cK-12

CK-12 Physics - Intermediate Teacher's Edition

CK-12 Physics - Intermediate Teacher's Edition

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cK-12 *f*lexbooK
next generation textbooks

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The Teacher's Edition

- The CK-12 Physics Intermediate Teacher's Edition complements CK-12's Physics Intermediate FlexBook®. The TE follows a three-step instructional model: *(1) Inspire and Inquire, (2) Explain and Elaborate, (3) Assess and Reassess*.

Workbook

The CK-12 Physics Intermediate Workbook complements CK-12's Physics Intermediate FlexBook® and contains a worksheet for every lesson. Each worksheet has a set of practice problems corresponding to every lesson objective.

The classification of practice problems by lesson objectives:

- Motivates students and teachers to maintain focus on the learning objectives
- Allows students to easily recognize the connection between practice problems and the learning objectives
- Facilitates student-teacher conversations centered around the learning objectives
- Enables students to easily assess their own progress toward the mastery of lesson objectives

Quizzes and Tests

The CK-12 Physics Intermediate Quizzes and Tests complements CK-12's Physics Intermediate FlexBook® and contains one quiz per lesson, one chapter test, and one unit exam. All quizzes and tests are objective-based and include questions to assess student understanding of each lesson objective.

The classification of test questions by lesson objectives:

- Promotes students to think of quizzes and tests as learning tools
- Helps students connect their grade with their ability to meet lesson objectives
- Prompts teachers to leave feedback centered around lesson objectives

Teaching Strategies

- The teaching strategies described are aligned with the constructivist view of learning in which students develop their own understanding as a result of their experiences.
- The goal of this teacher's edition is to provide students with learning experiences that enable them to recognize and correct their misconceptions regarding scientific concepts.

- The sequence of instruction is the same for each lesson and follows a linear three-step model: *(1) Inspire and Inquire, (2) Explain and Elaborate, (3) Assess and Reassess.*

Inspire

- Begin each lesson by promoting student interest, generating curiosity, and examining previous knowledge.

  – Demonstrations
  – Big Questions
  – Student surveys
  – Quick-writes
  – Current events

Inquire

- Provide activities that encourage critical thinking, creativity, and collaboration.

  – Lab activities
  – Inquiry activities

Explain

- Require students to describe what they have learned in their own words and provide evidence for their claims.

  – Data-Sharing
  – White-board work
  – Think-Pair-Share
  – SEE-Is
  – Exit Slips

Elaborate

- Prompt students to make connections between class concepts and real world applications, as well as to other academic disciplines.

  – Dispelling Misconceptions
  – Class discussions
  – Points to consider
  – Blogging
  – Interdisciplinary connections
  – Real world applications

Assess

- Evaluate students' achievement of the learning objectives through formative assessments.

    - Lab notebooks
    - Portfolios
    - Projects
    - Objective-based worksheets and quizzes

Reassess

- Continue to measure students' achievement of learning objectives through summative assessments.

    - Objective-based chapter tests and unit exams
    - Unit projects

Chapter Overview
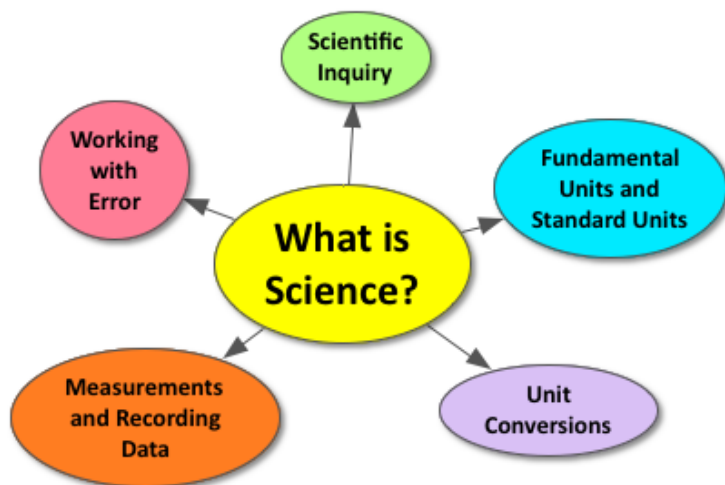
The goal of scientific inquiry is to understand how nature works. The laws of nature are defined by mathematical equations that represent real physical quantities. Throughout the world, scientists use the same International System of Units and complete unit conversions to reinterpret quantities. Scientists derive the laws of nature from their data by taking careful measurements and performing mathematical analyses. It is important for scientists to address the limited precision of measuring tools and mathematical estimations as sources of error.

Online Resources

Google Sites

Many of the activities in this Teacher's Edition have been included as web links and creating a class website would be a great way to share these links with your students. The URL below will guide you through the process of creating a class website through Google Sites.

http://learn.googleapps.com/sites

Apps

Notability

The URL below describes this note-taking App, which is a useful tool for students interested in keeping a digital lab notebook.

http://gingerlabs.com/cont/learn.php

WolfamAlpha

This is a computational App that can assist students with mathematical problems and unit conversions.

http://www.wolframalpha.com/

TABLE 1.1: Pacing The Lessons

Lesson	Class Periods (60 min)
Lesson 1.1 Scientific Inquiry	3
Lesson 1.2 Fundamental Units and Standard Units	1
Lesson 1.3 Unit Conversions	1
Lesson 1.4 Measurement and Recording Data	1
Lesson 1.5 Working with Error	1

1.1 Scientific Inquiry

Key Concept
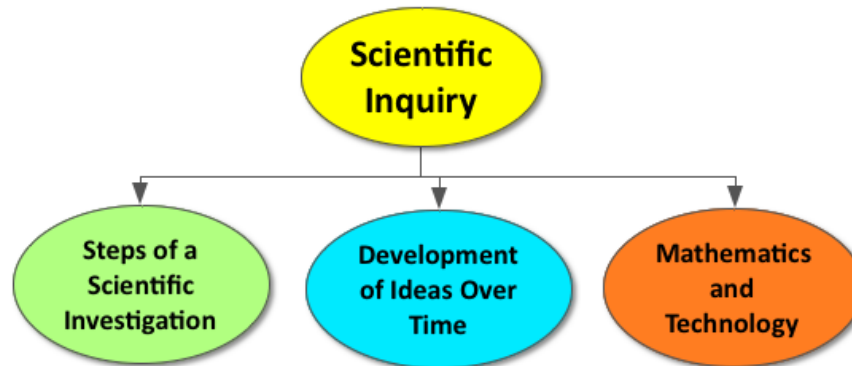
Scientific inquiry leads to our understanding of the natural world. Science is a process that begins with curiosity. Specific steps are used to test scientific hypotheses and draw conclusions. Based on these conclusions, scientists form laws defined by mathematical equations. A group of experimental conclusions that describe the same natural phenomena lead to scientific theories. These theories are simply the best explanation of how the natural world works based on the experimental evidence at the time. The purpose of scientific inquiry is to continually challenge preexisting theories and develop new theories to ensure coherency and truth regarding our understanding of the natural world.

Lesson Objectives

- Explain the role of using postulates in science.
- Explain the role of mathematics in science.
- Explain how scientists investigate nature by ensuring their models are able to be proven incorrect (falsifiable) and are tested by many independent researchers.
- Describe the difference between a hypothesis, theory, and law.
- Explain that new theories explain phenomena more accurately than preexisting theories, and such theories are consistent with the correct predictions of previous theories.
- Describe the scientific method

Lesson Vocabulary

hypothesis
   A proposed explanation for an observation, phenomenon, or scientific problem that can be tested by further

investigation.

inquiry

An approach to learning that involves exploring the natural or material world, then leads to asking new questions and making new discoveries.

scientific law

A concise mathematical relationship that always occurs under specific conditions. A law is not an explanation, and it is no more or less final than a theory.

scientific method

A systematic approach used to investigate the natural world that must make predictions, provide testable hypotheses, draw conclusions from evidence, and allow conclusions to be potentially disprovable.

theory

A statement or set of statements devised to explain a group of observations or phenomena. Theories have often been repeatedly tested or are widely accepted, and can thus be used to make predictions about natural phenomena

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The Marshmallow Challenge

This is a fun activity to do the first day of school. Students will leave your class on the first day feeling excited about physics and looking forward to a great school year!

http://marshmallowchallenge.com/Welcome.html

Mystery Tubes Lesson

This activity is a wonderful way to introduce students to the steps of a scientific inquiry. The best part of the activity is at the end, when you collect all the Mystery Tubes without ever revealing the truth about what is inside.

http://undsci.berkeley.edu/lessons/mystery_tubes.html

Whiteboarding

Divide the class into groups of 3-4 students and provide each group with a whiteboard and dry erase markers. Students should work together to answer the following two questions on their whiteboard:

1. What is the goal of science?
2. What are we learning when we study physics?

Each group should present their whiteboard to the class and you should facilitate a discussion on the common themes. Students can take pictures of their whiteboards with a phone or iPad and insert them into their digital notebooks, if applicable.

Learn more about using whiteboards at the links below:

http://home.comcast.net/~whiteboardsusa/whiteboardsusa/whiteboarding_flier.pdf

http://physicsed.buffalostate.edu/AZTEC/BP_WB/

The Questioning Mind: Newton, Darwin, and Einstein

This is a fantastic article from the Critical Thinking Community about how the greatest scientists in history were neither the best students nor natural geniuses, but were simply curious people.

You should first have students read the article found on this link:

- https://www.criticalthinking.org/resources/articles/questioning-mind.shtml

Then, have students complete a Quick Write on the questions below:

- How did you connect with this article?
- How did it inspire you?

