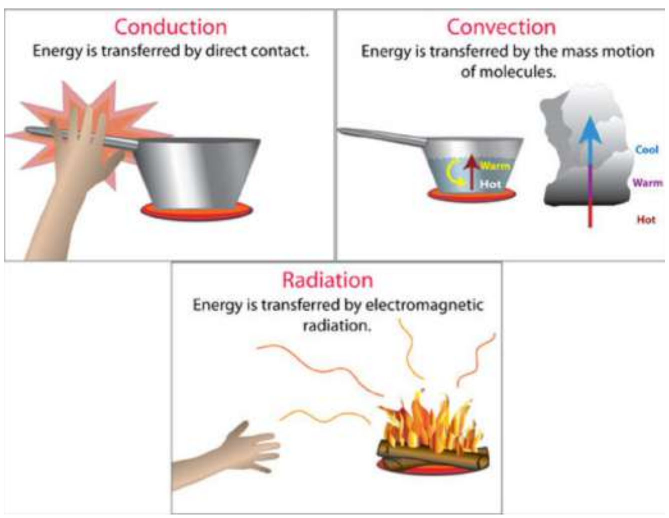
## ENRICHMENT (10 MINS)

Discuss how the Stefan-Boltzmann radiation law is used to determine the size of stars.

i. Some mathematical examples are presented in the references.
ii. The Stefan-Boltzmann radiation law can be re- written as: $\frac{Q}{t} = e\sigma T^4 A = L$, which is "luminosity" and used to determine the size of stars as well as classify them through the Hertzsprung- Russell diagram.

## EVALUATION (10 MINS)

Is the picture accurate? Explain your answer.



60 MINS

# Context-Rich Problem Solving in Heat and Mechanisms of Heat Transfer

**Content Standards**
The learners shall be able to learn knowledge and application of:

1. Zeroth Law of Thermodynamics and Temperature
2. Thermal expansion
3. Heat and heat capacity
4. Calorimetry
5. Mechanisms of Heat Transfer

**Performance Standards**
The learners shall be able to:

1. Explain the difference and relationship of temperature and heat as well as the mechanisms involved in heat transformation and transfer;
2. Relate the concepts of heat to the concepts of energy, basic kinetic molecular theory, and states of matter;
3. Apply the mechanisms of heat and its transfer to various phenomena; and,
4. Analyze and solve problems in both the theoretical and practical sense.

**Learning Competencies**
The learners shall be able to describe the various modes of heat transfer; Solve problems involving temperature,thermal expansion, heat capacity, heat transfer, and thermal equilibrium in various contexts **(STEM_GP12TH-IIg-53)**; Solve problems using the Stefan-Boltzmann law and the heat current formula for radiation and conduction. **(STEM_GP12TH-IIh-56)**

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction/ Review** | Review on the prerequisite knowledge on temperature and heat capacity | 15 |
| **Instruction** | Content-rich Problem Solving | 45 |
| **Materials** | pen and paper, calculator | |

**Resource**

- Sears' and Zemanky's University Physics by Young and Freedman (13th Edition)
- Physics by Cutnell and Johnson (8th Edition).

## INTRODUCTION (15 MINS)

1. Make sure that students have prerequisite knowledge on temperature and heat capacity.
2. Make sure that students have the following skills: mathematical problem solving, equation analysis.
3. Review the students on the main ideas and concepts of the two chapters:
    a. Temperature scales
    b. Temperature and Heat
    c. Thermal Expansion
    d. Heat Capacity
    e. Phase Changes and Heat
    f. Modes of Heat Transfer

4. Clarify muddy points and reinforce ideas when necessary:
    a. Differences across constants, such as coefficient of linear/volume expansion, specific heat capacity, latent heat, etc. and the instances when and where they apply
    b. Distinguishing between temperature (°C) and temperature difference(C°)
    c. Determining modes of heat transfer

## INSTRUCTION/DELIVERY (30 MINS)

1. *(This problem is a straightforward illustration of conversion among the various temperature scales. You can use this problem to repeat the emphasis on why the Kelvin scale does not use the degree, "0", symbol. It also provides an example of the medical application of the "cold treatment" for certain disorders.)*

    Dermatologists often remove small precancerous skin lesions by freezing them quickly with liquid nitrogen, which has a temperature of 77 K. What is this temperature on the (a) Celsius and (b) Fahrenheit scales?

**Teacher tip**
These problems were chosen to show the width and breadth of the two chapters preceding thermodynamics and intend to emphasize the major concepts in heat. Most of the problems are pretty straight-forward because students will have to take into consideration a lot of different ideas as well as certain conventions (e.g. When is heat lost? When is it gained?). As teacher, you will know your students best and you can always exercise the option of giving them more complicated problems to analyze. Consider these as a "starter pack".

$$\text{The initial given is } T_K = 77\ K.$$
$$\text{(a) To convert this to Celsius, we recall that:}$$
$$T_K = T_C + 273.15 \text{ which we convert to yield the equation: } T_C = T_K - 273.15.$$
$$\text{We then substitute the given value of}$$
$$T_K = 77\ K \text{ to get the equivalent temperature in the Celsius scale of } T_C = -196.15°\text{C}$$

$$\text{(b) To convert the given temperature to the Fahrenheit scale, we can use}$$
$$T_C = -196.15°\text{C and that } T_F = \frac{9}{5}T_C + 32°.$$
$$\text{By substitution, we obtain: } T_F = -321.07°\text{F}.$$

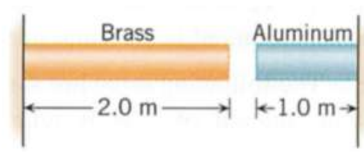
2. *(This problem provides a good discussion point regarding the coefficient of linear expansion; the expression that is generated shows that the coefficient can be derived from the ratio between the change in length and its original length for a given change in temperature. Thus, for any given temperature change, a substance with a higher coefficient of thermal expansion will also have a higher increase/decrease in length. The problem also demonstrates how to spot temperature differences – the unit is written in C$^O$ instead of $^O$C and the presence of the verbal clue phrase of "raised by".)*

   When the temperature of a coin is raised by 75 C$^O$, the coin's diameter increases by 2.3 x $10^{-5}$ m. If the original diameter of the coin is 1.8 x $10^{-2}$ m, find the coefficient of linear expansion.

$$\text{The given values are: } \Delta T = 75C°, L_0 = 1.8x10^{-2}m, \text{ and } \Delta L = 2.3x10^{-5}m.$$
$$\text{To solve for the coefficient of linear expansion, we use the expression:}$$
$$\Delta L = \alpha L_0 \Delta T \text{ which we transform to: } \alpha = \frac{\Delta L}{L_0}\Delta T$$
$$\text{By substitution, we obtain a coefficient of } \alpha = 0.096/C°.$$

3. *(This is a challenge problem in the sense that students must be able to figure out that the sum of the changes in length of the brass and aluminum bars must equal the air gap. Once the student is able to figure this out, it is a matter of applying algebraic principles.)*

   The brass bar and the aluminum bar in the drawing are each attached to an immovable wall. At 28$^O$C the air gap between the rods is 1.3 x $10^{-3}$ m. At what temperature will the gap be closed?



$$For\ this\ problem, we\ subscript\ all\ values\ for\ brass\ with\ \text{"br" and that of aluminum with "Al".}$$
$$Thus, from\ the\ table\ of\ coefficients\ we\ obtain:$$
$$\propto_{br} = 19x10^{-6}\ /\ C^\circ\ and\ \propto_{Al} = 23x10^{-6}\ /C^\circ \text{ and the corresponding lengths are:}$$
$$L_{0,br} = 2m\ and\ L_{0,Al} = 1m\ and\ that\ T_i = 28°C$$
$$and\ we\ note\ that\ the\ desired\ situation\ is\ to\ close\ the\ airgap\ such\ that:$$
$$\Delta L_{br} + \Delta L_{Al} = 1.3x10^{-3}m\ and: \Delta L = \propto L_0 \Delta T$$
$$From\ that\ we\ obtain\ the\ expression: (\propto L_0 \Delta T)_{br} + (\propto L_0 \Delta T)_{Al} = 1.3x10^{-3}m.$$
$$We\ expect\ that\ the\ change\ in\ temperature, \Delta T, will\ be\ the\ same\ so\ we\ can\ factor\ it\ out\ thus:$$
$$\Delta T[(\propto L_0)_{br} + (\propto L_0)_{Al}] = 1.3x10^{-3}m$$
$$By\ substituting\ all\ known\ values, we\ obtain: \Delta T = 21C^\circ.$$
$$Finally, we\ solve\ for\ T_f\ from\ \Delta T = T_f - T_i\ so\ that: T_f = 49°C$$

4. *This is an introductory problem for the ideas relating to heat gain and heat loss. The idea of "metabolic rate" in terms of heat lost to the environment is also explored in this problem. Note that in this problem the person experiences "heat loss" that is equal to the water's "heat gain". This is also an opportunity to appreciate how substantial water's heat capacity is.)*

   When resting, a person has a metabolic rate of about 3 x $10^5$ joules per hour. The person is submerged neck-deep into a tub containing 1.2 x $10^3$ kg of water at 21$^O$C. If the heat from the person goes only into the water, find the water temperature after half an hour.

$$The\ values\ given\ in\ the\ problem\ are:$$
$$\frac{Q}{t} = 3x10^5 \frac{J}{hr}, m_w = 1.2x10^3 kg, T_{i,w} = 21°C, and\ t = 0.5hr.$$
$$From\ the\ table\ of\ heat\ capacities, we\ obtain\ c_w = 4{,}186 \frac{J}{kg.C^\circ}.$$
$$We\ change\ the\ basic\ equation\ to\ reflect\ the\ time\ element\ so\ that:$$
$$\frac{Q}{t} = \frac{mc\Delta T}{t}\ and\ also\ note\ that\ heat\ lost\ by\ the\ person\ is\ gained\ by\ the\ water.$$
$$We\ thus\ solve\ for\ \Delta T = \frac{\frac{Q}{t}(t)}{(mc)_w}\ (note\ that\ t\ is\ not\ cancellable\ here!)$$
$$and\ obtain: \Delta T = 0.02986C^\circ = 0.03C^\circ.$$
$$This\ allows\ us\ to\ obtain\ T_f = 21.03°C.$$

5. *(This type of problem is almost a standard for heat capacity problems but it demonstrates the important point of heat being "additive". This problem also allows us to recall the relationships between work, energy, and heat while reviewing the concept of power.)*

   A 0.35-kg coffee mug is made from a material that has a specific heat capacity of 920 J/(kg.C$^O$) and contains 0.25 kg of water. The cup and water are at 15$^O$C. To make a cup of coffee, a small electric heater is immersed in the water and brings it to a boil in three minutes. Assume that the cup and water always have the same temperature and determine the minimum power rating of this heater.

$$We\ will\ subscript\ the\ values\ for\ the\ mug\ with\ \text{"m" and the values for the water with "w".}$$

$$Thus, we\ have\ the\ following\ given\ values:$$

$$m_m = 0.35kg, c_m = 920\frac{J}{kg.C^\circ}, m_w = 0.25kg, and c_w = 4{,}186\frac{J}{kg.C^\circ}\ and,$$

$$while\ the\ initial\ temp\ of\ water\ is\ 15°C, we\ can\ deduce\ \Delta T = 85C^\circ$$

$$since\ the\ water\ is\ expected\ to\ boil.$$

$$The\ total\ heat\ requirement\ to\ boil\ the\ water\ and\ heat\ the\ mug\ would\ therefore\ be:$$

$$Q_T = Q_m + Q_w\ where\ \Delta T_m = \Delta T_w\ and\ Q = mc\Delta T.$$

$$Using\ these\ we\ obtain\ the\ expression: Q_T = [(mc)_m + (mc)_w]\Delta T.$$

$$This\ allows\ us\ to\ solve\ for\ Q_T = 116{,}322.5J.$$

$$We\ now\ solve\ for\ power: P = \frac{Work}{time} = \frac{Q_T}{t}\ when\ t = 3mins = 180s\ so\ that\ P = 646.2W.$$

6. *(This problem involves a change in phase and is distinguished from the previous problem because changes in phase require a different constant – heat of fusion as opposed to heat capacity. It is also possible to discuss the direction of heat gain – by the ice cubes – because of the heat loss of the water. This problem also reviews the concept of density to complete the required values to solve the problem.)*

   A thermos contains 150 $cm^3$ of coffee at 85$^O$C. To cool the coffee, you drop two 11-g ice cubes into the thermos. The ice cubes are initially at 0$^O$C and melt completely. What is the final temperature of the coffee? Treat the coffee as if it were water.

$$We\ first\ examine\ the\ heat\ gained\ by\ the\ ice\ as\ it\ changes\ phase.$$

$$We\ are\ given: m = 2(11g) = 22g = 0.022kg\ and\ that\ L_f = 3.35x10^5\frac{J}{kg}.$$

$$Using\ the\ expression, Q = mL_f, Q_{gain} = 7{,}370J.$$

$$We\ now\ shift\ focus\ to\ the\ heat\ lost\ by\ the\ water, which\ is\ the\ heat\ gained\ by\ the\ ice.$$

$$We\ thus\ have\ Q_{lost} = -7{,}370J\ and\ Q_{lost} = mc\Delta T.$$

$$We\ obtain\ the\ other\ given: T_i = 85°C\ and\ c = 4{,}186\frac{J}{kg.C^\circ}.$$

$$To\ obtain\ the\ mass\ of\ the\ water, we\ recall: \rho = \frac{m}{V}\ and\ V = 150cm^3 and\ \rho_w = 1\frac{g}{cm^3}.$$

$$From\ these\ considerations\ we\ obtain\ m_w = 0.15kg.$$

$$Going\ back\ to\ Q_{lost} = mc\Delta T, we\ can\ solve\ for\ \Delta T\ and\ obtain\ \Delta T = -11.73C^\circ.$$

$$This\ allows\ us\ to\ solve\ for\ T_f\ knowing\ that\ T_i = 85°C\ and\ T_f = 73.26°C$$