Learn more about using Quick Writes at the link below:

http://nrhs.nred.org/www/nred_nrhs/site/hosting/Literacy%20Website/Literacy%20Strategy%20Templates/Quick_-Write__description.pdf

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Suggested Use: The lesson worksheet in the CK-12 Physics Intermediate Workbook could be used as a "Test Ticket", which students must complete in order to take the lesson quiz. The lesson worksheet should be assigned at the beginning of each lesson and students should have until the day of the lesson quiz to complete all of the problems. Rather than having homework due every day, students should be prompted to do the work around their schedule and will inadvertently develop skills regarding time management. This system will also prompt students to make the connection between completing the worksheet and preparing for the quiz.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

Suggested Use: The objective-based structure of the quizzes and tests facilitates teacher use of Standards Based Grading. Learn more about Standards Based Grading by clicking the links below:

https://www.youtube.com/watch?v=E7m4762pjH8

http://en.wikipedia.org/wiki/Standards-based_assessment

1.2 Fundamental Units and Standard Units

Key Concept
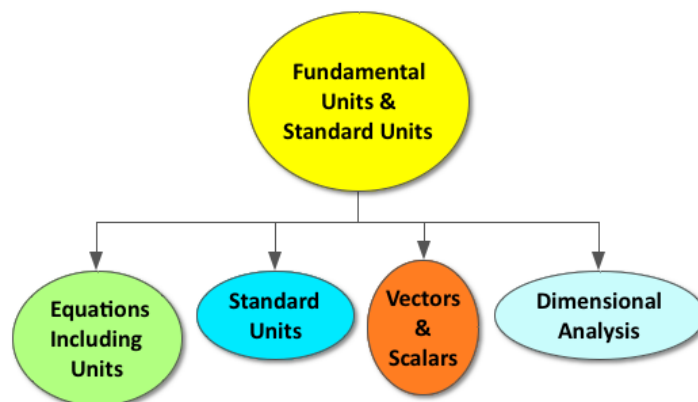
It is important to include units in an equation to signify the physical quantity each number represents. Most scientists use the same units based on the metric system, called the International System of Units.

Lesson Objectives

- List and use fundamental units in the study of mechanics.
- List and use standard units in the study of mechanics.
- Use dimensional analysis.

Lesson Vocabulary

dimensional analysis
    Checking your mathematical equations by keeping units with every number, or predicting units based on the relation of other units.
length
    The measurement of the extent of something along its greatest dimension.
mass
    A property of matter equal to the measure of an object's resistance to changes in either the speed or direction of its motion. The mass of an object is not dependent on gravity and therefore is different from but proportional to its weight.
meter stick
    A ruler exactly one meter in length.

scalar
> A quantity, such as mass, length, or speed that is completely specified by a single number. It is said to have magnitude, but no direction.

SI units
> The most modern version of the metric system, also known as the International System of Units (SI).

time
> An ordered continuum in which events occur in succession from the past through the present to the future.

vector
> A quantity, such as velocity or force, that must be completely specified by both a magnitude and a direction. For example, if an object is moving, we must know both the amount of motion as well as the direction of motion to know the vector quantity velocity.

How do we quantify the world around us?

As a class, develop a simple definition for a "physical quantity" and discuss its importance to science.

Ask: What is a physical quantity? *(Refer to sample answers).*

Ask: Why would we want to quantify the world around us? *(Refer to sample answers).*

Physical Quantity Inquiry

Divide students into groups of 3-4. Give each group the same object (*example*: a wood block) and tools to measure the object (*example*: a ruler, a scale, a stop watch). Challenge students to make a list describing as many **physical quantities** of the object as possible in five minutes.

When the time is up, compare group results and discuss. Be sure to highlight the importance of using units when recording physical quantities. Use this activity to introduce the concepts of fundamental units and dimensional analysis.

Whiteboarding

Students should work in groups of 3-4 and complete the following table on their whiteboard. *(Refer to sample answers).*

TABLE 1.2: SI units

Physical Quantity	SI Units
Length	
Mass	
Time	
Weight	
Temperature	

Sample Answer:

TABLE 1.3: SI units

Physical Quantity	SI Units
Length	*meters, m*
Mass	*kilograms, kg*
Time	*seconds, s*
Weight	*Newtons, N*
Temperature	*degree Celsius, °C*

Elaborate

Challenge groups that finish with the following questions:

Ask: Which physical quantities listed in the chart above are scalar? *(Refer to sample answers).*

Ask: What is the difference between mass and weight? *(Refer to sample answers).*

Ask: If the gravitational constant on Earth is 9.8N/kg, use dimensional analysis to prove that W=mg (W= weight in Newtons, m=mass in kg, and g=9.8N/kg). *(Refer to sample answers).*

Exit Slip

Pass out index cards to the students and ask them to write their response to the following prompt on the card. Collect the cards as students exit the classroom and assess.

Prompt: Why do you think it is important for scientists to all use the same International System of Units? *(Refer to sample answers).*

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook.* You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

1.3 Unit Conversions

Key Concept
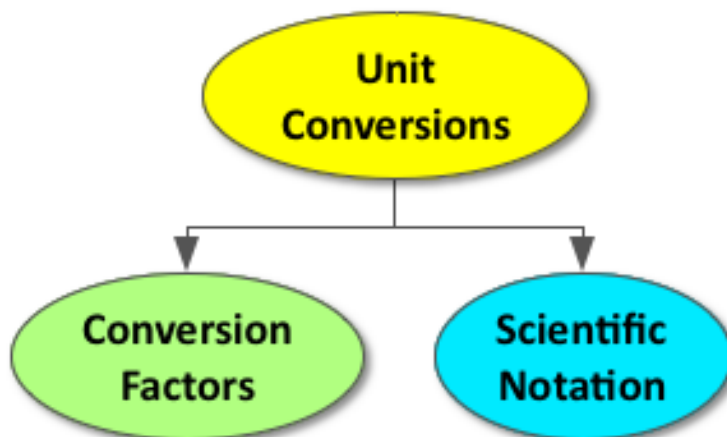
Scientists use unit conversions and scientific notation to reinterpret physical quantities. A conversion factor equates two different units and can be used to convert from one unit to another. Any number can be translated into scientific notation by writing it as a number between 1 and 10 multiplied by a power of ten.

Lesson Objectives

- Perform unit conversions.
- Properly use scientific notation.

Lesson Vocabulary

conversion factor
    A mathematical expression equating two different units, such as 1 m = 100 cm.
scientific notation
    A number expressed in scientific notation is written as a number between 1 and 10 multiplied by a power of ten.

Think*Pair*Share

Give students time to think about the question below on their own, share their answer with the person next to them, and then discuss the question as a class.

Ask: If I need 48 donuts total, how many dozen donuts should I order? *(Refer to sample answers).*

A Metric World

The link below describes a lesson that prompts students to think of the many ways they use measurements in their everyday lives and practice converting these measurements into the metric system.

http://www.discoveryeducation.com/teachers/free-lesson-plans/a-metric-world.cfm

Peer Teaching

Give students some practice problems with unit conversions and scientific notation. Pair each student up and have them alternate between tutor and tutee.

Dispelling Misconceptions

Write the following fractions on the board: 1m/100cm, 1s/1000ms, 1hr/60 min, 1kg/1000g.

Ask: Which of the fractions on the board are equal to 1? *(Refer to sample answers).*

Discuss: It is a common misconception that the numerator and denominator of a fraction have to be the same number in order to be equal to 1. In science, the numerator and denominator simply have to equal the same physical quantity (refer to the example of 12 donuts in 1 dozen). These are called conversion factors and can be used to translate physical quantities from one unit to another.

Exit Slip

Pass out index cards to the students and ask them to write their response to the following prompt on the card. Collect the cards as students exit the classroom and assess.

Prompt: Write the following quantity in scientific notation: 1200 kg. *(Refer to sample answers).*

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook.* You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

1.4 Measurement and Recording Data

Key Concept
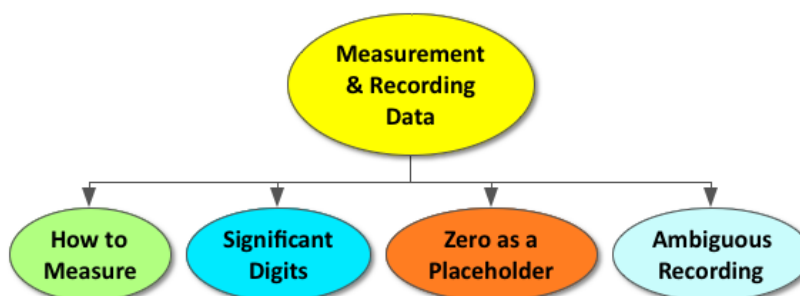
The last digit of any measurement is always an estimate. Although it is uncertain, it is still considered important and referred to as a significant digit. The best method for writing significant digits is to put the numbers in scientific notation.

Lesson Objectives

- Describe measurement.
- Explain what is meant by significant digits.
- Determine the number of significant digits in a measurement.
- Add, subtract, multiply, and divide with significant digits.
- Use scientific notation.

Lesson Vocabulary

precision
> The smallest unit that a device can reliably and accurately measure.

significant digits
> The number of precisely-measured digits in a measurement or result.

uncertainty (in measurement)
> The possible variance between a measurement and the actual result.

Powers of Ten

Show this famous video to get students interested in learning about significant digits and scientific notation.

https://www.youtube.com/watch?v=0fKBhvDjuy0

The Thickness of Aluminum Foil Lab

The link below describes a lab in which students make measurements, apply the principles of significant figures, and express numbers in scientific notation.

http://www.sd71.bc.ca/Sd71/school/gpvanier/school/teachers_departments/links/Chem%2011%20Website/UNIT1_-files%5CPart%20B%5CThe%20Thickness%20of%20Aluminum%20Foil%20Lab.html

IOW

Prompt students to write out each of the rules of significant figures in their own words and include an example for each rule. Students can then turn to the person next to them and compare their list and examples.

Computing with Significant Digits

Provide students with some practice problems requiring them to add, subtract, multiply and divide with significant digits. Encourage them to apply the list of rules they wrote in their own words to help them with their problem solving.

Lesson Worksheets

Copy and distribute the lesson worksheet in the *the CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

1.5 Working with Error

Key Concept
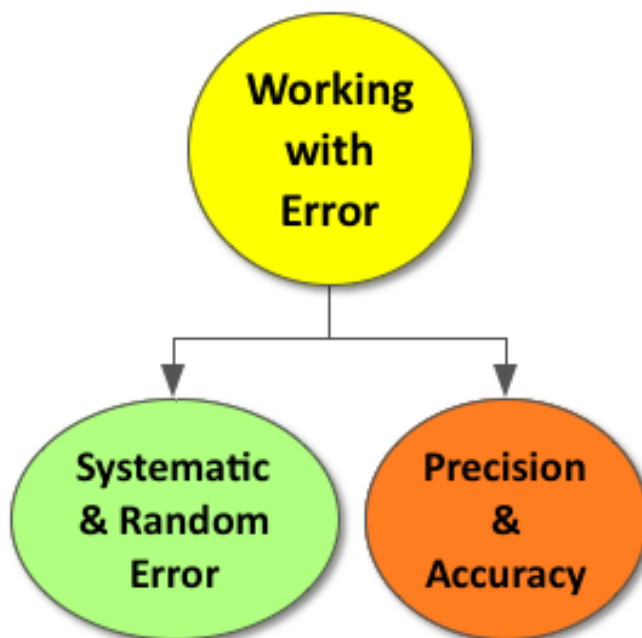
It is important for scientists to address sources of error when conducting an experiment. If the error is precise but inaccurate, it is most likely a result of the faulty calibration of measurement equipment and referred to as a systematic error. If the error is precise and accurate, it is most likely a result of the limited precision of measuring tools and referred to as random error.

Lesson Objectives

- Describe systematic and random error.
- Explain precision and accuracy as they relate to error.

Lesson Vocabulary

accuracy
   Measure of how close a measurement is to the correct or accepted value of the quantity being measured.

precision
>   The measure of how close a series of measurements are to one another.

random error
>   Error that varies within the inherent uncertainty of a measuring device.

systematic error
>   An error of constant value that is made repeatedly.

Guess My Age

Display a picture of a famous person. Prompt students to guess the age of this celebrity and discuss the precision and accuracy of their guesses.

SEE-I

Divide the class into groups of 3-4 students and provide each group with a whiteboard and dry erase markers. Demonstrate how to use the SEE-I method to clarify terms and show understanding (*see below for more information*). Prompt students to use the SEE-I method to describe the following scientific terms:

- Precision
- Accuracy
- Systematic Error
- Random Error

Learn more about the SEE-I method by visiting the link below:

http://en.wikipedia.org/wiki/SEE-I

Percent Error

Prompt advanced students to research the percent error formula and explain the purpose of making this calculation. They can apply this formula to calculate the percent error of the data collected in the Guess My Age game.

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

Chapter Test

Copy and distribute the Chapter 1 Test using the *CK-12 Physics Intermediate Quizzes and Tests* link.

CHAPTER **2** **One-Dimensional Motion Teacher's Edition**

Chapter Outline

Chapter Overview
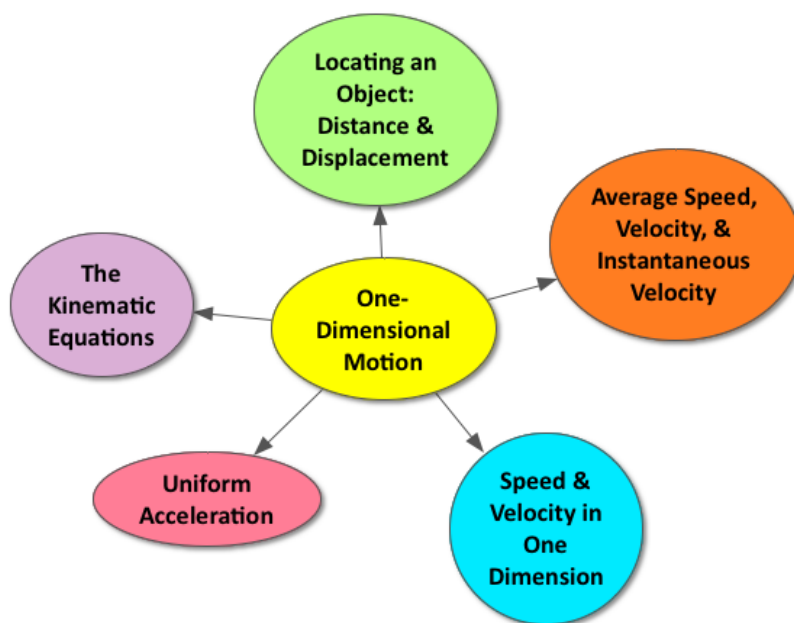
Although motion is easily observed, it is challenging to define. One Dimensional motion is the simplest type of motion to analyze because an object is moving linearly. All motion is relative; physicists must analyze how two objects move with respect to each other. In this chapter, we will analyze the motion of objects with respect to the surface of the Earth. The key to understanding motion is to grasp the idea of rates, or how any quantity changes over time. Key rates in physics are speed, velocity, and acceleration.

Online Resources

Physics Classroom: 1-Dimensional Kinematics

This website provides a student friendly description of a variety of physics concepts, including one dimensional motion.

http://www.physicsclassroom.com/Physics-Tutorial/1-D-Kinematics

Apps

Video Physics

This App allows students to analyze the motion of an object on their iPhone, iPod Touch, and iPad. The App automatically creates position versus time and velocity versus time graphs for the object in motion and makes data sharing easy.

https://itunes.apple.com/us/app/vernier-video-physics/id389784247?mt=8

https://www.youtube.com/watch?v=ugfWRPORSNg

Graphical Analysis

This App allows students to input data and generate graphs. They can easily annotate, apply a linear fit and export their graphs.

https://itunes.apple.com/us/app/vernier-graphical-analysis/id522996341?mt=8

TABLE 2.1: Pacing The Lessons

Lesson	Class Periods (60 min)
Lesson 2.1 Locating an Object: Distance & Displacement	1
Lesson 2.2 Speed and Velocity in One Dimension	2
Lesson 2.3 Average Speed, Velocity, & Instantaneous Velocity	2
Lesson 2.4 Uniform Acceleration	2
Lesson 2.5 The Kinematics Equations	2

2.1 Locating an Object: Distance & Displacement

Key Concept
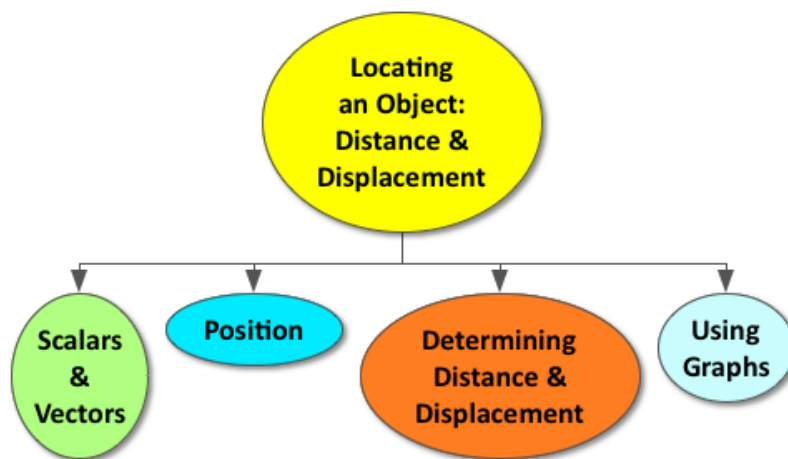
Kinematics, or the study of motion, requires a physicist to examine the position of an object and changes in this position. The position of an object defines its location in a frame of reference. Distance is the total length traveled by a moving object from one position to the next. Distance is a scalar quantity and direction is not applicable. Displacement is the separation between the original and final positions of a moving object. Displacement is a vector quantity, so we must always take into account the direction an object is moving. We can use graphs to depict an object's change in position over time.

Lesson Objectives

- Define scalar and vector.
- Define distance and displacement.
- Distinguish between distance and displacement.
- Graphically model distance and displacement.

Lesson Vocabulary

displacement
    The difference between final and initial positions.

distance
    The positive length describing the amount of ground covered by an object in motion.
position
    The place of an object based on a reference point.
scalar
    The magnitude of a numerical quantity.
vector
    The magnitude and direction of a numerical quantity.

Equations

- Distance: $x = |P_2 - P_1| + |P_3 - P_2| + ...$
- Displacement: $\Delta x = p_f - p_i$

Think*Pair*Share

Allow students time to think about the question below on their own, share their answer with the person next to them, and then discuss as a class.

Stand still at the front of the classroom and ask: Am I moving right now? If so, how fast am I going? *(Refer to sample answers).*

Use this activity to introduce this concept: **Motion is Relative**. It doesn't make sense to ask, "How fast am I going?" unless I state the question RELATIVE to something. For example, I am not moving relative to this room but I am moving relative to the sun. I am on the Earth and the Earth is orbiting the Sun at about 66,000 MPH. In this chapter, we will analyze the motion of objects relative to the surface of the Earth.

Position and Displacement Simulation

Students should use this simulation to explore the concepts of position, distance and displacement. Students can play this simulation on a computer or tablet device, alone or in pairs. (*If your students do not have access to electronic devices in the class, this can also be assigned as homework*).

http://www.ck12.org/physics/Position-and-Displacement/simulation/Position-and-Displacement-Simulation/

Number Line Demonstration

Create a large number line in the classroom by taping index cards on the floor or wall 1 meter apart. Move from Position A (pick a position on the number line) to Position B (pick another position on the number line) to Position C (yet another position on the number line).

- Prompt students to calculate the **distance** (in meters) from Position A to Position B to Position C.

– *Be sure to highlight these important concepts:*

  * *SI Units of distance (meters)*
  * *Definition of position*
  * *Definition of distance*
  * *Distance is scalar (direction does not matter)*

- Prompt students to calculate the **displacement** (in meters) from Position A to Position B to Position C (**In* *your example, the displacement should be a different value than the distance, to help students recognize that* *distance and displacement are not the same*).

  – *Be sure to highlight these important concepts:*

    * *SI Units of displacement (meters)*
    * *Definition of Displacement*
    * *Displacement is a vector (direction does matter; rightward and upward are positive; leftward and* *downward are negative)*
    * *Distance and displacement are not the same*

- Prompt students to sketch a **Position-Time graph** of your motion from Position A to Position B to Position C

  – Be sure to highlight these important concepts:

    * Labeling graph axes with correct units (m vs s)
    * Definition of a rate

Creating Position-Time Graphs with Motion Detectors

If you have access to motion detectors, you can prompt students move around and use the detectors to generate position-time graphs of their motion.

Optional: Students can use the Video Physics App and/or the Graphical Analysis App on their iPhone, iPod Touch, or iPad to do this activity. See the App descriptions in the chapter overview for more information.