7. *(This is almost exclusively an exercise in algebra, were it not for the illustrative comparison of the relationship between conductivity and length. It shows that, for the same values of temperature difference, rate of heat, and surface area, materials that have high thermal conductivity can be made longer than materials with lower thermal conductivity.)*

   Due to a temperature difference ΔT, heat is conducted through an aluminum plate that is 0.035 m thick. The plate is then replaced by a stainless steel plate that has the same temperature difference and cross-sectional area. How thick should the steel plate be so that the same amount of heat per second is conducted through it?

$$\text{The only numerical value given is } L_{al} = 0.035m.$$
$$\text{From the table of values we obtain: } k_{al} = 240\frac{J}{(s.m.C^{\circ})} \text{ and } k_{st} = 14\frac{J}{(s.m.C^{\circ})}.$$
$$\text{The following equalities } \Delta T_{al} = \Delta T_{st}, A_{al} = A_{st}, \text{and } \frac{Q}{t}_{al} = \frac{Q}{t}_{st}.$$
$$\text{Thus, the equation } \frac{Q}{t} = \frac{kA\Delta T}{L} \text{ can be reduced to } \frac{k_{al}}{L_{al}} = \frac{k_{st}}{L_{st}}.$$
$$\text{This allows us to solve for } L_{st} = 2.042x10^{-3}m$$

8. *(This type of problem explores the use of implicit, as opposed to explicit values. Many student difficulties in problem solving stem from their inability to grasp context clues. In this problem, the student must be able to surmise that the temperature difference between the ends of the rods is 100C$^{O}$. This is a good way to recall the standard temperatures of water in the Celsius scale. This problem also combines with the concepts of conduction the previous concepts of heat exchange resulting in a change in phase.)*

A copper rod has a length of 1.5m and a cross-sectional area of 4 x 10$^{-4}$m$^{2}$. One end of the rod is in contact with boiling water and the other with a mixture of ice and water. What is the mass of ice that melts per second? Assume no heat is lost through the side surface of the rod.

$$\text{The rod in the problem has dimensions of } L = 1.5m \text{ and } A = 4x10^{-4}m^2.$$
$$\text{Because it is copper, we know its thermal conductivity } k_{Cu} = 390\frac{J}{(s.m.C^{\circ})}$$
$$\text{Because it is between boiling and frozen water, } \Delta T = 100C^{\circ} \text{ and also } t = 1s.$$
$$\text{Using } Q = \frac{(kA\Delta T)t}{L}, \text{we obtain } Q = 10.4J.$$
$$\text{This value is construed as } Q_{gain} \text{ for the ice so that } Q_{gain} = 10.4J.$$
$$\text{This heat is used to melt ice so that } Q = mL_f \text{ where } L_f = 3.35x10^5\frac{J}{kg}.$$
$$\text{Thus, every second a mass of ice } m = 3.1x10^{-5}kg \text{ melts.}$$

9. *(This problem can be used to re-discuss the Hertzsprung-Russell diagram. It is also good practice in algebraic substitution.)*

Sirius B is a white star that has a surface temperature (in kelvin) that is four times that of our sun. Sirius B radiates only 0.040 times the power radiated by the sun. Our sun has a radius of 6.96 x 10$^{8}$m. Assuming that Sirius B has the same emissivity as the sun, find the radius of Sirius B.

All data for Sirius B is subscripted as "Si" while that for the sun will have "Su".

$$\text{From the statement of the problem, the following relationships among variables are given:}$$

$$T_{Si} = 4T_{Su}, \frac{Q}{t}_{Si} = 0.40\frac{Q}{t}_{Su}, e_{Si} = e_{Su}$$

$$\text{Using the equation } Q = e\sigma T^4 At, \text{ we solve for } e = \frac{Q}{t}\frac{1}{T^4 A\sigma} \text{ so that:}$$

$$\left(\frac{Q}{t}\frac{1}{T^4 A\sigma}\right)_{Si} = \left(\frac{Q}{t}\frac{1}{T^4 A\sigma}\right)_{Su}$$

$$\text{by substitution so that all unknowns are expressed in terms of the Sun,}$$

$$\text{we obtain the remaining expression: } \frac{1.5x10^{-3}}{A_{Si}} = \frac{1}{A_{Su}} \text{ where } A = 4\pi r^2$$

$$\text{Further substitution allow us to solve for } r_{Si} = \sqrt{1.56x10^{-3}(r_{Su}^2)} \text{ and } r_{Si} = 2.75x10^7 m$$

10. *(This problem is a good discussion point on why bald heads have lower emissivity than heads with hair. You should have a fun discussion.)*

A person is standing outdoors in the shade where the temperature is 28$^{O}$C. (a) What is the radiant energy absorbed per second by his head when it is covered by hair? The surface area of the hair (assumed to be flat) is 160cm$^2$ and its emissivity is 0.85. (b) What would be the radiant energy absorbed per second by the same person if he were bald and the emissivity of his head were 0.65?

$$\text{We are given } T = 28°\text{C} = 301.15K \text{ and the area of the head is } A = 160cm^2 = 0.016m^2$$

$$\text{This is a radiation problem so } Q = e\sigma T^4 At \text{ where } t = 1s \text{ and } \sigma = 5.67x10^{-8}\frac{J}{(s.m^2.K^4)}$$

$$\text{and we solve first for } \sigma T^4 At = 7.46J.$$

$$\text{For the head with hair in (a), } e = 0.85 \text{ so } Q = 6.34\,J.$$

$$\text{For the bald head in (b), } e = 0.65 \text{ so } Q = 4.85J.$$

60 MINS

# Experiments on Heat Transfer

**Content Standards**
The learners shall be able to learn knowledge and application of:

1. Zeroth Law of Thermodynamics and Temperature
2. Thermal expansion
3. Heat and heat capacity
4. Calorimetry
5. Mechanisms of Heat Transfer

**Performance Standards**
The learners shall be able to:

1. Explain the difference and relationship of temperature and heat as well as the mechanisms involved in heat transformation and transfer;
2. Relate the concepts of heat to the concepts of energy, basic kinetic molecular theory, and states of matter;
3. Apply the mechanisms of heat and its transfer to various phenomena; and,
4. Analyze and solve problems in both the theoretical and practical sense.

**Learning Competencies**
The learners shall be able to perform an experiment investigating factors affecting thermal energy transfer and analyze the data – identifying deviations from theoretical expectations when appropriate. **(STEM_GP12TH-IIg-54)**

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction/ Review** | Review on the prerequisite knowledge on temperature and heat capacity | 10 |
| **Instruction** | Experiment on Heat Transfer | 35 |
| **Evaluation** | Concluding questions | 15 |
| **Materials** | construction steel cable in various lengths (at least 3 shorter than 0.5 meter), meter stick, ice, Bunsen burner or alcohol lamp, tripod, beakers, calipers, 2 metal cans, awl (anything sharp to pierce a hole in the can), weighing scale, graduated cylinder, protective gloves | |

**Resource**

- Sears' and Zemanky's University Physics by Young and Freedman (13th Edition)
- Physics by Cutnell and Johnson (8th Edition).

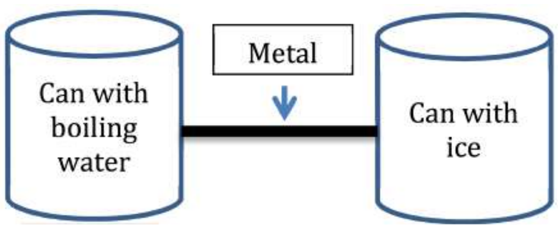
## INTRODUCTION (5 MINS)

**Teacher tip**
Students will be using an open flame and objects with high temperatures so it is necessary to ensure their safety. If available, protective gear must be used.

1. Make sure that students have prerequisite knowledge on modes of heat transfer, heat capacity and heat of fusion.
2. Make sure that students have the following skills: use of laboratory equipment such as calipers and thermometers and handling of hot (1000C) materials.
3. Review the equation for heat conduction: $Q = \frac{(kA\Delta T)t}{L}$
4. Introduce the activity: The purpose is to examine and confirm the relationship of the variables in the equation above as well as measure an approximate value for thermal conductivity of the metal rod.
5. Review lab safety procedures.

## INSTRUCTION/DELIVERY

1. Experiment: Measuring Thermal Conductivity:
    a. Measure the length of three rods and their cross-sectional areas
    b. Make a small hole around the middle of the cans. Put water in one can up to the level of the hole and boil it. Put ice in the other can and cover it with insulating but non- absorbent material. Thread one of the metal rods into the holes in the cans. The set-up is roughly diagrammed as follows:




    c. Maintain this set-up for about three minutes after which remove the rod. Immediately pour out the water from the melted ice and measure its mass. (Note: if there is no weighing scale, the volume can be measured and the mass computed using the density of water.) Repeat this procedure three times.
    d. Repeat the procedure in (c) for the two other rods.

e. Fill up the table below and discuss the results:

| | Time (s) | $\Delta$ T ($C^O$) | Area ($m^2$) | Mass of Melted ice | | | Compute for Q | | | Compute for k | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rod 1 | | | | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| Rod 2 | | | | | | | | | | | | |
| Rod 3 | | | | | | | | | | | | |

## EVALUATION (5 MINS)

1. Ask students to present their results and discuss.
2. Ask students to devise another experiment to confirm the relationship of other variables.

**Teacher tip**

Students will require some guidance in presenting their results. The use of graphs and diagrams during their discussion would be helpful. Provide sufficient guidance in the creation of these.

60 MINS

# Ideal gas law  and applications; Internal energy of an ideal Gas; Heat capacity of ideal gases

**Content Standards**
The learners shall be able to learn knowledge and application of:

1. Ideal gas law
2. Internal energy of an ideal gas
3. Heat capacity of an ideal gas
4. Thermodynamic systems

**Learning Competencies**
The learners shall be able to numerate the properties of an ideal gas **(STEM_GP12GLT-IIh-57);** Solve problems involving ideal gas equations in contexts such as, but not limited to, the design of metal containers for compressed gases **(STEM_GP12GLT-IIh-58**); Distinguish among system, wall, and surroundings **(STEM_GP12GLT-IIh-59).**

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction/ Review** | Cite instances wherein the interplay of pressure, temperature, volume, and/or number of particles of a gas is observed. | 5 |
| **Instruction** | Discussion of the following:<br>• Ideal gas law<br>• Kinetic theory of ideal gases<br>• Heat capacity of ideal gases | 35 |
| **Practice** | Plug and play problem | 5 |
| **Enrichment** | Use of ideal gas law in explaining storage tank implosion | 5 |
| **Evaluation** | Problem solving exercise | 10 |

**Resource**

- Fundamentals of Physics by Halliday and Resnick (9th Edition)
- Storage tank implosion: https://www.youtube.com/watch?v=2WJVHtF8Gwl

## INTRODUCTION (5 MINS)

**Teacher tip**
Blowing up a microwave using a bottle of water: https://www.youtube.com/watch?v=nYk8fz3JjEM

1. Cite instances wherein the interplay of pressure, temperature, volume, and/or number of particles of a gas is observed.
   a. When you microwave food in a container, you make sure you remove the lid. This is because when you heat the food, the temperature of the air inside the container increases. Also, water molecules evaporate, increasing the number of gas particles inside the container. As a result, the pressure inside the container increases until it's enough to pop the lid off, or worse, break the container.
   b. In some car engines, air is mixed with a mist of fuel. To ignite the fuel, the gas chamber is compressed. The volume of the air-fuel gas decreases, and as a result, temperature increases until it's hot enough that the fuel ignites.
   3. Pressure decreases with altitude. So when an airplane ascends, the pressure in air-tight containers decreases, and as a result, the volume of the air inside air-tight packages increases, making them look inflated.*
2. Summarize the results and state the objectives of the lecture: the pressure, temperature, volume, and number of particles of a gas are interrelated. The exact relationships vary from one gas to another, but under certain conditions, all gases behave similarly. In this lecture, we will discuss this general behavior.

## INSTRUCTION/DELIVERY (35 MINS)

**Ideal Gas Law**

1. Point out that the relationship of pressure, volume, temperature, and number of particles differs from one gas to another, but under small enough pressures and high enough temperatures, the discrepancies tend to disappear. All gases approach the so-called ideal gas.
2. State the ideal gas law: Under small enough pressures and high enough temperatures, all gases follow the equation of state

$$pV = nRT$$

where p is pressure, V is volume n is the number of moles of gas, T is temperature, and R is a constant of proportionality.

$$R = 8.31 \frac{\mathrm{J}}{\mathrm{mol \cdot K}}$$

State the other form involving the number of particles N of the gas:

$$pV = NkT$$

where

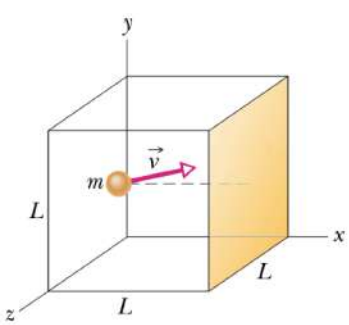
$$k = 1.38 \times 10^{-23}\,\frac{\text{J}}{\text{K}}$$

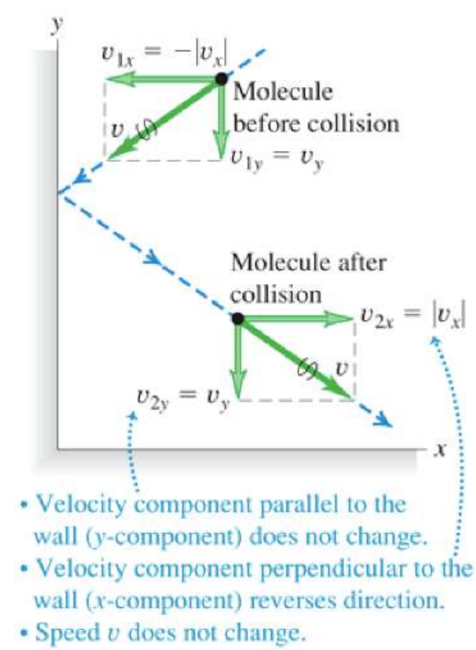
Point out that $R = kN_A$, where $N_A$, is the Avogadro's number. Emphasize that an ideal gas is just an idealization and is only applicable under certain circumstances.