Exit Slip

Pass out index cards to the students and ask them to write their response to the following prompt on the card. Collect the cards as students exit the classroom and assess.

Sketch this graph on the board or display the following image on the overhead projector. Establish that the rightward direction is positive and that the leftward direction is negative compared to the ant's starting position.

Motion of Ant
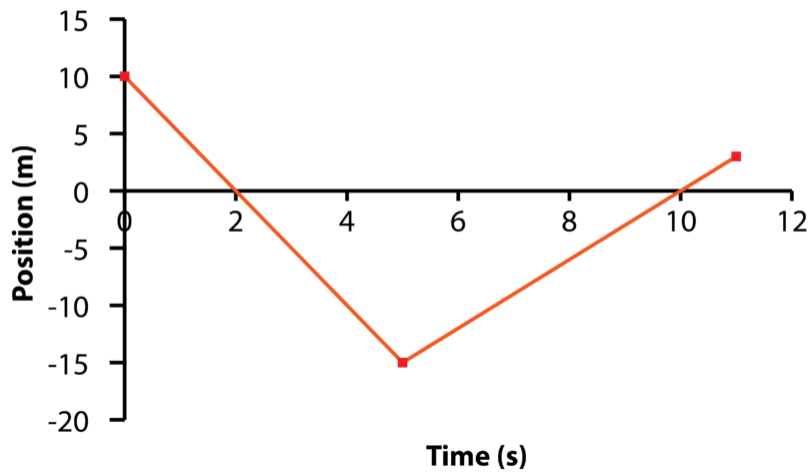
Prompt: Describe the motion of the ant in words. *(Refer to sample answers).*

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook.* You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

2.2 Speed and Velocity in One Dimension

Key Concept
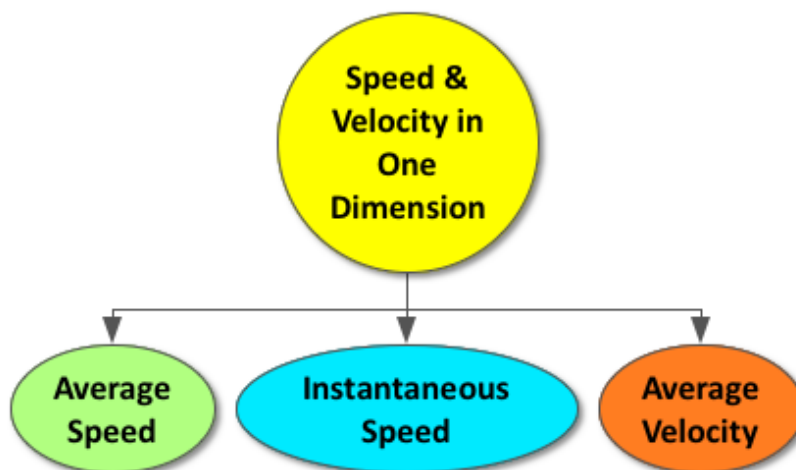
A moving object travels a certain distance over time. Speed is the rate of motion, or the amount of distance traveled over time. An object's speed at any point in time is referred to as the instantaneous speed. The total distance traveled divided by the total travel time can be used to calculate an object's average speed. The speed of an object is scalar, so direction does not matter. Velocity is an object's speed in a certain direction. Velocity can be calculated by dividing the change in an object's position (displacement) by the change in time. The velocity of an object can also be derived from the slope of a position-time graph. Velocity is a vector quantity, so it is important to always record the magnitude and direction.

Lesson Objectives

- Define constant speed and velocity.
- Distinguish between speed and velocity.
- Determine velocity from position-time graphs.

Lesson Vocabulary

average speed
    Total distance traveled divided by total travel time.
average velocity
    Change in position divided by change in time.

uniform speed
>A constant speed, one that does not change over time.

uniform velocity
>A constant velocity, one that does not change over time.

Equations

- $v = \frac{x}{t}$
- $\Delta v = \frac{\Delta x}{(t_f - t_i)}$

Thrust SSC –Super sonic land speed record holder

Get students excited about analyzing speed and velocity by showing them this video (4:47) on the Thrust Super Sonic Car (SSC). This jet-propelled car holds the World Land Speed Record and broke the sound barrier.

https://www.youtube.com/watch?v=J2QuOfOGoqU

Battery Buggy Car Lab

Divide students into groups of 3-4. Provide each group with a stopwatch, meter stick and battery buggy (or other object that can travel at a constant velocity). Also, provide a whiteboard and dry erase markers for data sharing.

Challenge students to determine the **average velocity** of the battery buggy.

Their whiteboards should include the following:

- Average velocity of the rolling object (remember SI units!)
- A position-time graph
- A sentence describing how the answer was derived from the graph

Note: Do not provide students with any more instruction than this simple prompt. It will challenge students to think critically about their experimental design. *(Refer to sample answers).*

Optional: Students can use motion detectors, the Video Physics App and/or the Graphical Analysis App on their iPhone, iPod Touch, or iPad to do this activity. See the App descriptions in the chapter overview for more information.

Graphing Motion

Place students in pairs. Provide each group with a whiteboard and dry erase markers. Read the following prompts and challenge groups to make a predictive sketch of the position-time graph for each one. Go through each prompt one at a time, acknowledging groups with correct whiteboards and answering any questions that arise.

1. An object at rest (no velocity)
2. An object with a positive, uniform velocity
3. An object with a slow, rightward uniform velocity
4. An object with a fast, rightward uniform velocity
5. An object with a slow leftward uniform velocity
6. An object with a fast leftward uniform velocity

(Refer to sample answers).

Describing Motion from Graphs

You can then reverse the above activity; provide groups with a variety of position-time graphs and have students describe the velocity of the object in words based on the graph.

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook.* You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

2.3 Average Speed, Velocity, & Instantaneous Velocity

Key Concept
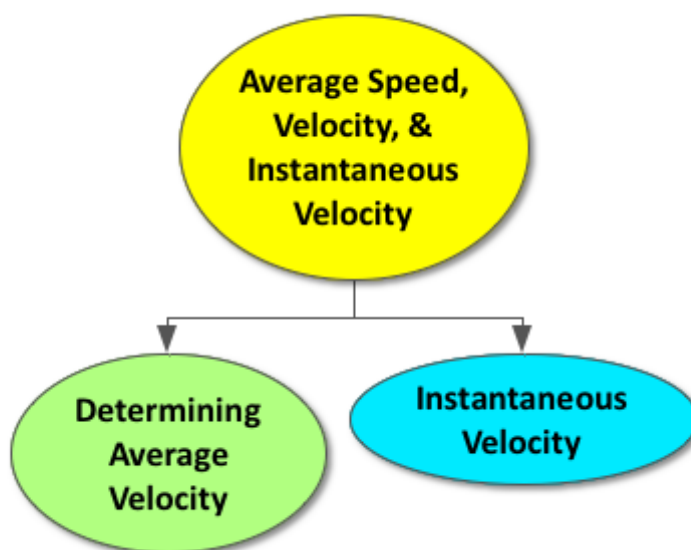
The average speed of a moving object can be calculated by dividing the total distance traveled by the total time of travel. If the direction of motion is the same for the entire journey, a moving object's average velocity will have the same magnitude as its average speed and the direction will simply need to be included. If the direction of motion changes at any point in the journey, a moving object's average velocity will be different from its average speed. The average velocity can be calculated by dividing the difference between final and initial positions (displacement) by the total time of travel. When we measure average velocity over smaller and smaller intervals of time, we can get closer to calculating the instantaneous velocity. The instantaneous velocity is the closest possible approximation of an object's velocity at a specific time.

Lesson Objectives

- Calculate average speed for varying rates.
- Explain what is meant by instantaneous velocity.

Lesson Vocabulary

average speed
  Found by dividing the total distance traveled by the total time required to travel.
instantaneous velocity
  Velocity at a specific time, estimated by finding an average velocity over smaller and smaller time intervals.

Equations

- Average Speed: $\frac{(d_1+d_2+...)}{(t_1+t_2+...)}$
- Average Velocity: $\frac{(p_f-p_i)}{(t_f-t_i)}$

Science of NFL Football: Kinematics

Begin class by showing students this quick video clip (5:25) to inspire them to connect physics and football. http://www.nbclearn.com/nfl/cuecard/50770

Measuring Speed on a Football Field

Divide students into pairs. Provide each group with a stopwatch and move to the school football field. (*Make sure to get the appropriate clearance to use the football field and to remind students to bring pencils and notebooks to record their data*).

Prompt: Measure the time it takes your partner to complete each of the following tasks (repeat each task three times):

- Walking 10 yards
- Running 20 yards
- Sprinting 3 yards
- Skipping 15 yards
- Hopping 4 yards total –3 yards out 1 yard back
- Crawling 2 yards –1 yard out 1 yard back

Encourage students to be organized when recording their data and suggest making the following chart:

TABLE 2.2:

Task	Distance (yards)	Trial 1 time (seconds)	Trial 2 time (seconds)	Trial 3 time (seconds)
Walking	10			
Running	20			
Sprinting	3			
Skipping	15			
Hopping	4 (3 out; 1 back)			
Crawling	2 (1 out; 1 back)			

Optional: Students can use the Video Physics App and/or the Graphical Analysis App on their iPhone, iPod Touch, or iPad to do this activity. See the App descriptions in the chapter overview for more information.

Calculating Average Speed and Average Velocity

Students should use the data collected in the previous activity (Measuring Speed on a Football Field) to calculate their partner's average speed and average velocity.

Encourage students to be organized when making their calculations and suggest using the following chart:

TABLE 2.3:

Task	Average Speed $\left(\frac{d}{\Delta t}\right) = \left(\frac{yds}{s}\right)$	Average Velocity $\left(\frac{\Delta x}{\Delta t}\right) = \left(\frac{yds}{s}\right)$
Walking		
Running		
Sprinting		
Skipping		
Hopping		
Crawling		

Unit Conversions

Prompt students to convert the values they calculated for the average speed and average velocity into meters/second (SI units). Students can use the conversion factor 1 yard= 0.914 meters.