**Kinetic theory of ideal gases**

1. Ask a series of questions that would lead the class to the objective of this part of the lecture:
    a. Does a gas have energy?
    b. Can we compute for the energy of a gas? What expression can we use?
    c. How do we get the speed?

    Yes, a gas has energy. Each particle in the gas moves, so it must have a kinetic energy. We can compute for the energy if we knew the masses and speeds of each particles; the kinetic energy of the gas would just be the sum of all $\frac{1}{2}mv^2$'s. The speeds differ from one particle to another, but we can get the average speed by relating it to pressure. That means, at best, we can only compute for the average energy of a gas. State the objective of this part of the lecture: We want to derive an expression for the kinetic energy of an ideal gas.
2. Consider an ideal gas confined in a cube of side length $L$. Consider one particle striking one of the walls. Convince the class (using the figure below as visual reinforcement) that by impulse momentum theorem, the impulse delivered by the wall on the particle along the x-axis is given by $(-mv_x) - (+mv_x) = -2mv_x$ and hence, by Newton's 3rd Law, the impulse delivered by the particles on the wall is $+2mv_x$.
3. Convince the class that the time in between collisions with this wall is ec $\Delta t = \frac{2L}{v_x}$ the time it takes for the molecule to travel to the opposite wall and then back again, that is



4. From the previous two equations, derive an expression for the force on the wall:

$$F_x = \frac{\Delta p_x}{\Delta t} = \frac{2mv_x}{2L/v_x} = \frac{mv_x^2}{L}$$

5. Convince the class that the pressure on the wall is the sum of the forces due to all particles. Derive an expression for the pressure on the wall:

$$p = \frac{F_x}{A} = \frac{\sum_{i=1}^{N} mv_{x,i}^2/L}{L^2} = \frac{m}{V}\sum_{i=1}^{N} v_{x,i}^2$$

   Multiply and divide the right-hand side of the equation by the *N*. Point out that the average value of the square of the speeds is

$$(v_x^2)_{\text{ave}} = \frac{\sum_{i=1}^{N} v_{x,i}^2}{N}$$

   and so the previous relation can be written as

$$p = \frac{mN}{V}(v_x^2)_{\text{ave}}$$

6. Perform the following manipulations on the board:

$$pV = mN(v_x^2)_{\text{ave}}$$

By ideal gas law,

$$NkT = mN(v_x^2)_{\text{ave}}$$

Cancel out N and multiply both sides by 1/2.

$$\frac{1}{2}kT = \frac{1}{2}m(v_x^2)_{\text{ave}}$$

Notice that the right-hand side is the average kinetic energy of a particle for the motion along the x-axis. We still need to add the contributions of motions along the y- and z-axes. By symmetry, they should all have the same contributions. Hence, the average kinetic energy of a particles is

**Teacher tip**
Students might get confused between (pressure) and (x-component of momentum). It might be better to just spell out the word momentum in the derivation to avoid confusion.

There might be a need to go slow here and emphasize what each symbol means. If the students are not yet familiar with the summation symbol, just write down it down in expanded form.

$$K_{\text{ave},1} = \frac{3}{2}kT$$

and the total kinetic energy of the system is

$$K_{\text{ave},tot} = NK_{\text{ave},1} = \frac{3}{2}NkT$$

Emphasize the simplicity and significance of the equation: When we measure the temperature of an ideal gas, we are also measuring the average kinetic energy of the particles comprising it.

**Heat capacity of ideal gases**

1. Review the concept of heat capacity. Write down the previously derived expression for the heat required to increase a temperature when volume is held constant:

$$Q = nC_V\Delta T$$

2. Recall in class that heat is energy in transit, and argue that the heat we put into a system amounts exactly to the energy increase of the system.

$$Q = \Delta K_{\text{ave,tot}}$$

3. Using the previous two expressions, derive an expression for the heat capacity of an ideal gas:

$$nC_V\Delta T = \frac{3}{2}Nk\Delta T$$
$$C_V = \frac{3}{2}\frac{Nk}{n} = \frac{3}{2}N_A k = \frac{3}{2}R$$

**Teacher tip**
This is only true because we held the volume of the container constant. Otherwise, there will be work done to the environment, and by then the 1st law of thermodynamics must be used.

## PRACTICE (5 MINS)

1. Give a simple plug-and-play example: What is the volume, total kinetic energy, and heat capacity (at constant volume) of a container with 1 mole of an ideal gas at standard temperature and pressure (STP)

*Equations to use:* $pV = nRT$ *and* $K_{\text{ave},tot} = \frac{3}{2}NkT = \frac{3}{2}nRT$

## ENRICHMENT (5 MINS)

1. Show the students this video of a storage tank imploding: https://www.youtube.com/watch?v=2WJVHtF8GwI
2. Give an introduction: Steam was used to clean the interior of a storage tank. The hot gas was left to cool without properly venting it. This is what happened next.
3. Give a minute for the students to think about the reason why the storage tank collapsed in the context of ideal gas law.

Give the explanation: As the steam cooled down, temperature decreased. Also, some of the steam condensed to water, decreasing the number of gas molecules. The volume (prior to implosion) was constant. It follows from ideal gas law, $pV=NkT$, that the pressure should also decrease. The internal pressure reached a value so low that the external pressure outside was able to crush the tank.

## EVALUATION (10 MINS)

1. Give the class 2 or 3 plug-and-play problems, similar to the practice problem but solving for different unknowns.

60 MINS

# Work done during Volume Changes and the First Law of Thermodynamics

**Content Standards**
The learners shall be able to learn knowledge and application of:

1. Thermodynamic Systems
2. Work done during volume changes
3. First Law of thermodynamics

**Learning Competencies**
The learners shall be able to  define thermodynamic systems and processes; state and explain the Zeroth and First Law of Thermodynamics; apply the First Law of Thermodynamics to the appropriate situations; Compute the work done by a gas using dW=PdV **(STEM_GP12GLT-IIh-61)**; and, state the relationship between changes in internal energy, work done, and thermal energy supplied through the First Law of Thermodynamics **(STEM_GP12GLT-IIH-62)**.

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction/ Review** | Brief history of the engine; definition of terms | 5 |
| **Motivation** | Observation activity | 5 |
| **Instruction** | Discussion proper | 40 |
| **Enrichment** | Review of the Zeroth Law of Thermodynamics | 5 |
| **Evaluation** | Computation activity | 5 |
| **Materials** | rice cooker, water, more reference materials if available | |

**Resource**

- Sears' and Zemanky's University Physics by Young and Freedman (13th Edition)
- Physics by Cutnell and Johnson (8th Edition).

## INTRODUCTION (5 MINS)

1. Use the demonstration above to discuss the history of the engine in the industrial age and the early beginnings of thermodynamics. (Please Google: "history of thermodynamics", if you have internet access) Discuss the need for engines for manufacture and transport that do not require animals or people as source of mechanical energy. Discuss how steam was the first option for engines. (Or you may ask a group of your students to prepare a short presentation on this.)
2. Define some starting terms:
    a. Thermodynamics - the study of relationships involving heat, mechanical work, and other aspects of energy and energy transfer (from University Physics) or
    b. Thermodynamics: *therme* (heat) + *dynamis* (power or force causing motion)
    c. Thermodynamic system – an object or group of objects with the capacity to exchange energy with its surroundings through a thermodynamic process
    d. Thermodynamic process – a change in a system's pressure, volume, temperature, or mass, which is sometimes referred to as a "change in state" (review from previous lessons on the ideal gas)

**Teacher tip**
Review students' understanding of equations of state, energy transfer through mechanical means and heat, and law of conservation of energy.

Review the following skills: recall of appropriate related concepts, symbolic analysis of quantities, associating appropriate phenomena to scientific concepts.
For item 1, an advanced assignment to students will provide for a more engaged discussion.

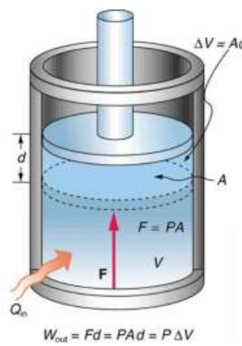
## MOTIVATION (5 MINS)

Boil some water in the rice cooker before the class so that, by the beginning of the class, the water will already be boiling. Boil just enough so that the resulting steam will be strong enough to lift the lid (the steam will periodically "rattle" the lid). Ask the class, in open discussion, to observe and explain their observations. Use directing questions such as, "what do you think lifts the lid?" and "why does the lid fall back down?"

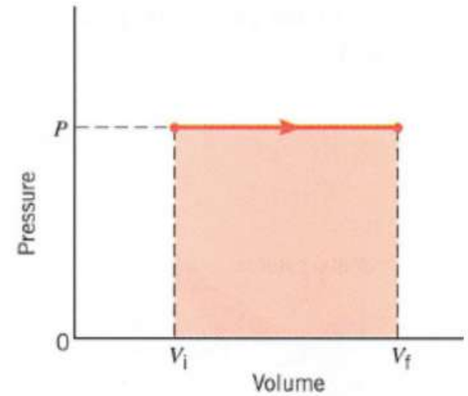
**Teacher tip**
Emphasize the heat transfer from flame to water, the changes that water undergo as it is heated (conversion to steam), the energy carried by the water (steam) at the higher temperature, and its ability to do work in this state.

## INSTRUCTION/DELIVERY (30 MINS)

1. Discuss an example of a thermodynamic system by referring to the earlier demonstration:
    a. Ask: Which of the materials here can be considered a thermodynamic system?
    b. Emphasize: A thermodynamic system must have the *capacity* to exchange energy with its surroundings through a *thermodynamic process*
    c. Discuss: Steam can be considered a thermodynamic system because it can lift the lid (do work on the lid – mechanical energy transfer) by expanding (changing its volume state)
    d. Ask students for other examples of possible thermodynamic systems *(the general rule being these examples should require a change of state for the object or objects)*
2. Discuss the work done by a thermodynamic system and how it relates to changes in state:
    a. Consider a gas inside a container that has a movable piston:



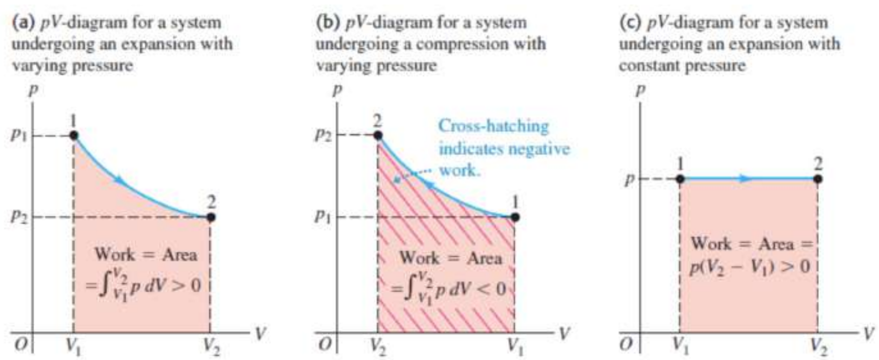

    b. The gas exerts pressure on its container given by: $P = \frac{F}{A}$ or $F = PA$
    c. The gas is able to move the piston upwards by a certain displacement, d, which we can refer to as *d = dx* so that *W = Fdx when cosϴ = 1.*
    d. Substitution of *F = PA to W = Fdx yields: W = PAdx*. We note that *Adx = dV,* or a change in volume.
    e. Thus, the work done by an expanding gas can be written as: *W = PdV.*
3. Discuss further details of the work done by an expanding gas:
    1. This is also called an isobaric thermal process and can be graphed thus:




2. The area under the curve can be computed as *PdV*, which indicates that this area is a representation of the work done by the gas.
3. Discussion point: What happens to the work done if the values of final and initial volumes are exchanged? (Recall discussion on "work done by system" and "work done on system")

4. Discuss P-V diagrams and the implication to the work done:

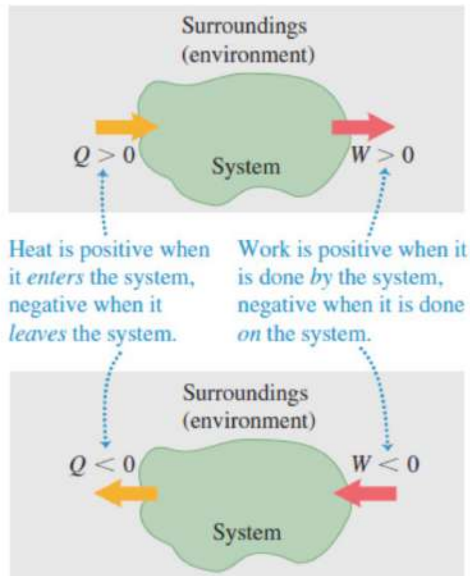
The work done in P-V graphs can be computed from the "area under the curve"(in the graphs below, the curve is the blue line); note that work is positive when volume increases (Vf > Vi), work is negative when volume decreases ($V_f < V_i$), and work is zero if there is no change in volume (graph not shown – ask students to draw that graph)




5. Review previous lessons on energy and heat and how they affect internal energy:
   a. In mechanics, we learn that W = ± Δ*U* and there are two possible outcomes:
      i. *If the system does work,* $U_i > U_f$ *and* $\Delta U = -W$

    ii. *If work is done on the system,* $U_f > U_i$ *and* $\Delta U = W$

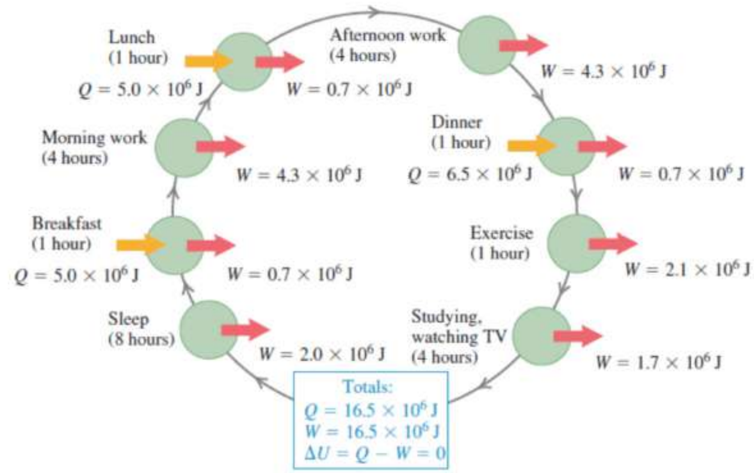
b. In heat transfer, we learn that $Q = \Delta U$ and there are two possible outcomes:
    i. *If there is heat loss,* $U_i > U_f$ *and* $\Delta U = -Q$
    ii. *If there is heat gain,* $U_f > U_i$ *and* $\Delta U = Q$




6. Discuss: Consider a thermodynamic system that is able to absorb heat and do work:
    a. *If* $W = 0$ *and Q is added, then:* $\Delta U = Q$
    b. *If* $Q = 0$ *and W is done by the system, then* $\Delta U = -W$
    c. *Thus, combining these would yield:* $\Delta U = Q - W$
7. Restate 4c: $Q = \Delta U + W$
    a. The heat gain of a thermodynamic system changes its internal energy and allows it to do work.
    b. Statement 4c and its restatement are both statements of the First Law of Thermodynamics and show the relationship between internal energy, mechanical work, and heat. It is also a restatement of the Law of Conservation of Energy.
    c. Ask students to explain why we can consider the statement/s above as being the same as the Law of Conservation of Energy.
8. Discuss implications of the First Law of Thermodynamics:

a. While the term $\Delta U$ indicated potential energy in mechanics, it is now used to indicate internal energy, which may be considered as the sum of potential and kinetic energies possessed by the system – thus, the measurement of internal energy is always indirect and only through the change that is caused by either *Q or W.*

b. Special case 1: When $\Delta U$= 0, or $U_i$= $U_f$,the system is said to have undergone a *cyclic process* so that *Q = W*. This essentially means that all the heat that enters a system is transformed into work.




c. Special case 2: When a system does no work on its surroundings and there is no heat flow, *W = Q = 0* so that there is also no change in the internal energy. This kind of system is an isolated system.

9. Discuss sample problems:

a. You propose to eat a 900-calorie candy bar and then walk up stairs until you have "burned" all the energy you have taken in. How high do you have to climb to achieve this? Assume that your mass is 50 kg.

We recall that a 1 food calorie = 1000 calories = 4,190 Joules. Thus, the energy from the candy bar is 3.77 x 106 Joules. We assume that this energy comes in the form of heat gain for the body and you propose to convert this all to work (Special Case 1) so that: Q = 3.77 x 106 Joules. The work needed to climb the stairs is equal to your weight and the vertical displacement so that: *W = mgh.*

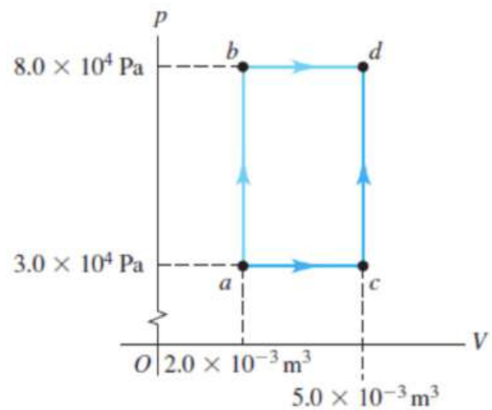
Thus, *Q = W = mgh and h = Q/mg*. We get and answer of h = 7,696 m; quite a long way to go for a candy bar.

b. One gram of boiling water ($1 cm^3$) becomes 1671 $cm^3$ of steam when boiled at constant pressure of $1.013 \times 10^5$ Pa. The heat of vaporization at this pressure is $L_v = 2.256 \times 10^6$ J/kg. Compute: (a) the work done by the water when it vaporizes and (b) its increase in internal energy.

In (a), the work done is defined by the change in volume so that $W = PdV$. We note the quantities of: $P = 1.013 \times 10^5$ Pa $V_i = 1 \times 10^{-6}$ $m^3$, and $V_f = 1671 \times 10^{-6} m^3$. Substitution to the equation yields that the work done by the vaporizing water is: W = 160 *J*.

*In (b), the change in internal energy is given by: $\Delta U = Q - W$. We compute for the heat gained by the water from: $Q = mL_v = (1 \times 10^{-3}$ kg) $\left(\frac{2.256x10^6 J}{kg}\right) = 2256J$. By substituting the values to the equation, we obtain: $\Delta U = Q - W = 2256J - 160J = 2{,}087J$.*

c. The P-V diagram below shows a series of thermodynamic processes. In process *ab*, 150 J of heat are added to the system. In process *bd*, 600 J of heat are added. Find (a) the internal energy change in process *ab*; (b) the internal energy change in process *abd*; and (c) the total heat added in the process *acd*.




We begin by writing what is given at the onset: $Q_{ab}$ = 150 J and $Q_{bd}$ = 600J.

*To answer (a), we note that dV = 0 so W = 0. This means that $\Delta U_{ab} = Q_{ab} - W_{ab} = 150J - 0 = 150J$.*

*To answer (b), we note that: $W_{abd} = W_{ab} + W_{bd}$ such that $W_{ab} = 0$ and $W_{bd} = PdV = (8 \times 10^4 Pa)(5 \times 10^{-3} m^3 - 2 \times 10^{-3} m^3)$ 240J. And the heat is: $Q_{abd} = Q_{ab} + Q_{bd} = 150J + 600J = 750J$. We can solve for the change in internal energy by: $\Delta U_{abd} = Q_{abd} - W_{abd} = 750J - 240J = 510J$.*

*To answer (c), we note that the path abd and acd are equivalent (both lead to point d and internal energy is not path dependent) so that we can assume that the internal energy change is the same for both: $\Delta U_{abd} = \Delta U_{acd} = 510J$. To find the heat added, we first look at the work done in acd: $W_{acd} = W_{ac} + W_{cd} = PdV_{ac} + 0$ (since there is no volume change from c to d). We thus solve: $W_{acd} = (3x10^4 Pa)(5x10^{-3}m^3 - 2x10^{-3}m^3) = 90J$. From here, we go back to: $\Delta U_{acd} = Q_{acd} - W_{acd}$ and $Q_{acd} = \Delta U_{acd} + W_{acd} = 510J + 90J = 600J$.*

## ENRICHMENT (5 MINS)

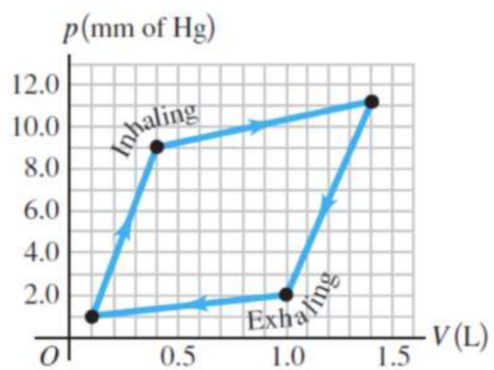
Review the Zeroth Law of Thermodynamics:

a. Explain why it is called the "zeroth" (i.e. there was already a "first" law but that the zeroth law is more fundamental than the other laws)
b. Recall thermal equilibrium: Two objects with the same temperature are in "thermal equilibrium" because no heat will flow between objects of the same temperature
c. Recall heat flow: Heat will flow from an object of higher temperature to an object of lower temperature in an attempt to achieve thermal equilibrium
d. State and explain the Zeroth Law of Thermodynamics: "Two systems individually in thermal equilibrium with a third system are in thermal equilibrium with each other."

Ask students to recall what mathematical property of equality is similar to the Zeroth law (transitive property).

## EVALUATION (10 MINS)

The graph below shows the thermodynamic changes in a lung as it inhales and exhales (Note: this graph is a straightened approximation). How many joules of net work does this lung do during one complete breath?



120 MINS

# Application of 1st Law of Thermodynamics to Adiabatic, Isothermal, Isobaric, and Isochoric processes; Heat engine and Engine Cycles.

**Content Standards**
The learners shall be able to learn knowledge and application of:

1. 1st law of Thermodynamics and Thermodynamic processes
2. adiabatic, isothermal, isobaric, isochoric process
3. Heat engines
4. Engine cycles

**Performance Standards**
The learners shall be able to Solve multi-concept, rich context problems using concepts from rotational motion, fluids, oscillations, gravity, and thermodynamics

**Learning Competencies**
The learners shall be able to differentiate the following thermodynamic processes and show them on a PV diagram: isochoric, isobaric, isothermal, adiabatic, and cyclic **(STEM_GP12GLT-IIh-63)**; Use the First Law of Thermodynamics in combination with the known properties of adiabatic, isothermal, isobaric, and isochoric processes **(STEM_GP12GLT-IIh-64)**; Define the mechanism of a heat engine and describe it using an energy-flow diagram; explain how a heat engine can operate in reverse; calculate the efficiency of a heat engine **(STEM_GP12GLT-IIi-67).**

## LESSON OUTLINE

| | | |
|---|---|---|
| **Introduction/ Review** | Review of prerequisite knowledge | 10 |
| **Motivation** | Observation activity | 15 |
| **Instruction** | Discussion proper | 80 |
| **Enrichment** | Homework | |
| **Evaluation** | Seatwork | 15 |

**Resource**

- Essentials of College Physics, Serway
- Physics for Scientists and Engineers, Tipler
- University Physics with Modern Physics, Young and Freedman
- Physics, Cutnell and Johnson

## INTRODUCTION (10 MINS)

1. Make sure that students have prerequisite knowledge on PV diagrams, First Law of Thermodynamics, work done on a gas, heat, internal energy, temperature, and heat capacity.
2. Make sure that students have the following skills: Sketching PV diagrams and the direction of energy flow, performing basic differential calculus techniques, performing integration to solve for the area under a curve, and doing simple arithmetic calculations.
3. Review the students on the following topics:
    - Definition of an ideal gas and the ideal gas equation of state
    - Heat capacity of a gas
    - Work done on a gas at constant pressure and the effect on its internal energy
    - PV diagrams, calculating the area under the curve by integration, and path dependence.
    - First Law of Thermodynamics and practical applications in contexts such as human metabolism.

## MOTIVATION (15 MINS)

1. Do a quick demonstration on cloud formation in a water bottle. For the procedure, refer to the link: http://www.planet- science.com/categories/experiments/weather/2011/03/make-a-cloud-in-a- bottle.aspx; the alternative address is http://bit.ly/1G3LqQ6.
2. While squeezing the bottle, ask the students the following:
    - Does the number of air molecules inside the bottle change?
    - Does the air pressure inside the water bottle increase or decrease?
    - Compare the pressure inside the bottle with the atmospheric pressure.
    - Does the temperature inside the water bottle increase or decrease?
3. As you remove the bottle cap, ask the students the same set of questions as the ones listed above.
4. Explain how the clouds are formed inside the water bottle

- Importance of the smoke (i.e. it acts as the condensation nuclei).
- Temperature, pressure, work and internal energy relations during the process.

An important thermodynamic process happens during cloud formation; introduce the term adiabatic cooling.

## INSTRUCTION/DELIVERY (80 MINS)

**Teacher tip**
In calorimetry, the latter is the one usually being measured since the atmosphere dictates the pressure which is approximately constant at sea level

**Teacher tip**
Students may encounter the inexact differential of some variable x, đ#. This refers to the path dependence of a variable. As an example, internal energy is path independent since only the endpoints matter; it doesn't matter if the process happens fast or slow or if it changed first in between before settling in its final state, hence it can be expressed as an exact differential. Heat and thermodynamic work is path dependent because they describe a process.)

1. As a prerequisite, define the heat capacities at constant volume and at constant pressure, $c_v$ and $c_p$, respectively.
2. Relate $c_v$ and $c_p$.

- The heat capacity at constant pressure is greater than the heat capacity at constant volume by an amount given by the gas constant and the number of moles of that gas.
- As a result, some gases such as helium and carbon dioxide have different gas constants.
- The ratio of the heat capacities $c_p/c_v$ is given by the adiabatic index, $\gamma$

| Type of Gas | Gas | $C_v$ J/mol - K | $C_p$ J/mol - K | $C_v$ - $C_p$ J/mol - K | $\gamma = C_p/C_v$ |
|---|---|---|---|---|---|
| **Monatomic** | He | 12.47 | 20.78 | 8.31 | 1.67 |
| | Ar | 12.47 | 20.78 | 8.31 | 1.67 |
| **Diatomic** | $H_2$ | 20.42 | 28.74 | 8.32 | 1.41 |
| | $N_2$ | 20.76 | 29.07 | 8.31 | 1.40 |
| | $O_2$ | 20.85 | 29.17 | 8.31 | 1.40 |

| | | | | | |
|---|---|---|---|---|---|
| | CO | 20.85 | 29.16 | 8.31 | 1.40 |
| **Polyatomic** | $CO_2$ | 28.46 | 36.94 | 8.48 | 1.30 |
| | $SO_2$ | 31.39 | 40.37 | 8.98 | 1.29 |
| | $H_2S$ | 25.95 | 34.60 | 8.65 | 1.33 |

Molar heat capacities of some gases at low pressure.