Encourage students to be organized when making their calculations and suggest using the following chart:

TABLE 2.4:

Task	Average Speed (m/s)	Average Velocity (m/s)
Walking		
Running		
Sprinting		
Skipping		
Hopping		
Crawling		

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

2.4 Uniform Acceleration

Key Concept
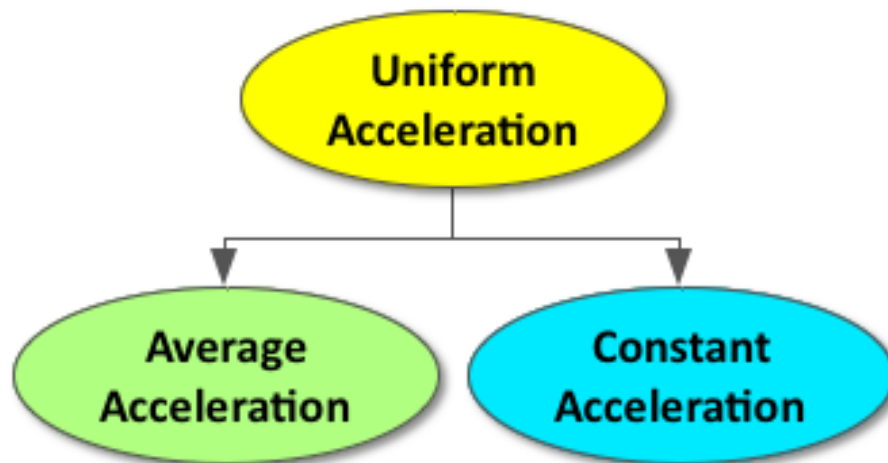
Acceleration is a vector quantity that describes the rate of change in the velocity of a moving object. An object accelerates when it speeds up, slows down or changes direction. Constant acceleration describes a moving object whose velocity changes in equal amounts in a given time period.

Lesson Objectives

- Define and explain acceleration.

Lesson Vocabulary

average acceleration
    The change in velocity divided by the duration of the time period.
constant acceleration
    A type of motion in which the velocity of an object changes by an equal amount in every equal time period.

Equation

- $\vec{a}_{avg} = \frac{\Delta\vec{v}}{\Delta t}$

Survey

The following statements highlight common misconceptions regarding acceleration. Prompt students to take the following survey at the beginning of the lesson. Before the end of the lesson, students should review their initial answers and make any changes they feel necessary. At the end of the lesson, you should post the answer key and dispel any common misconceptions as a class.

Circle T/F to indicate if the following statements are true or false:

- (T / F) Acceleration must mean that an object is speeding up.
- (T / F) An object does not accelerate if it remains at the same speed but changes direction.
- (T / F) If an object has a very large velocity (it is moving fast), then it must have a very large acceleration.
- (T / F) If the acceleration of a moving object is negative, it must be slowing down.
- (T / F) Acceleration always occurs in the same direction as the object's velocity.

(**All of the above statements are FALSE and should unveil common student misconceptions regarding acceleration).

The Acceleration on an Inclined Plane Inquiry Demonstration

Set up an inclined plane in your classroom and choose a rolling object to use for the demonstration (examples: marble, golf ball, tennis ball, or toy car). Draw an image of the inclined plane on the board, labeling points A, B, and C as depicted below. Discuss the following questions as you demonstrate rolling the object up the inclined plane and watching the object roll back down.
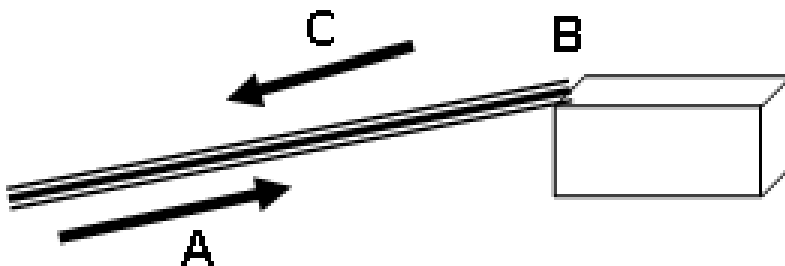
- **Point A:** The rolling object is traveling up the ramp
- **Point B:** The rolling object has reached the top of the ramp and is changing direction
- **Point C:** The rolling object is traveling down the ramp

Prompt: At which point: A, B, or C does the rolling object have constant velocity? *(Refer to sample answers).*

Prompt: If acceleration is defined as a change in velocity over time, at which point is the object accelerating? *(Refer to sample answers).*

Discuss the Key Concept as a class: Acceleration is a vector quantity that describes the change in the velocity of a moving object over time. An object accelerates when it speeds up, slows down or changes direction.

Prompt: Sketch a position-time graph to depict the horizontal motion (x-dimension) of the rolling object as it travels from Point A to Point B to Point C. *(Refer to sample answers).*

Prompt: Sketch a velocity-time graph to depict the horizontal motion (x-dimension) of the rolling object as it travels from Point A to Point B to Point C. *(Refer to sample answers).*

Highlight that the slope of a position-time graph is velocity and the slope of a velocity-time graph is acceleration.

Determining the Acceleration of a Rolling Object on an Inclined Plane

Break students up into groups of 3-4. Provide each group with materials to build their own inclined plane, a rolling object, a meter stick and a stopwatch. Also, provide a whiteboard and dry erase markers. Use the same set up as the demonstration above and continue to have the image of the inclined plane on the board, labeling points A, B, and C.
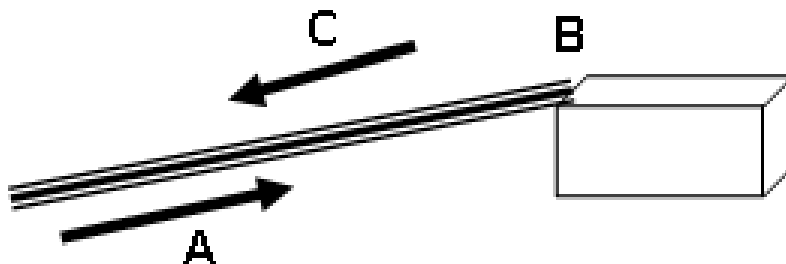
Challenge students to determine the **average acceleration** of the rolling object as it travels up and down the ramp.

The whiteboards should include the following:

- Average acceleration of the rolling object (remember SI units!)
- A velocity-time graph
- A sentence describing how you derived your answer from your graph

Note: Do not provide students with any more instruction than this simple prompt. It will challenge students to think critically and apply what they have just learned about the graphs of position-time and velocity graphs. *(Refer to sample answers).*

Optional: Students can use motion detectors, the Video Physics App and/or the Graphical Analysis App on their iPhone, iPod Touch, or iPad to do this activity. See the App descriptions in the chapter overview for more information.

Galileo's Inclined Planes

Students can watch this video to learn how Galileo also used the inclined plane to examine the acceleration of objects on Earth.

http://www.pbslearningmedia.org/resource/phy03.sci.phys.mfw.galileoplane/galileos-inclined-plane/

Survey

Students should review their initial answers to the survey given at the beginning of the lesson and make any changes they feel necessary. At the end of the lesson, you should post the answer key and dispel any common misconceptions as a class.

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

2.5 The Kinematics Equations

Key Concept
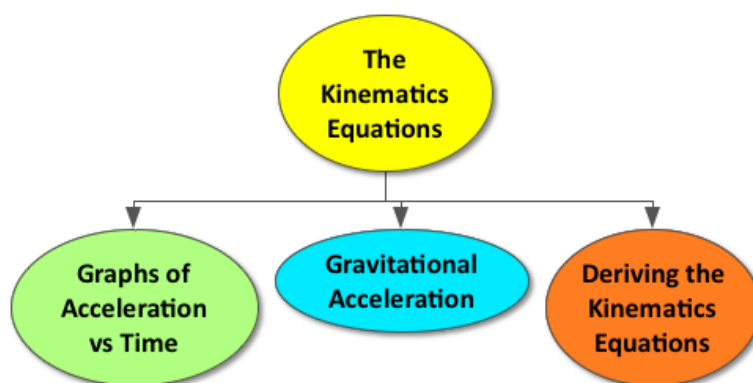
The Kinematics Equations can be used mathematically define the relationship between position, velocity, and constant acceleration. The Kinematics Equations are derived from velocity-time and acceleration-time graphs.

Lesson Objectives

- Interpret area in an acceleration-time graph.
- Represent motion using a velocity-time graph.
- Interpret slope and area in a velocity-time graph.

Lesson Vocabulary

linear
    Related to, or resembling a straight line.
midpoint
    The point of a line segment or curvilinear arc that divides it into two parts of the same length; a position midway between two extremes.

Equations

- $\vec{v}_{avg} = \frac{\Delta \vec{x}}{\Delta t}$
- $\vec{a}_{avg} = \frac{\Delta \vec{v}}{\Delta t}$
- $\vec{v}_f = \vec{a}t + \vec{v}_i$
- $\vec{v}_{avg} = \frac{\vec{v}_f + \vec{v}_i}{2}$
- $\vec{x} = \frac{1}{2}\vec{a}t^2 + \vec{v}_i t + \vec{x}_i$
- $\vec{v}_f^2 = \vec{v}_i^2 + 2\vec{a}\Delta x$

Seven Minutes of Terror: The Challenges of Getting to Mars

Show this quick video clip (5:07) regarding how team members at NASA's Jet Propulsion Laboratory relied on their understanding of kinematics to land the Curiosity rover on Mars.

https://www.youtube.com/watch?v=Ki_Af_o9Q9s

One Shot Cup Lab

Just like the team members at NASA's Jet Propulsion Laboratory, use the activity found at the link below to challenge students to use kinematics equations to predict the precise distance a marble will land.

http://www.physicslessons.com/xlab-projectile.html

The Moving Man PHET

Prompt students to create position-time, velocity-time, and acceleration-time graphs with the simulation found on the link below. They should explain the connection between the kinematics equations and their graphs.

http://phet.colorado.edu/en/simulation/moving-man

IOW

Prompt students to write out every kinematic equation, define what each variable means and include the units of the variable.

For example: $\vec{v}_f = \vec{a}t + \vec{v}_i$

- $\vec{v}_f$ = final velocity (m/s; vector)
- $\vec{a}$ = acceleration (m/s^2; vector)
- t = time (seconds)
- $\vec{v}_i$ = initial velocity (m/s; vector)

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

Chapter Test

Copy and distribute the Chapter 2 Test using the *CK-12 Physics Intermediate Quizzes and Tests* link.