3. Define a thermodynamic process and discuss the different thermodynamic processes.
4. **Adiabatic process**
    a. The change in internal energy of a system is solely due to the work done on the system. Hence, there is zero energy transfer by heat.
        i. Such a process occurs when the system is thermally isolated.
        ii. It also depends on the brevity of the process (i.e., a very fast thermodynamic process can be considered adiabatic since there is no time for any significant transfer of energy by heat.).

    b. Write the First Law for an adiabatic process and discuss what happens to the following state variables when an ideal gas is compressed and expands adiabatically:
        i. Internal energy
        ii. Temperature

    c. Show the PV diagram for an adiabatic process and compare the steepness of the curve with respect to an isotherm passing through the same point. The behavior of the curve can be expressed in terms of the adiabatic index γ:

$$PV^{\gamma} = constant$$

    d. Provide real life examples of adiabatic processes (e.g. opening a cork from a  bottle of champagne).
5. **Isothermal Process**
    a. The temperature of a system is constant during an isothermal process
        i. A heat reservoir supplies energy onto the system by heat as the system uses up its energy to perform work, hence maintaining a constant temperature.
        ii. In an ideal gas, since the temperature is a constant, the change in internal energy *dU* is zero.

b. Given the conditions, write the First Law for an ideal gas undergoing an isothermal process and interpret this new expression.
c. Hence, an ideal gas in an isothermal process follows Boyle's Law:

$$pV = constant$$

d. Show the PV diagram; the curve for which the temperature is constant is called an isotherm.
e. e. Have real life examples of isothermal processes (e.g. phase changes).

6. **Isochoric process**
    a. A system undergoes a thermodynamic process at a constant volume with no work done during the process.
    b. Formulate the First Law for an ideal gas proceeding in an isochoric process and show that the change in internal energy is equal to the energy transferred by heat.
    c. Sketch the PV diagram for an isochoric process; the vertical line is called an isochor. The students would easily see that there is no area and hence, no work.
    d. Have real life examples of isochoric processes (e.g. pressure cookers
7. **Isobaric Process**
    a. At constant pressure, formulate the First Law for an ideal gas. Its internal energy change would have the form:

    $$dU = đQ - pdV$$

    b. Sketch the PV diagram for an isobaric process; the horizontal line is called an isobar. The area under the curve for this process would then be analogous to the area of a rectangle.
    c. Have real life examples of isobaric processes (e.g. heating a monatomic gas in a cylinder covered by a movable frictionless piston).

8. Define a heat engine and discuss its importance and applications in various contexts such as in automotive vehicles, appliances, and power plants.
9. Discuss how a heat engine works by focusing on the following:
    - Reversible and cyclic processes
    - Ideal heat engines and thermodynamic equilibrium
    - Working substance
    - Formulation of the First Law of Thermodynamics
10. Flash or sketch the energy flow diagram of a heat engine and discuss how heat is partially converted to work and the remaining to be absorbed by the cold reservoir.

11. Ask the students if it is possible to convert all the input heat into useful work (after some pauses, hint the students on the Second Law of Thermodynamics which will be fully studied later as the lecture progresses).
12. Starting with the First Law, derive the expression for the efficiency of a heat engine.

$$e = 1 - \frac{|Q_C|}{|Q_H|}$$

13. As an application, discuss how heat engines can operate in reverse, i.e., consider heat pumps and refrigerators.
    - Show the energy-flow diagram of a refrigerator
    - Explain the coefficient of performance (COP) for both heating and cooling modes
14. Have the following problems as examples:
    - *An automobile engine has an efficiency of 22% and produces 2510 J of work. How much heat is rejected by the engine? (See ref. 4)*
    - *The energy absorbed by an engine is three times greater than the work it performs. (a) What is its thermal efficiency? (b) What fraction of the energy absorbed is expelled to the cold reservoir?*
    - *2.00 L of leftover soup at a temperature of 323 K is placed in a refrigerator. Assume the specific heat of the soup is the same as that of water and the density is 1250 kg/m$^3$. The refrigerator cools the soup to 283 K. (a) If the COP of the refrigerator is 5.00, find the energy needed, in the form of work, to cool the soup. (b) If the compressor has a power rating of 0.250 hp, for what minimum length of time must it operate to cool the soup to 283 K? (The minimum time assumes the soup cools at the same rate that the heat pump ejects thermal energy from the refrigerator.).*

## ENRICHMENT

1. An ideal compressible monatomic gas of n moles occupies a volume at STP whose equation of state is given by the ideal gas equation:

$$pV = nRT$$

a. Express this equation in a form such that it is independent on the amount of the gas, that is, relate the ideal gas equation with density ρ. Let $R_{specific} = \frac{R}{molar\ mass}$.

b. Suppose that the gas expands at the expense of its energy, however, a heat bath is in contact with the system compensating for the loss in energy. What happens to the density of the gas?

Density, therefore depends on the state variables. In oceanography, a term called isopycnal, is useful to distinguish different layers of water arising from a process known as stratification. Define an isopycnal.

## EVALUATION (15 MINS)

1. As an assessment tool, have the students answer the following questions and place it on a 1⁄4 sheet of paper:
    a. Given the following processes:
        i. Expansion of the burned gasoline – air mixture in the cylinder of an automobile engine;
        ii. Opening a bottle of champagne;
        iii. Filling a scuba tank with compressed air;
        iv. Partial crumpling of a sealed, empty water bottle, as you drive from the mountains down to the sea level.

    b. Identify (a) which has a negative or positive work done on the gas and (b) which process has increased or decreased the internal energy of the gas
    c. You want to cool a storage cylinder containing 20 moles of compressed gas from 41°C to 25°C. For which kind of gas would this be easiest? (a) Monatomic, (b) diatomic, (c) polyatomic, (d) it would be equally easy for the three
    d. Cite one example for each type of thermodynamic process.

2. Show a video of a toy called insatiable birdie in action.
    - Call on a student and have him/her explain why it is repeatedly tipping off using the principles of a heat engine from his/her understanding.
    - If there were no volunteers, you may do a cold call.
    - Discuss how it works as you close the lecture

# APPENDIX (15 MINS)

Heat capacities at constant pressure and temperature:

$$đQ = c_v dT$$
$$đQ = c_p dT$$

Writing the First Law of Thermodynamics at constant volume would mean,

$$đW = pdV = 0$$

Which then follows that,

$$dU = đQ = c_v dT$$

At constant pressure, *dU* can be expressed in terms of $c_p$ as,

$$dU = c_p dT - pdV$$

Since we are dealing with ideal gases, recall that the equation of state and taking dp = 0 gives,

$$pdV = nRdT$$

Substituting the terms, and solving for *dU*,

$$dU = c_p dT - nRdT$$

Recall that the internal energy of an ideal gas only depends on temperature; even if the volume is changing, cv would still be equal to dU/dT. Therefore,

$$c_v dT = c_p dT - nRdT$$
$$c_p - c_v = nR$$
$$c_p - c_v = nR$$

Heat capacity ratio of ideal gases:

$$\gamma = \frac{c_p}{c_v} = 1 + \frac{R}{c_v}$$

# 2nd Law of Thermodynamics

**Content Standards**
2nd Law of Thermodynamics; Reversible and Irreversible processes

**Performance Standards**
Solve multi-concept, rich context problems using concepts from rotational motion, fluids, oscillations, gravity, and thermodynamics

**Learning Competencies**
1. **(STEM_GP12GLT-IIi-70)** State the 2nd Law of Thermodynamics.
2. **(STEM_GP12GLT-IIi-68)** Describe reversible and irreversible processes.

**60 MINS**

| LESSON OUTLINE | | |
|---|---|---|
| **Introduction/ Review** | Recall the First Law of Thermodynamics | 2 |
| **Motivation** | Ask the students to predict what will happen if you left some ice cubes floating in a glass of water for 5 minutes | 8 |
| **Instruction/ Delivery** | A. Discuss the second law of thermodynamics<br>B. Discuss the Clausius statement of the second law.<br>C. Discuss the Kelvin-Planck Statement of the second law of thermodynamics<br>D. Discuss the equivalence of the Heat Engine and Refrigerator Statements<br>E. Discuss irreversible and reversible processes<br>F. Discuss the conditions for reversibility<br>G. Give examples of irreversible processes. | 30 |
| **Practice** | Using peer instruction strategy, ask the students to give examples of reversible and irreversible processes and discuss them among themselves | 10 |
| **Evaluation** | Give a quiz on determining whether a process is reversible or irreversible | 10 |
| **Resources**<br>See Appendix | | |

## INTRODUCTION (2 MINS)

Recall the First Law of Thermodynamics.

## MOTIVATION (8 MINS)

Now, consider some ice cubes floating in a glass of water. If we let it be for 5 minutes, what will happen to the ice and water? Which of these two scenarios are more probable to happen:

A. The ice will melt and the water will be the colder.
B. The ice will be larger and the water will be hotter.

ANSWER: A. The ice will melt and the water will be the colder.

In the first scenario, there is flow of energy from the substance with higher temperature (water) to the substance with lower temperature (ice). In the second case, the flow of energy will be from the ice to the water that is why the ice became more frozen and the water's temperature increased. Both scenarios do not violate the first law of thermodynamics. Energy can be conserved in each case. However, the first law of thermodynamics does not tell the whole story. Many thermodynamic processes proceed naturally in one direction but not the opposite. For example, heat by itself always flows from a hot body to a cooler body, never the reverse. Why not? It has something to do with the directions of thermodynamic processes and is called the second law of thermodynamics.

## INSTRUCTION/DELIVERY (30 MINS)

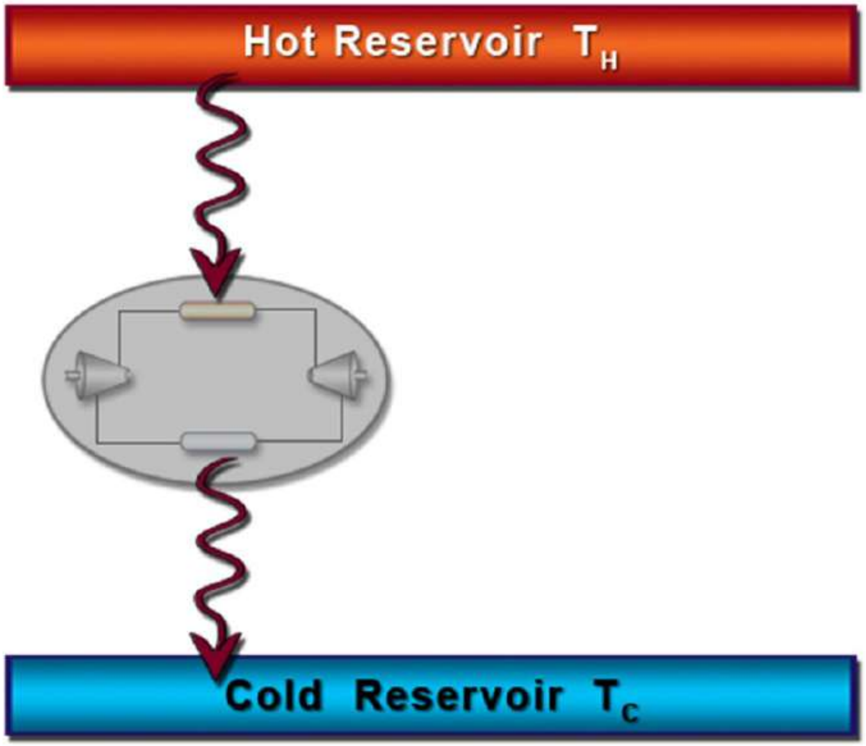
1. Discuss the second law of thermodynamics.

   The second law of thermodynamics states that:

   Heat energy is transferred spontaneously from a hotter to a colder system but never from a colder system to a hotter system.

2. Discuss the Clausius statement of the second law.

Consider the process shown in the diagram.




(PLEASE REDRAW)

Heat flows from a hot reservoir to a cold reservoir through some material. As long as QH is equal to QC, this process obeys the 1st Law. Long experience has taught us that heat does indeed flow spontaneously from hot to cold. But what about if heat flows in the opposite direction? Is that possible?

It is possible to make heat flow from a cold reservoir to a hot reservoir. One way to do this is to use a heat pump. However, a heat pump cannot operate without any work input.

There are many ways to state the 2nd Law of Thermodynamics. The form that is easiest to understand is the Clausius Statement of the 2nd Law.

Clausius Statement: *It is impossible for any process to have as its sole result the transfer of heat from a cooler to a hotter body.*

This is also called the “refrigerator” statement of the second law. Basically, this statement means that heat pumps require a net work input.