CHAPTER 3

Two-Dimensional Motion Teacher's Edition

Chapter Outline

Chapter Overview
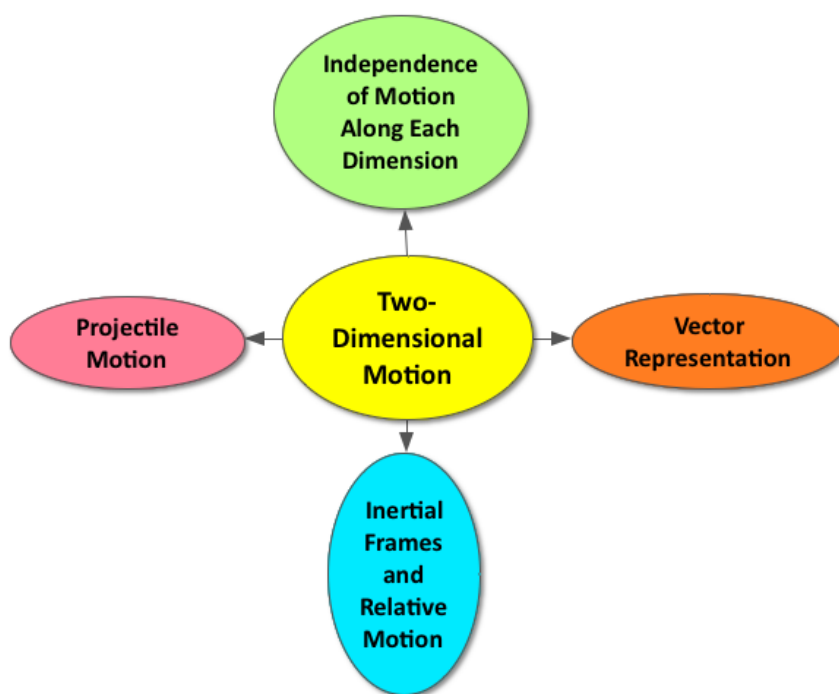
Two-dimensional motion describes nonlinear motion, or an object traveling along a curved path. Two-dimensional motion refers to the simultaneous movement in both the horizontal and vertical dimensions. These dimensions are independent of each other; what happens in one dimension does not have an effect on the other. Vectors and trigonometric functions can be used to analyze non-linear motion. According to the Galilean Principle of Relativity, objects moving with a constant velocity provide inertial frames of reference. The Earth continues to serve as a reference frame in this chapter. Projectiles have a constant horizontal velocity and an accelerated vertical velocity due to gravity, which results in the curved path of their motion.

Online Resources

Navigational Vectors

The Center for Innovation in Science and Engineering Education (CIESE) describes a two week unit, consisting of nine lessons, at the following URL.

http://ciese.org/curriculum/vectorproj/

PhET Vector Addition

The link below is great simulation for students who are visual learners or need more practice with vector addition.

http://phet.colorado.edu/en/simulation/vector-addition

PhET Projectile Motion

Students will be prompted to learn about projectile motion by firing a canon in this simulation.

http://phet.colorado.edu/en/simulation/projectile-motion

Apps

Video Physics

This App allows students to analyze the motion of an object on their iPhone, iPod Touch, and iPad. The App automatically creates position versus time and velocity versus time graphs for the object in motion and makes data sharing easy.

https://itunes.apple.com/us/app/vernier-video-physics/id389784247?mt=8

https://www.youtube.com/watch?v=ugfWRPORSNg

Graphical Analysis

This App allows students to input data and generate graphs. They can easily annotate, apply a linear fit and export their graphs.

https://itunes.apple.com/us/app/vernier-graphical-analysis/id522996341?mt=8

TABLE 3.1: Pacing The Lessons

Lesson	Class Periods (60 min)
Lesson 3.1 Independence of Motion Along Each Dimension	2
Lesson 3.2 Vector Representation	2
Lesson 3.3 Inertial Frames and Relative Motion	2
Lesson 3.4 Projectile Motion	2

3.1 Independent Motion Along Each Dimension

Key Concept
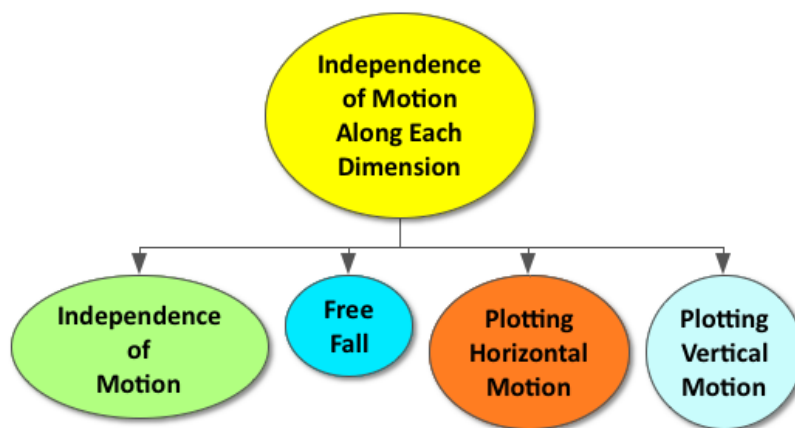
An object traveling along a curved path exhibits two-dimensional motion. This nonlinear motion coexists in both the horizontal and vertical dimensions. The most important characteristic of two-dimensional motion is that each dimension is completely independent from the other. When the effects of these two independent dimensions combine, an object follows a downward curve, commonly referred to as projectile motion. Objects in free fall experience a constant horizontal velocity and accelerated vertical velocity, resulting in projectile motion. The kinematics equations and graphs can be used to analyze two-dimensional motion.

Lesson Objectives

The student will:

- Understand how motion along each axis can be resolved independently.
- Solve problems involving objects which are simultaneously under the influence of uniform acceleration and constant velocity along different dimensions.

Lesson Vocabulary

free fall
> The condition of acceleration due only to gravity. An object in free fall is not being held up, pushed, or pulled by anything except its own weight. Though objects moving in air experience some force from air resistance, this is sometimes small enough that it can be ignored and the object is considered to be in free fall.

instantaneous velocity of a projectile

   The velocity of an object at one instant during its motion. In the case of a projectile, the instantaneous velocity vector would be the result of a constant velocity in horizontal motion and an accelerated velocity in vertical motion.

projectile motion

   Projectile motion is a form of motion where a projectile is thrown near the Earth's surface with some horizontal component to its velocity. The projectile moves along a curved path under the force of gravity. The path followed by a projectile is called its trajectory. Projectile motion is motion in two directions. In the vertical direction, the motion is accelerated motion and in the horizontal direction, the motion is constant velocity motion.

range

   A projectile launched with specific initial conditions for velocity will travel a predictable horizontal displacement before striking the ground. This distance is referred to as the projectile's range.

Equations

- $x_f = v_x t + x_i$
- $y_f = \frac{1}{2} g t^2 + y_i$

Think*Pair*Share

Allow students time to think about the question below on their own, share their answer with the person next to them, and then discuss as a class.

Prompt: What does it mean to say the real world is three-dimensional? *(Refer#space#to#space#sample#space#answers)*.

Be sure to highlight the following: In this chapter, we will be focusing on two-dimensional motion, in which an object is moving in both the horizontal (x) and vertical (y) dimensions. Two-dimensional motion is nonlinear, whereas one-dimensional motion is linear.

Dropped Penny vs Projected Penny

Allow students to work in pairs. Provide each group with two pennies. Describe the inquiry activity below to the class and ask students the following:

Ask: Which penny do you think will hit the ground first –the dropped penny or the projected penny? Why?

Provide students some time to think and possibly write down their answer or share their prediction with their partners.

Instruct students to place one penny near the edge of a table and another penny behind it. Prompt students to flick the penny that is furthest from the edge so that it hits the penny at the edge and they both fall off the table; one should drop and one should be projected off the table at the same time. They should repeat as necessary and record their observations.

Students should observe that both pennies always hit the ground at the same time.

Use this inquiry activity to introduce this important concept: **Motion in each dimension works independently**. Each penny's horizontal motion is completely independent from its vertical motion. Although their horizontal motion

differs –one penny is dropped and the other is projected, their vertical motion is the same. Both pennies experience the same vertical acceleration due to the Earth's gravity. As a result of falling from the same height, they hit the ground at the same time.

Solving for the Muzzle Velocity of a Toy Dart Gun

Divide students into groups of 3-4. Provide each group with a toy dart gun, a meter stick, masking tape, and a stopwatch.

Challenge students to determine the initial velocity ($v_{x-initial}$) of the dart as it exits the barrel of the toy dart gun using the materials provided and the kinematics equations.

Note: Do not provide students with any more instruction than this simple prompt. It will challenge students to think critically about their experimental design. (*See the Lab Example in Lesson 3.1 of the CK-12 Physics Intermediate Flexbook for an exemplary experimental design:* http://www.ck12.org/book/CK-12-Physics---Intermediate/section/3.1/).

Optional: Students can use motion detectors, the Video Physics App and/or the Graphical Analysis App on their iPhone, iPod Touch, or iPad to do this activity. See the App descriptions in the chapter overview for more information.

Plotting the Motion of the Dart in the X and Y Dimensions

Provide each group with a whiteboard and dry-erase markers. Challenge students to sketch the following position-time graphs of their toy dart from the lab above on their whiteboards:

1. The horizontal position-time graph of their dart
2. The vertical position-time graph of their dart

See the Lab Example in Lesson 3.1 of the CK-12 Physics Intermediate Flexbook for exemplary graphs: http://www.ck12.org/book/CK-12-Physics---Intermediate/section/3.1/

Exit Slip

Pass out index cards to the students and ask them to write their response to the following prompt on the card. Collect the cards as students exit the classroom and assess.

Prompt: A physics student shoots one toy dart horizontally from their toy dart gun, while at the same time simply dropping a second dart from the same height. Which toy dart will hit the ground first: the one shot from the toy dart gun or the one dropped? *(Refer#space#to#space#sample#space#answers).*

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

3.2 Vector Representation

Key Concept
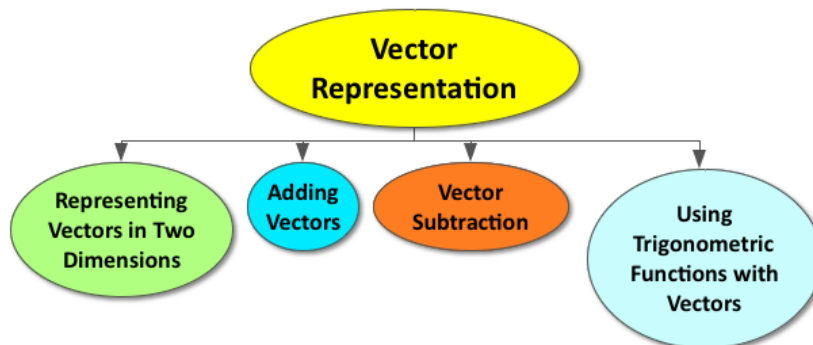
A vector quantity has both magnitude and direction, such as displacement, velocity, and acceleration. Vector diagrams illustrate the direction of the vector with an arrow and the magnitude of the vector with the length of the arrow. Vectors that exist in two-dimensions must be broken down into their x and y components. You can add or subtract vectors, and use trigonometric functions to express vector components.

Lesson Objectives

The student will:

- Explain the relationship between coordinates and components.
- Use vectors and vector components to add and subtract vectors.
- Use trigonometric relationships to express vector components.

Lesson Vocabulary

resultant vector
     A single vector that is the vector sum of two or more other vectors.

trigonometric functions
     sine, cosine, tangent, inverse tangent

vector addition
     Vector addition is the process of finding one vector that is equivalent to the result of the successive application of two or more given vectors. Another way to define addition of two vectors is by a head-to-tail construction that creates two sides of a triangle; the third side of the triangle determines the sum of the two vectors.

vector components

Parts of a vector that add up to the whole. In two-dimensional problems, there are usually two components- the horizontal x-component and the vertical y-component. Vector addition of all the components yields the original vector.

vector subtraction

An operation identical to adding a negative inverse of a vector. The inverse of a vector is defined as a vector with the same magnitude but in the opposite direction of the original vector.

Equations

- $r = \cos\theta$
- $y = r\sin\theta$
- $\theta = \tan^{-1}\frac{y}{x}$

Vector Addition Warm-up

Draw the following three prompts on the board. Allow students time to sketch their answers. Then, review the rules for adding these vectors as a class.

- Determine the resultant vector for the following three scenarios:

1.

(1)

2.

3.

(2)
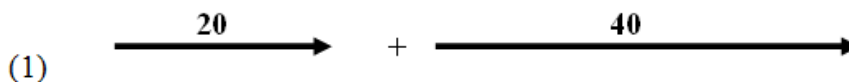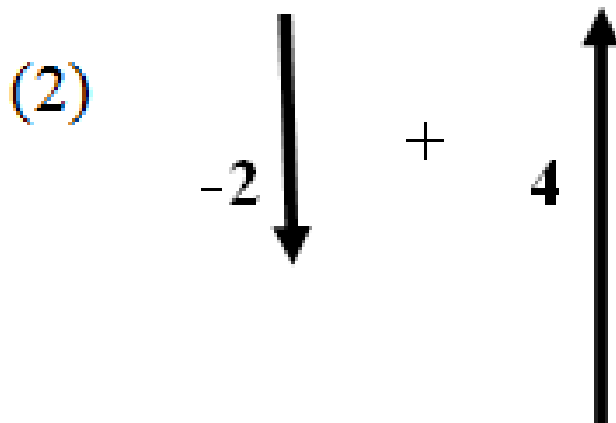
4.

5.

(3) ⟶ 16 + ↑ 3

6.

(Refer to sample answers).

The Vector Addition Map Lab

In the activity below, students will engage in vector addition on a map to determine the resultant displacement of various trips.

http://physicsphunhouse.com/physics/Vector_Addition_Lab.pdf

Peer Teaching

Give students some practice problems with adding vectors, subtracting vectors, and using trigonometric functions to express vector components. Pair each student up and have them alternate between tutor and tutee.

Making Real-World Connections

Challenge students to brainstorm some other real-world applications of vector addition, subtraction, and using trigonometric functions to express vector components.

See the links below for examples of ways we rely on vectors in the real-world:

- Aviation Navigation: http://virtualskies.arc.nasa.gov/navigation/6.html
- Sailing: http://www.physics.unsw.edu.au/~jw/sailing.html

Still Sticky

At the end of class, pass out sticky notes to each students and provide them with the opportunity to write down any questions they still have or discuss concepts that are still unclear to them regarding vectors.

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

3.3 Inertial Frames and Relative Motion

Key Concept
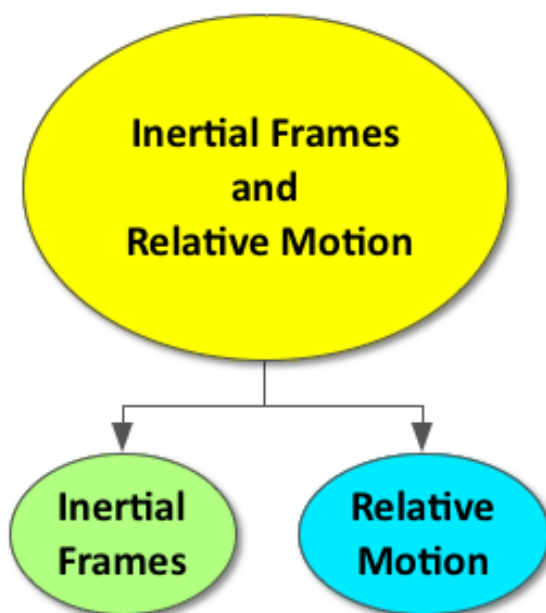
All motion is relative, so a reference point must be defined when analyzing velocity. It is impossible to sense constant velocity; only changes in velocity (acceleration) can be perceived. The Galilean Principle of Relativity equates all constant velocity reference frames and labels them as inertial frames of reference. The most common inertial frame of reference is the Earth. The velocity of moving objects in different inertial frames of reference can be added using the principles of vector addition.

Lesson Objectives

The student will:

- Explain frames of reference and inertial frames.
- Solve problems involving relative motion in one-dimension.
- Solve problems involving relative motion in two-dimensions.

Lesson Vocabulary

inertial frame
> A reference frame in which the observers are not subject to any force of acceleration.

reference frame
> A coordinate system or set of axes within which the position, orientation, and other properties of objects in it can be measured. It may also refer to an observational reference frame tied to the state of motion of an observer.

relative velocity
> The vector difference between the velocities of two bodies, or the velocity of a body with respect to another body which is at rest.

Equations

- $\vec{v}_{ba} = \vec{v}_b - \vec{v}_a$
- $\vec{v}_{ab} = \vec{v}_a - \vec{v}_b$

The Dawn Mission

Provide a hook for the activities below by prompting students to learn more about the Jet Propulsion Laboratory's *Dawn* mission at the following URL:

http://dawn.jpl.nasa.gov/mission/

Frames of Reference

Prompt students to read this article from the JPL Dawn Classroom, which applies inertial frames of reference to the motion of the Dawn spacecraft. They should answer the questions at the bottom of the article when they are finished reading.

http://dawn.jpl.nasa.gov/DawnClassrooms/2_ion_prop/development/2_sr_frames.pdf

Here is the link to the Teacher Guide Supplement, which provides answers to the questions in the article above.

http://dawn.jpl.nasa.gov/DawnClassrooms/2_ion_prop/development/1_tg_development.pdf

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Relative Motion RAFT Writing Activity

After reading the article above, students should complete the writing activity described at the link below.

http://dawn.jpl.nasa.gov/DawnClassrooms/2_ion_prop/development/3_sa_frames.pdf

Here is the link to the Teacher Guide Supplement, which provides a rubric for the Relative Motion RAFT Writing Activity above.

http://dawn.jpl.nasa.gov/DawnClassrooms/2_ion_prop/development/1_tg_development.pdf

Motion and Relativity

Advanced students might be interested in this video clip (2:07) from the American Museum of Natural History, which contrasts Galilean relativity with Einstein's theory of relativity.

http://www.pbslearningmedia.org/resource/lsps07.sci.phys.fund.motionrel/motion-and-relativity/

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook.* You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

3.4 Projectile Motion

Key Concept
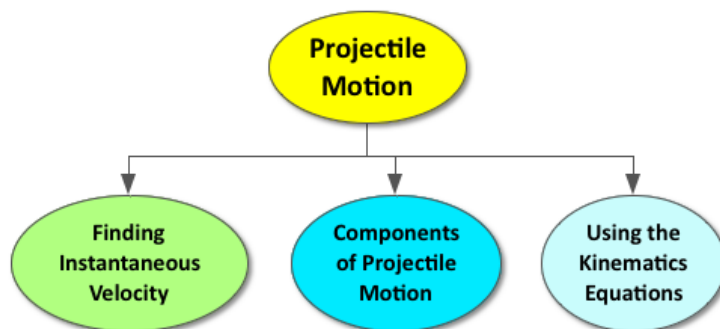
Descriptive Paragraph

Lesson Objectives

The student will:

- Draw and interpret graphs involving two-dimensional projectile motion.
- Solve for the instantaneous velocity of a projectile.
- Predict a projectile's range.

Lesson Vocabulary

Free fall

> The condition of acceleration which is due only to gravity. An object in free fall is not being held up, pushed, or pulled by anything except its own weight. Though objects moving in air experience some force from air resistance, this is sometimes small enough that it can be ignored and the object is considered to be in free fall.

Projectile motion

> a form of motion where an object (called a projectile) is thrown near the earth's surface with some horizontal component to its velocity. The projectile moves along a curved path under the action of gravity. The path followed by a projectile is called its trajectory. Projectile motion is motion in two directions. In the vertical direction, the motion is accelerated motion and in the horizontal direction, the motion is constant velocity motion.

Instantaneous velocity of a projectile

the velocity of an object at one instant during its motion. In the case of a projectile, the instantaneous velocity vector would be the resultant of a constant velocity horizontal motion and an accelerated velocity vertical motion.