3. Discuss the Kelvin-Planck Statement of the second law of thermodynamics.

   Experimental evidence suggests strongly that it is impossible to build a heat engine that converts heat completely to work--that is, an engine with 100% thermal efficiency. This impossibility is the basis of one statement of the second law of thermodynamics, as follows:

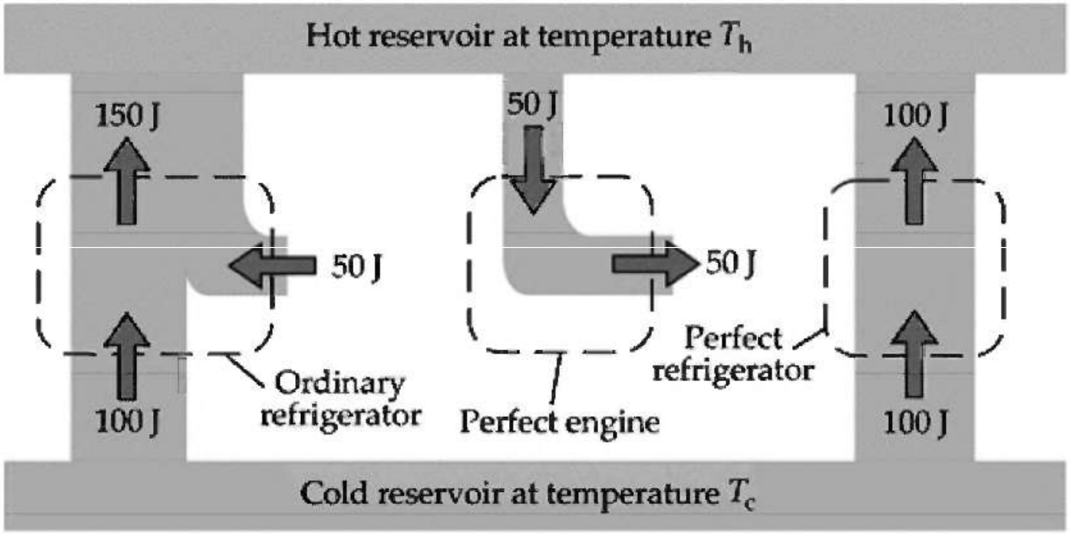
   Kelvin-Planck statement: *It is impossible for any system to undergo a process in which it absorbs heat from a reservoir at a single temperature and converts the heat completely into mechanical work, with the system ending in the same state in which it began.*

   This is also called the “engine” statement of the second law. Basically, it says that thermodynamic cycles cannot completely convert heat into work.

4. Discuss the equivalence of the Heat Engine and Refrigerator Statements

   We can prove that the heat-engine and refrigerator statements (or the Kelvin and Clausius statements) of the second law of thermodynamics are actually equivalent by showing that if either statement is assumed to be false, the other must also be false.

   Consider an ordinary refrigerator as shown in the figure.




(a) An ordinary refrigerator removes 100 J from a cold reservoir, requiring the input of 50 J of work.

(b) A perfect heat engine violates the heat engine statement of the second law by removing 50 J from the hot reservoir and converting it completely into work.

(c) Putting the two together makes a perfect refrigerator that violates the refrigerator statement of the second law by transferring 100 J from the cold reservoir to the hot reservoir with no other effect.

(PLEASE REDRAW)

This refrigerator uses 50 J of work to remove 100 J of energy from a cold reservoir and reject 150 J of energy to a hot reservoir. If the heat engine statement of the second law were not true, a perfect heat engine could remove energy from the hot reservoir and convert it completely into work with 100% efficiency. We could use this perfect heat engine to remove 50 J of energy from the hot reservoir and do 50

J of work. Then, using the perfect heat engine in conjunction with the ordinary refrigerator, we could construct a perfect refrigerator that would transfer 100 J of energy from the cold reservoir to the hot reservoir without requiring any work. But, this violates the refrigerator statement of the second law. Therefore, if the heat engine statement is false, the refrigerator statement is also false.

5. Discuss irreversible and reversible processes.

   The Kelvin-Planck Statement tells us that the efficiency of a heat engine must be less than 100%.What is the maximum efficiency for a heat engine?

   To determine the maximum efficiency of a heat engine we need to define an ideal process and determine the efficiency of such a process. The ideal process is called a reversible process.

   Reversible processes are processes in which both the system and its surroundings can be simultaneously returned to their initial states after the process has been completed.

   It is important to realize that reversible processes are ideal processes and no real process is completely reversible. This leads us to the definition of an irreversible process.

   Irreversible processes are processes in which the system and its surroundings cannot be simultaneously returned to their initial states after the process has been completed. Irreversible processes are those that proceed spontaneously in one direction but not the other. Thermodynamic processes that occur in nature are all irreversible processes. Heat flow with finite temperature difference, free expansion of a gas, and conversion of work to heat by friction are all irreversible processes. In these processes the system is not in thermodynamic equilibrium at any point until the end of the process. They are all nonequilibrium processes.

   It is often easy to return the system to its initial state, but while doing so we often disturb the surroundings by the exchange of heat or work with the system. In fact, no real process is completely reversible. We can never return the entire universe to the state it was in before any given process took place.

6. Discuss the conditions for reversibility.

A. No work must be done by friction, viscous forces, or other dissipative forces that produce heat.

B. Heat conduction can only occur isothermally.

C. The process must be quasi-static so that the system is always in an equilibrium state (or infinitesimally near an equilibrium state).

7. Discuss examples of irreversible process.

Here are some examples of irreversible process:

A. Heat transfer through a finite temperature difference

Consider a warm cup of liquid. Heat is transferred from the hot liquid to the cooler ambient air until both are at the same temperature. We could use a heat pump to restore the liquid in the cup to its original temperature, but that would require a work input. As a result, the surroundings would not be returned to their initial state. We cannot simultaneously restore both the liquid and its surroundings to their initial states. Therefore, the heat transfer from the liquid to the ambient air is irreversible.

B. Friction

Friction is associated with bodies in motion that are in contact with each other. The bodies could be: Two solids (e.g. A block sliding down an inclined plane), a solid and a fluid (e.g. a car moving through air), two fluids at different velocities (e.g. wind blowing across the surface of a lake)

Frictional force acts to oppose any motion. Work is required to overcome the frictional force. Work input is converted to thermal energy. Friction causes the block and surroundings to heat up. If you push the block up the plane the block and surroundings will not cool to their initial temperature. Since we cannot simultaneously return the system and the surroundings to their initial states, we conclude that any process that includes friction is irreversible.

C. Unrestrained or fast expansion or compression of a fluid

Consider a cylinder and a piston device. Molecules within the fluid cannot redistribute quickly enough to get out of the way of the piston. Excess molecules near the inner face of the piston cause the pressure force that must be overcome in order to compress the gas to be greater than if the piston moved at an infinitesimal rate. More work must be done to compress the gas than if the compression had occurred at an infinitesimal rate. The additional energy input in the form of work causes the gas in the cylinder to get warmer. When we return the system to its original state by an infinitesimally slow process, we get less work out of the system because the restraining force is always equal to the pressure within the cylinder. As the system returned to its original volume it is still above its original temperature. We must then transfer heat out of the system to bring it back to its initial temperature. What has happened to the surroundings during this process? The surroundings have done a net amount of work on the system, but have gotten back the same net amount of energy in the form of heat. This means that the process is irreversible. In order to return the surroundings to their initial state, we would have to convert ALL of the heat received from the system into work. A heat engine that could accomplish this task would violate the Kelvin-Planck Statement of the 2nd Law. So, it is impossible to simultaneously restore both the system and the surroundings to their initial states. We may conclude that compression at any finite rate is an irreversible process. A very similar analysis of a fast expansion would reveal that any expansion at a finite rate is also irreversible.

D. Mixing of two different substances

Let say you put ink in water. Molecules spontaneously migrate or diffuse from regions where their concentration is high into regions where their concentration is low. The reverse process does not occur spontaneously because work is required to separate the ink and water molecules once they have mixed. We can conclude that any process that happens spontaneously requires work to be reversed and is, therefore, irreversible.

## PRACTICE (10 MINS)

Peer instruction strategy: This can be done in pairs. The students may learn better from discussions with their peers.

Give two examples of reversible processes and two examples of irreversible processes in purely mechanical systems, such as blocks sliding on planes, springs, pulleys, and strings. Explain what makes each process reversible or irreversible.

## EVALUATION (10 MINS)

Peer instruction strategy: This can be given as a quiz. The students may discuss their answers with their classmates. Studies have shown that students learn better from discussions with their peers.

A pot is half-filled with water, and a lid is placed on it, forming a tight seal so that no water vapor can escape. The pot is heated on a stove, forming water vapor inside the pot. The heat is then turned off and the water vapor condenses back to liquid. Is this cycle reversible or irreversible? Why?

## APPENDIX

**Resources**


(1) Hewitt, P. G. (2007). Conceptual physics (Vol. 8). Addison-Wesley, Massachusets.

(2) Knight, R. (2007). Physics for Scientists and Engineers: A Strategic Approach with Modern Physics [and Mastering Physics TM]. Pearson Education.

(3) Tipler, P.A. & Mosca, G. (2007). Physics for scientists and engineers. Macmillan.

(4) Young, H., & Freedman, R. (2008). University Physics with modern physics 12th edition.

60 MINS

# Carnot Cycle

**Content Standards**
Carnot cycle

**Performance Standards**
The learners shall be able to solve multi-concept, rich context problems using concepts from rotational motion, fluids, oscillations, gravity, and thermodynamics

**Learning Competencies**

1. **(STEM_GP12GLT-IIi-72)** Describe the Carnot cycle.
2. **(STEM_GP12GLT-IIi-73)** State Carnot's theorem and use it to calculate the maximum possible efficiency of a heat engine.

**Specific Learning Outcomes**

1. Enumerate the processes involved in the Carnot cycle
2. Illustrate the Carnot's cycle on a PV diagram.
3. State Carnot's theorem.
4. Use Carnot's theorem to calculate the maximum possible efficiency of a heat engine.

| LESSON OUTLINE | | |
|---|---|---|
| **Introduction/ Motivation** | Introduce Sadi Carnot and the Carnot Cycle | 5 |
| **Instruction/ Delivery** | A. Discuss Carnot Theorem<br>B. Discuss the steps of the Carnot Cycle<br>C. Discuss Carnot efficiency | 25 |
| **Practice** | Solve sample problems on calculating the Carnot efficiency and other related problems | 15 |
| **Enrichment** | Give assignment | 5 |
| **Evaluation** | Quiz on the steps of the Carnot cycle or Carnot efficiency calculation | 10 |

**Resources**


- Cassidy, D. C., Holton, G., & Rutherford, F.J. (2002). Understanding physics. Springer Science & Business Media.
- Hewitt, P. G. (2007). Conceptual physics (Vol. 8). Addison-Wesley, Massachusets.
- Knight, R. (2007). Physics for Scientists and Engineers: A Strategic Approach with Modern Physics [and Mastering Physics TM]. Pearson Education.
- Tipler, P.A. & Mosca, G. (2007). Physics for scientists and engineers. Macmillan.
- Young, H., & Freedman, R. (2008). University Physics with modern physics 12th edition.

# INTRODUCTION/MOTIVATION (5 MINS)

**Introduce Sadi Carnot and the Carnot Cycle**

According to the second law, no heat engine can have 100% efficiency. The question now is: Is there a limit to the maximum possible efficiency given two heat reservoirs at temperatures $T_H$ and $T_C$?

This question was answered in 1824 by the French military engineer and physicist Sadi Carnot (Nicolas Léonard Sadi Carnot, 1796-1832). Carnot sought to answer two questions about the operation of heat engines: "Is the work available from a heat source potentially unbounded?" and "Can heat engines in principle be improved by replacing the steam with some other working fluid or gas?" He attempted to answer these in a memoir, published as a popular work in 1824 when he was only 28 years old. It was entitled Réflexions sur la Puissance Motrice du Feu ("Reflections on the Motive Power of Fire").

# INSTRUCTION/DELIVERY (25 MINS)

1. Discuss Carnot theorem

Carnot theorem can be stated as: *No engine working between two given heat reservoirs can be more efficient than a reversible engine working between those two reservoirs.*

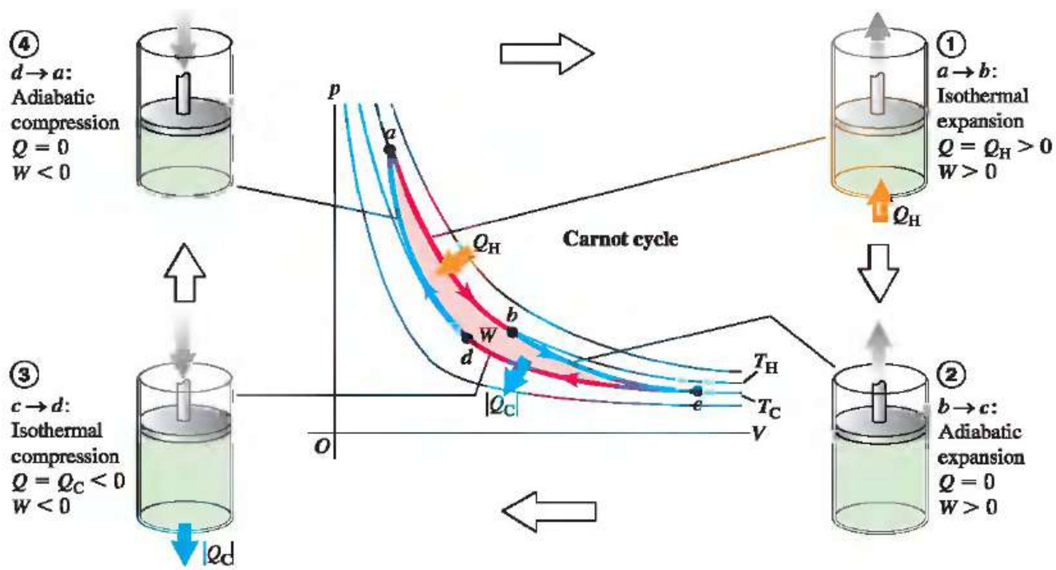
A reversible engine is thus an ideal engine, in that it operates with the greatest possible efficiency. A reversible engine working in a cycle between two heat reservoirs is called a Carnot engine, and its cycle is called a Carnot cycle.

2. Discuss the steps of the Carnot Cycle.

The Carnot cycle consists of two reversible isothermal and two reversible adiabatic processes as

**Teacher Tips:**
In all calculations involving the Carnot cycle, you must make sure that you use absolute (Kelvin) temperatures only. That's because the Carnot efficiency equation come from the ideal-gas equation pV=nRT, in which T is absolute temperature.

shown in the Figure.

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The figure shows a Carnot cycle using an ideal gas in a cylinder with a piston as its working substance. It consists of the following steps:

i. The gas expands isothermally at temperature $T_H$, absorbing heat $Q_H$ (ab).

ii. It expands adiabatically until its temperature drops to $T_C$ (bc).

iii. It is compressed isothermally at $T_C$, rejecting heat $|Q_C|$ (cd).

iv. It is compressed adiabatically back to its initial state at temperature $T_H$ (da).

3. Discuss the Carnot efficiency

If no engine can have a greater efficiency than a Carnot engine, it follows that all Carnot engines working between the same two reservoirs have the same efficiency. This efficiency, called the Carnot efficiency, must be independent of the working substance of the engine. Since all Carnot cycles have the same efficiency independent of the working substance, the equation will be valid in general.

The Carnot efficiency is given by the equation:

$$\varepsilon_c = 1 - \frac{T_C}{T_H}$$

where $T_c$ and $T_H$ is the temperature of the cold and hot reservoir, respectively.

The efficiency of an engine can also be determined by getting the ratio of the work we get from it to what we have to supply.

$$\varepsilon = \frac{W}{Q_H}$$

where W is the work done by the engine and $Q_H$ is the heat extracted from the hot reservoir.

Because of the limits placed by Carnot's finding on heat engines, it is sometimes important not only to give the actual efficiency of a heat engine but also to specify how close it comes to the maximum possible value.

Many large electrical heat-engine devices, such as refrigerators and air conditioners, now come with an "energy guide" sticker indicating the efficiency of the apparatus and the potential annual savings in electricity costs.

## PRACTICE (15 MINS)

1. A steam engine works between a hot reservoir at 100°C and a cold reservoir at 0°C. What is the maximum possible efficiency of this engine?

   ANSWER: The maximum possible efficiency is the Carnot efficiency as given by

$$\varepsilon_c = 1 - \frac{T_C}{T_H}$$

   We should first convert the given temperature values to absolute temperature before using them in the equation.

$$T_C = 0°C = 273K \text{ and } T_H = 100°C = 373K$$

$$\varepsilon_c = 1 - \frac{T_C}{T_H} = 1 - \frac{273K}{373K} = 0.268 = 26.8\%$$

2. A Carnot engine extracts 240 J from its high-temperature reservoir during each cycle, and rejects 100 J to the environment at 15°C.
   A. How much work does the engine do in one cycle?
   B. What's its efficiency?
   C. What's the temperature of the hot reservoir?

ANSWER:

A. To solve this problem, we will use the first law of thermodynamics to find the work done by the engine in one cycle. Since there's no change in internal energy over one cycle, the first law requires that the work W done by the engine be equal to the net heat absorbed.

$$W = Q_{in} - Q_{out} = 240 \text{ J} - 100 \text{ J} = 140 \text{ J}$$

B. $\varepsilon = \frac{W}{Q_H} = \frac{140J}{240J} = 58.3\%$

C. From the equation $\varepsilon_c = 1 - \frac{T_C}{T_H}$, we can derive an equation for $T_H$. This will give us $T_H = \frac{T_C}{1 - \varepsilon_c} = \frac{288K}{1 - 0.583} = 691 \text{ K} = 418°C$.

## ENRICHMENT (5 MINS)

Assignment: Some physicists include a third law among the laws of thermodynamics. The third law states that no system can be cooled to absolute zero. If we include the third law, the three laws of thermodynamics can be summarized as:

1. You cannot win; you can only break even;
2. You can break even only at absolute zero;

3. You cannot reach absolute zero.

Explain how these statements are related to the three laws of thermodynamics.

## EVALUATION (10 MINS)

1. Tell the students that they may work in pairs. Ask the students to illustrate the steps of the Carnot cycle in a PV diagram and describe each step.

   OR

2. An electric power plant boils water to produce high-pressure steam at 400°C. The high-pressure steam spins a turbine as it expands, then the turbine spins the generator. The steam is then condensed back to water in an ocean-cooled heat exchanger at 25°C. What is the maximum possible efficiency with which heat energy can be converted to electric energy?

ANSWER:

$$\varepsilon_c = 1 - \frac{T_C}{T_H} = 1 - \frac{298K}{673K} = 0.56 = 56\%$$

60 MINS

# Entropy

**Content Standards**
Entropy as a measure of disorder; Entropy calculations for isothermal, free expansion, and constant pressure processes

**Performance Standards**
The learners shall be able to solve multi-concept, rich context problems using concepts from rotational motion, fluids, oscillations, gravity, and thermodynamics

**Learning Competencies**
1. **(STEM_GP12GLT-IIi-69)** Explain how entropy is a measure of disorder
2. **(STEM_GP12GLT-IIi-71)** Calculate entropy changes for various processes e.g., isothermal process, free expansion, constant pressure process, etc.

**LESSON OUTLINE**

| | | |
|---|---|---|
| **Introduction/ Review** | Review the second law of thermodynamics. Relate the second law to entropy. | 2 |
| **Motivation** | Ask the students what will happen to the state of the system if a glass or vase dropped. | 3 |
| **Instruction/ Delivery** | A. Define entropy.<br>B. Discuss how to calculate for entropy changes for various processes: isothermal expansion of an ideal gas, free expansion of an ideal gas, constant-pressure processes, and Carnot cycle | 30 |
| **Practice** | Solve sample problems on entropy change for different thermodynamic processes | 15 |
| **Enrichment** | Give a reading assignment about the"heat-death" of the Universe or problem solving assignment on entropy change. | 5 |
| **Evaluation** | Quiz. Identify if the entropy of the named system increase, decrease, or state the same | 5 |

**Resources**


- Cassidy, D. C., Holton, G., & Rutherford, F.J. (2002). Understanding physics. Springer Science & Business Media.
- Hewitt, P. G. (2007). Conceptual physics (Vol. 8). Addison-Wesley, Massachusets.
- Knight, R. (2007). Physics for Scientists and Engineers: A Strategic Approach with Modern Physics [and Mastering Physics TM]. Pearson Education.
- Tipler, P.A. & Mosca, G. (2007). Physics for scientists and engineers. Macmillan.
- Young, H., & Freedman, R. (2008). University Physics with modern physics 12th edition.

## INTRODUCTION (2 MINS)

1. Review the second law of thermodynamics. Relate the second law to entropy.

    The second law can be stated as a quantitative relationship with the concept of entropy.

## MOTIVATION (3 MINS)

1. Show the students a glass or a vase.
2. Ask the students what will happen if the glass or vase dropped.

    POSSIBLE ANSWER: The glass/vase will break into pieces.
    The glass/vase goes from an ordered to a disordered state. Its entropy increased.

## INSTRUCTION/DELIVERY (30 MINS)

1. Define entropy.

    Entropy is a measure of the disorder of a system. The change in entropy dS of a system when it goes from one state to another is defined as

$$dS = \frac{dQ}{T}$$

    where dQ is the heat that must be added to the system in a reversible process that brings the system from the initial state to the final state. Entropy has units of energy divided by temperature; the SI unit of entropy is $\frac{J}{K}$.

    If a total amount of heat Q is added during a reversible isothermal process at absolute temperature

**Teacher Tips:**
Note that entropy is a state function, its change when the system moves from one state to another depends only on the system's initial and final states, not on the process by which the change occurs.

T, the total entropy change $\Delta S = S_2 - S_1 = \frac{Q}{T}$ , is given by

$$\Delta S = S_2 - S_1 = \frac{Q}{T}$$

The general equation to calculate entropy change for any reversible process leading from one state to another is

$$\Delta S = \int_1^2 \frac{dQ}{T}$$

2. Discuss how to calculate for entropy changes for various processes.

**A. Entropy of an Ideal Gas**

Consider a reversible quasi-static process in which a system consisting of an ideal gas absorbs an amount of heat dQ. The entropy change for this ideal gas that undergoes a reversible expansion from an initial state of volume $V_1$ and temperature $T_1$ to a final state of volume $V_2$ and temperature $T_2$ is given by

$$\Delta S = C_V \ln \frac{T_2}{T_1} + nR \ln \frac{V_2}{V_1}$$

**B. ΔS for an Isothermal Expansion of an Ideal Gas**

When an ideal gas undergoes an isothermal expansion, $T_2 = T_1$ and its entropy change is

$$\Delta S = nR \ln \frac{V_2}{V_1}$$

This can be derived from the previous equation. Since $T_2 = T_1$ , $\ln \frac{T_2}{T_1} = 0$.

The gas expanded, therefore $V_2$ is greater than $V_1$. Based on the given equation, the entropy change of the gas ispositive.

The entropy change of the gas is +|Q|T. Since the same amount of heat leaves the reservoir at temperature T, the entropy change of the reservoir is −|Q|T. The net entropy change of the gas plus the reservoir is zero.

We refer to the system under consideration plus its surroundings as the "universe."

*In a reversible process, the entropy change of the universe is zero.*

## C. ΔS for a Free Expansion of an Ideal Gas

In the free expansion, a gas is initially confined in one compartment of a container, which is connected by a stopcock to another compartment that is evacuated. The whole system has rigid walls and is thermally insulated from its surroundings so that no heat can flow in or out, and no work can be done. When the stopcock is opened, the gas rushes into the evacuated chamber.

Since the change in the entropy of a system for any process depends only on the initial and final states of the system, the entropy change of the gas for the free expansion is the same as that for the isothermal expansion.

$$\Delta S = nR \ln \frac{V_2}{V_1}$$

Note, however, that there is no change in the surroundings. So, the entropy change of the gas is also the entropy change of the universe. This entropy change is positive since $V_2$ is greater than $V_1$.

*In an irreversible process, the entropy of the universe increases.*

A gas does not spontaneously compress by itself into a smaller volume. This leads to another statement of the second law of thermodynamics:

*For any process, the entropy of the universe never decreases.*

## D. ΔS for Constant-Pressure Processes

When a substance is heated from temperature $T_1$ to temperature $T_2$ at constant pressure, the change in entropy is given by

$$\Delta S = C_p \ln \frac{T_2}{T_1}$$

If the substance is cooled, $T_2$ is less than $T_1$ which gives a negative entropy change.

**E. ΔS for a Carnot Cycle**

Since a Carnot engine works in a cycle, its entropy change is zero.

## PRACTICE (15 MINS)

Solve sample problems on entropy change for different thermodynamic processes.

1. **Entropy change in melting.** Five kilograms of ice at 0°C is melted and converted to water at 0°C. Compute its change in entropy, assuming that the melting is done reversibly. The heat of fusion of water is $L_f = 3.34 \times 10^5$ J/kg.

   This is a reversible isothermal process. The system is at constant temperature T = 0°C = 273 K. The amount of heat added in terms of the heat of fusion is

   $$Q = mL_f = (5kg)\left(\frac{3.34 \times 10^5 J}{kg}\right) = 1.67 \times 10^6 \text{ J}$$

   We can calculate the entropy change using the equation

   $$\Delta S = \frac{Q}{T} = \frac{1.67 \times 10^6 J}{273\ K} = 6.12 \times 10^3 \frac{J}{K}$$

   This increase in entropy corresponds to the increase in disorder when the water molecules go from the highly ordered state of a crystalline solid to the much more disordered state of a liquid. When we refreeze the water, Q has the opposite sign, and the entropy change of the water is $\Delta S = -6.12 \times 10^3 \frac{J}{K}$. The water molecules rearrange themselves into a crystal to form ice, so disorder and entropy both decrease.

**Teacher Tips:**
Note that in entropy calculations we must always use absolute, or Kelvin, temperatures.

2. **Entropy change in a temperature change.** Two kilograms of water at 0°Cis heated to 100 °C. Compute its change in entropy.

The temperature of the water is increased reversibly in a series of infinitesimal steps, in each of which the temperature is raised by an infinitesimal amount dT. The heat required is dQ = mc dT.

$$\Delta S = \int_1^2 \frac{dQ}{T} = \int_{T_1}^{T_2} \frac{mc\, dT}{T} = mc \ln \left(\frac{T_2}{T_1}\right)$$

$$= (2kg)\left(4190 \frac{J}{kg \cdot K}\right)\left(\ln \frac{373\ K}{273\ K}\right)$$

$$= 2.62 \times 10^3 \frac{J}{K}$$

The entropy change is positive, as it must be for a process in which the system absorbs heat.

3. **Entropy change for a free expansion of an Ideal Gas.** A 0.5 mol of an ideal gas expands freely from a volume of 1 L to 3 L. What is the entropy change the ideal gas.

For a free expansion of an Ideal Gas, the entropy is given by

$$\Delta S = nR \ln \frac{V_2}{V_1}$$

$$= (0.5\ mol)\left(8.31 \frac{J}{mol \cdot K}\right)(\ln 3)$$

$$= 4.56 \frac{J}{K}$$

4. **Entropy change for constant pressure processes.** One kilogram of water at temperature 20°C is mixed with 0.500 kg of water at 80°C in a calorimeter of negligible heat capacity at a constant pressure of 1 atm. Find the change in entropy of the system.

When the two amounts of water are mixed, they eventually come to a final equilibrium temperature Tf that can be found by setting the heat lost equal to the heat gained. To calculate the entropy change of each mass of water, we consider a reversible isobaric (constant pressure) heating of the 1-kg mass of water from 20°C to $T_f$ and an isobaric cooling of the 0.500-kg mass from 80°C to $T_f$. The entropy change of the system is the sum of the entropy changes of each part.

Let $m_1$ = 0.500 kg and $T_1$ = 80°C = 353K, the mass and temperature of the hot water, respectively, and $m_2$ = 1.00 kg and $T_2$ = 20°C = 293K, the mass and temperature of the cold water, respectively. To calculate the final temperature $T_f$,

$$Q_{lost} = Q_{gained}$$

$$m_1c_p (T_1 - T_f) = m_2c_p (T_f - T_2)$$

$$m_1c_pT_1 - m_1c_pT_f = m_2c_pT_f - m_2c_pT_2$$

$$m_1c_pT_f + m_2c_pT_f = m_1c_pT_1 + m_2c_pT_2$$

$$(m_1 + m_2)c_{p\ f} = c_p(m_1T_1 - m_2T_2)$$

$$T_f = \frac{(m_1T_1 - m_2T_2)}{(m_1 + m_2)}$$

$$= \frac{(0.500\text{ kg})(353\text{K}) + (1.00\text{kg})(293\text{K})}{(0.500\text{ kg} + 1.00\text{ kg})}$$

$$T_f = 313\text{K}$$

We can calculate the entropy change in the isobaric cooling of the 0.500-kg mass from $T_1$ = 80°C = 353 K to $T_f$ using the equation,

$$\Delta S = C_p \ln \frac{T_f}{T_1}$$

$$= mc_p \ln \frac{T_f}{T_1}$$

$$= (0.500\text{ kg})\left(4190 \frac{\text{J}}{\text{kg} \cdot \text{K}}\right)\left(\ln \frac{313\text{ K}}{353\text{ K}}\right)$$

$$\Delta S_1 = -252 \frac{\text{J}}{\text{K}}$$

Likewise, the entropy change for the isobaric heating of the 1.00-kg mass of water from $T_2$ =20°C=293K to $T_f$ is given by

$$\Delta S_2 = C_p \ln \frac{T_f}{T_2}$$

$$= mc_p \ln \frac{T_f}{T_2}$$

$$= (1.00 \text{ kg}) (4190 \ \frac{\text{J}}{\text{kg} \cdot \text{K}}) (\ln \frac{313 \text{ K}}{353 \text{ K}})$$

$$\Delta S_2 = 277 \ \frac{\text{J}}{\text{K}}$$

The entropy change of the system is the sum of the entropy changes of each part.

$$\Delta S = \Delta S_1 + \Delta S_2 = -252 \frac{\text{J}}{\text{K}} + 277 \frac{\text{J}}{\text{K}} = 25 \frac{\text{J}}{\text{K}}$$

5. **Entropy and the Carnot cycle.** A Carnot engine takes 2000 J of heat from a reservoir at 500 K, does some work, and discards some heat to a reservoir at 350 K. Find the total entropy change in the engine during one cycle.

First we calculate for the heat discarded by the engine.

$$Q_c = -Q_H \frac{T_C}{T_H}$$

$$= -(2000\text{J}) \ \frac{350}{500}$$

$$= -1400 \text{ J}$$

All four steps in the Carnot cycle are reversible, so we can use the expression for the change in entropy in a reversible process.

$$\Delta S = \frac{Q}{T}$$

There is no entropy change during the adiabatic expansion or adiabatic compression. During the isothermal expansion at $T_H$ = 500 K the engine takes in 2000 J of heat, and its entropy change is given by

$$\Delta S_H = \frac{Q_H}{T_H} = \frac{2000\ J}{500\ K} = 4.0\ \frac{J}{K}$$

During the isothermal compression at $T_C$ = 350 K the engine gives off 1400 J of heat, and its entropy change is

$$\Delta S_C = \frac{Q_c}{T_c} = \frac{-1400\ J}{350\ K} = -4.0 \frac{J}{K}$$

The total entropy change in the engine during one cycle is

$$\Delta S = \Delta S_H + \Delta S_C = 4.0\ \frac{J}{K} + (-4.0\ \frac{J}{K}) = 0$$

## ENRICHMENT (5 MINS)

Give homework. Choose one from below.

A. Give questions in the Practice section that was not discussed in class as problem solving assignments.

B. Read The Last Question, a short story by Isaac Asimov. Write an essay about the idea of a "heat-death" of the universe.

**Teacher Tips:**
The idea of a "heat-death" of the Universe is based on predictions from thermodynamics. All familiar processes are to some degree irreversible, and thus contribute to an increase in the entropy of the Universe. As this happens, the usefulness of the heat available for work in engines will decline. Lord Kelvin predicted that eventually all bodies in the Universe would reach the same temperature by exchanging heat with one another. When this happened, it would be impossible to produce any useful work from heat, since work can only be done by means of heat engines when heat flows from a hot body to a colder body. Finally, the Sun and the other stars would cool, all life on Earth would cease, and the Universe would be dead.

## EVALUATION (5 MINS)

In each of the following processes, does the entropy of the named system alone increase, decrease, or stay the same? (a) A balloon deflates; (b) cells differentiate in a growing embryo, forming different physiological structures; (c) an animal dies, and its remains gradually decay; (d) an earthquake demolishes a building; (e) a plant utilizes sunlight, carbon dioxide, and water to manufacture sugar; (f) a power plant burns coal and produces electrical energy; (g) a car's friction-based brakes stop the car.

ANSWER: (a) increase; (b) decrease; (c) increase; (d) increase; (e) decrease; (f) increase; (g) increase.

60 MINS

# Context rich problems involving Ideal Gases and the Laws of Thermodynamics

**Content Standards**
Ideal Gases and the Laws of Thermodynamics

**Performance Standards**
The learners shall be able to solve multi-concept, rich context problems using concepts from rotational motion, fluids, oscillations, gravity, and thermodynamics

**Learning Competencies**
1. **(STEM_GP12GLT-IIh-58)** Solve problems involving ideal gas equations in contexts such as, but not limited to, the design of metal containers for compressed gases
2. **(STEM_GP12GLT-IIh-65)** Solve problems involving the application of the First Law of Thermodynamics in contexts such as, but not limited to, the boiling of water, cooling a room with an air conditioner, diesel engines, and gases in containers with pistons
3. **(STEM_GP12GLT-IIi-74)** Solve problems involving the application of the Second Law of Thermodynamics in context such as, but not limited to, heat engines, heat pumps, internal combustion engines, refrigerators, and fuel economy.

| LESSON OUTLINE | | |
|---|---|---|
| **Introduction** | Discuss the rationale of solving context-rich problems in Physics. | 2 |
| **Instruction/ Delivery** | Discuss the steps or framework for problem-solving | 3 |
| **Practice** | Using the cooperative Group Problem Solving strategy, let each group of students answer 1-2 context-rich problems involving Ideal Gases and the Laws of Thermodynamics. | 40 |
| **Evaluation** | Let the students report to class to allow students to be familiar with problems that they are not assigned to solve | 15 |
| **Materials** | Writing materials and other materials to be determined by the students depending on the problem | |
| **Resources** See appendix. | | |

## INTRODUCTION AND MOTIVATION (2 MINS)

1. Discuss the rationale of solving context-rich problems in physics.
2. Prepare students for group work by:

   A. Showing group/role assignments and classroom seating map;
   B. Passing out Problem and Useful Information and Answer Sheet

## INSTRUCTION (3 MINS)

Discuss the steps or framework for problem-solving.

## PRACTICE (40 MINS)

1. Using the Cooperative Group Problem Solving strategy, let each group of students answer 1-2 context-rich problems involving Ideal Gases and the Laws of Thermodynamics.
2. Introduce the problem by telling students:
   A. what they should learn from solving problem;
   B. the part of the solution you want groups to put on board
3. Coach groups in problem solving by:
   A. Monitoring (diagnosing) progress of all groups
   B. Helping groups with the most need.
4. Prepare students for class discussion by:
   A. giving students a "five-minute warning"
   B. selecting one person from each group to put specified part of solution on the board.

## EVALUATION (15 MINS)

1. Let the students report to class to allow students to be familiar with problems that they are not assigned to solve.
2. Lead a class discussion focusing on what you wanted students to learn from solving the problem (your goals)

   A. Start by asking open-ended questions.
   B. Follow up with questions specific to your goal or observed common errors.

## CONTEXT-RICH PROBLEMS INVOLVING IDEAL GASES AND THE LAWS OF THERMODYNAMICS

1. A seafood restaurant hires Lou to run its advertising campaign. Lou figures that snorklers are a great pool of potential customers for seafood, so he prints ads on Mylar balloons that he ties to the coral of an underwater reef. Each balloon has a volume of 4 L and is filled with air at 20°C. At 15 m below the ocean surface, the volume has diminished to 1.60 L. What is the temperature of the water at this depth?

2. On a cool morning in Baguio, when the temperature is 15°C, you measure the pressure in your car tires to be 30 psi (2.07x105 Pa). After driving 30 km on the highway, the temperature of your tires is 45°C. What pressure will your tire gauge now show?

3. Aliwagwag Falls in Davao Oriental is considered by hydraulic engineers as the highest waterfalls in the Philippines. At Aliwagwag Falls, the water drops 340 m. If the change in potential energy goes into the internal energy of the water, what is the increase in its temperature? (This temperature rise is not observed because the water cools by evaporation as it falls.)

4. You kick a soccer ball, compressing it suddenly to 2/3 of its original volume. In the process, you do 410J of work on the air (assumed to be an ideal gas) inside the ball. (a) What is the change in internal energy of the air inside the ball due to being compressed? (b) Does the temperature of the air inside the ball rise or fall due to being compressed? Explain.

5. A typical doughnut contains 2.0g of protein,1 7.0g of carbohydrates, and 7.0g of fat. The average food energy values of these substances are 4.0 kcal/g for protein and carbohydrates and 9.0 kcal/g for fat. During heavy exercise, an average person uses energy at a rate of 510 kcal/h. How long would you have to exercise to ''work off" one doughnut? If the energy in the doughnut could somehow be converted into the kinetic energy of your body as a whole, how fast could you move after eating the doughnut?

6. An inventor wants you to invest money in his company, offering you 10% of all future profits. He reminds you that the brakes on cars get extremely hot when they stop and that there is a large quantity of thermal energy in the brakes. He has invented a device, he tells you, that converts that thermal energy into the forward motion of the car. This device will take over from the engine after a stop and accelerate the car back up to its original speed, thereby saving a tremendous amount of gasoline. Now, you're a smart person, so he admits up front that this device is not 100% efficient, that there is some unavoidable heat loss to the air and to friction within the device, but the upcoming research for which he needs your investment will make those losses extremely small. You do also have to start the car with cold brakes after it has been parked awhile, so you'll still need a gasoline engine for that. Nonetheless, he tells you, his prototype car gets 500 miles to the gallon and he expects to be at well over 1000 miles to the gallon after the next phase of research. Should you invest? Base your answer on an analysis of the physics of the situation.

7. There has long been an interest in using the vast quantities of thermal energy in the oceans to run heat engines. A heat engine needs a temperature difference, a hot side and a cold side. Conveniently, the ocean surface waters are warmer than the deep ocean waters. Suppose you build a floating power plant in the Pacific Ocean where the surface water temperature is 30°C. This would be the hot reservoir of the engine. For the cold reservoir, water would be pumped up from the ocean bottom where it is always 5°C. What is the maximum possible efficiency of such a power plant?

8. You and your mom went to the appliance store to buy a new refrigerator. At the store, the sales man shows you the DreamFridge. According to its sticker, the DreamFridge uses a mere 100 W of power to remove 100 kJ of heat per minute from the 2°C interior. According to the fine print on the sticker, this claim is true in a 22°C kitchen. Should you buy? Explain.

9. To maintain the temperature inside a house at 25°C, the power consumption of the airconditioner is 6kW on a day when the outside temperature is 31°C. At what rate does this house contribute to the increase in the entropy of the universe?

10. Jay approached his guru in a depressed mood. "I want to change the world, but I feel helpless," he said. The guru turned and pushed a 5-kg rock over a ledge. It hit the ground 6 m below and came to rest. "There," said the guru. "I have changed the world." If the rock, the ground, and the atmosphere are all initially at 300 K, calculate the entropy change of the universe.

# APPENDIX

**Resources:**

(1) Heller, Kenneth, and Patricia Heller. "Cooperative Problem Solving in Physics: A User's Manual." Retrieved October 28, 2015. https://www.aapt.org/Conferences/newfaculty/upload/coop-Problem-Solving-Guide.pdf

(2) Polya, Geroge. How to Solve It: A New Aspect of Mathematical Method. Princeton university press, 2014.

(3) Knight, R. (2007). Physics for Scientists and Engineers: A Strategic Approach with Modern Physics [and Mastering Physics TM]. Pearson Education.

(4) Young, Hugh D., and Roger A. Freedman. University physics with modern physics. Pearson Higher Ed. 2015.

# Biographical Notes

## Jose Perico H. Esguerra, Ph.D.

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Dr. Jose Perico Henson Esguerra is a registered physicist and Professor at the National Institute of Physics, University of the Philippines Diliman where he has been working for over ten years now. Dr. Esguerra has also taught in UP Los Banos, UP San Fernando, and the De La Salle University specializing in Statistical Mechanics, Approximate Analytical solution Schemes for Quantum and Nonlinear Problems, and Physical applications of Fractional Calculus

Dr. Esguerra is member of organizations such as the International Astronomical Union, the Organizing Committee of the Philippine Astronomy Olympiad, and the National Research Council of the Philippines. He is the current Chair for the Physics Education Committee of the Samahang Pisika ng Pilipinas and has served as Technical Committee Member for the Philippine Physics Olympiad. Dr. Esguerra's service is extended to the government as he works as consultant for the Department of Education and Technical Panel Member for Physics at the Commission on Higher Education.

Dr. Esguerra has received a number of citations including the Silver Pillar Award by the Department of Science and Technology and the Outstanding Youth of Pampanga. His scholarly works and studies are published in National and International Science Citations Index Journals. He received his doctorate degree in Physics at the University of the Philippines Diliman. He completed his bachelor's and master's degrees in Physics at the same university.

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