Range

A projectile launched with specific initial conditions will travel a predictable horizontal displacement before striking the ground. This distance is referred to as the projectile's range.

Equations

- $y = (\frac{v_i + v_f}{2})t$
- $x_f = (v\cos\theta)t + x_i$
- $y_f = \frac{1}{2}gt^2 + (v\sin\theta)t + y_i$
- $v_x = v\cos\theta$
- $v_y = v\sin\theta$

Will it hit the hoop?

Complete the Three-Act Task described below by first asking students to predict which basketball will go in the hoop.

http://www.101qs.com/1195-will-it-hit-the-hoop

Basketball Lab

Divide students into pairs and move to the school basketball court. (*Make sure to get the appropriate clearance to use the basketball courts/basketballs and to remind students to bring pencils and notebooks to record their data*).

Prompt one person to take a free-throw shot. The other person should make a predictive **sketch** of the following based on their observations:

- A position-time graph for the horizontal motion of the basketball
- A position-time graph for the vertical motion of the basketball
- A velocity-time graph for the horizontal motion of the basketball
- A velocity-time graph for the vertical motion of the basketball

Move students back to the classroom and provide each group with whiteboards and dry erase markers. Students should create a model for projectile motion by including the following on their whiteboards:

- A definition of projectile motion (in their own words)
- A simple sketch of the following four graphs for a projectile (make sure to label all axes)
    - X-T: Position in the X direction as a function of time
    - Y-T: Position in the Y direction as a function of time
    - V_x-T: Velocity in the X direction as a function of time
    - V_y-T: Velocity in the Y direction as a function of time

- A sentence below each graph describing WHY it looks the way it does

(Refer to sample answers).

Optional: Students can use the Video Physics App and/or the Graphical Analysis App on their iPhone, iPod Touch, or iPad to do this activity. See the App descriptions in the chapter overview for more information.

Components of Projectile Motion

Provide students with the following information:

A basketball is launched 2 meters above the ground with an initial x-component velocity of +6 m/s and a y-component velocity of +8 m/s.

Prompt students to answer the following questions in pairs:

1. What is the time the projectile takes to reach the highest position above the ground?
2. What is the projectile's highest position above the ground?
3. What is the velocity of the projectile at its highest position above the ground?
4. What is the range of the projectile?

(Refer to sample answers).

The Science of Sports

Challenge students to apply what they have learned about projectile motion to a sport of their choice. They can write a brief paragraph, draw an illustration, or even create a voice-over narration of a video clip like those shown below.

Here are some links below that describe the projectile motion of various sports:

- Science of NHL hockey projectile motion video (5:35)

http://www.nbclearn.com/nhl/cuecard/56639

- Science of NFL Football: Projectile Motion Parabolas

http://science360.gov/obj/tkn-video/fc729ef0-22ee-4f61-bb2a-b6c07685fb02/science-nfl-football-projectile-motion-parabolas

Class Participation Reflection

At the end of class, prompt students to reflect on their class participation by answering the following questions on a piece of paper and turning it in for your review.

1. Rate your participation in today's class on a scale from 1-10. Explain the reason for your choice.
2. What was the most significant idea you contributed to your group?

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook.* You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link. link.

CHAPTER **4**

Newton's Three Laws Teacher's Edition

Chapter Outline

Chapter Overview
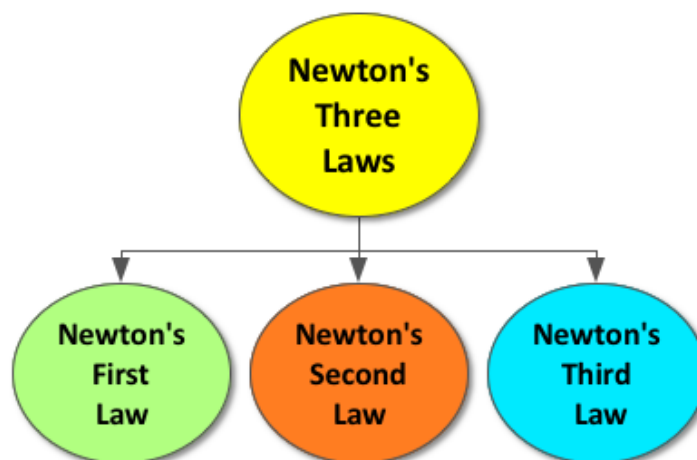
Isaac Newton developed three laws to analyze the motion of an object. A Newtonian analysis of motion requires the examination of all the forces acting on an object (the net force). A force can simply be described as a push or pull. Whenever two objects interact, a force exists between them. Newton's first law concentrates on the motion of an object as a result of balanced forces (no net force). Newton's second law centers on the motion of an object as a result of unbalanced forces (net force). Newton's third law focuses on force-pairs. Free-body diagrams can be used to illustrate the net force on an object while engaging in a Newtonian analysis of motion.

Online Resources

PhET: Forces in 1D

The link below is a wonderful simulation for students who are visual learners and need more practice with Newton's laws of motion.

http://phet.colorado.edu/en/simulation/forces-1d

The Elegant Universe

This PBS NOVA mini-series, based on the book by Brian Greene, has wonderful illustrations of the four forces of nature and describes the superstring theory. It would be great to show small clips, when appropriate, or to provide the link to advanced students interested in current theoretical physics.

http://www.pbs.org/wgbh/nova/physics/elegant-universe.html

CK-12 Newton's Laws Study Guide

Students can download or print out this study guide for Newton's three laws of motion.

http://www.ck12.org/physics/Newtons-Second-Law/studyguide/Newton's-Laws-Study-Guide/

Apps

Newton's Laws

This is an iBook from the Physics Classroom with student-friendly explanations of Newton's three laws of motion and provides interactive problems for students who need more practice.

https://itunes.apple.com/us/book/newtons-laws/id549165022?mt=13&ls=1

TABLE 4.1: Pacing The Lessons

Lesson	Class Periods (60 min)
Lesson 4.1 Newton's First Law	1
Lesson 4.2 Newton's Second Law	2
Lesson 4.3 Newton's Third Law	2

4.1 Newton's First Law

Key Concept
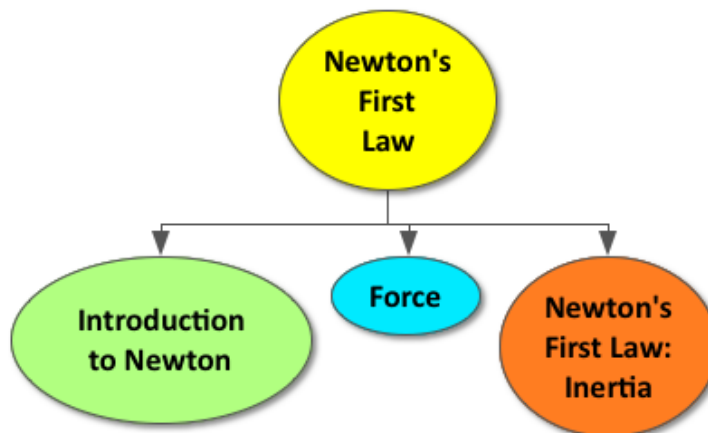
Isaac Newton was a 17th century physicist who explained the motion of an object as a result of all the forces acting on the object (the net force). Newton's first law of motion states that an object at rest will remain at rest and an object in constant motion will remain in constant motion unless acted upon by an unbalanced force. In other words, if all the forces acting on an object are balanced and the net force on the object is zero ($\Sigma F = F_{net} = 0$), the object will stay at rest or remain moving at a constant velocity.

Lesson Objectives

The student will:

- Describe what force is and different types of forces.
- Understand the meaning of inertia and Newton's First Law.

Lesson Vocabulary

force
    An interaction between two objects that effects the motion of the objects. This includes pushing and pulling, as well as resistance to being moved across or through some medium.

inertia
    The resistance of an object to changing its state of motion, directly proportional to its mass.

mass
> A measure of the amount of matter in an object. Weight on Earth's surface is based on mass, but an object's mass is the same wherever it is.

net force
> The combination of all the forces on a single object.

Equations

- Newton's First Law of Motion: An object remains at rest or in a state of uniform motion unless acted upon by an unbalanced force.

Misconception Survey

The following statements highlight common misconceptions regarding forces. Prompt students to take the following survey at the beginning of the chapter. Before the end of the chapter, students should review their initial answers and make any changes they feel necessary. At the end of the chapter, you should post the answer key and dispel any common misconceptions as a class (see Lesson 4.3: Assess & Reassess).

Circle T/F to indicate which of the following statements are true or false:

- (T / F) A force is needed to keep an object moving at a constant velocity.
- (T / F) A moving object will stop if it runs out of force.
- (T / F) Slower moving objects have less force acting on them than faster moving objects.
- (T / F) An object will slow down to a stop if a force is not constantly applied to keep it in motion.
- (T / F) The force on an object will always be in the same direction as the object's motion.

(**All of the above statements are FALSE and should unveil common student misconceptions regarding acceleration).

For more common misconceptions, see the link below that highlights student difficulties with forces:

http://www.physics.montana.edu/physed/misconceptions/forces/forces.html

Egg Drop: Newton's Law of Inertia

Begin by showing students the classic demonstration of an egg drop at the link below (video, 0:53s) to illustrate Newton's First Law of Motion.

https://www.youtube.com/watch?v=zEueIWMRXNQ

If possible, allow students to do the Egg Drop experiment by following the instructions found at this URL

http://www.stevespanglerscience.com/lab/experiments/egg-drop-inertia-trick

Egg Drop: How does it work?

Divide students into groups of 3-4 and provide each group with a whiteboard and dry erase markers. Prompt students to explain (in their own words) how the egg drop experiment worked with reference to Newton's First Law of Motion. They should include a brief summary of their explanation (1-3 sentences) on their whiteboards. If time allows, prompt students to share their whiteboards (ex: display all the whiteboards at the front of the class) and discuss common themes.

Four Forces of Nature

Highlight the incredible fact that only four forces govern the entire universe. Prompt students to learn more about the four fundamental forces at the links below.

Michio Kaku and Bill Nye on the 4 Forces of Nature (video, 2:53)

https://www.youtube.com/watch?v=R9FVFh3HYaY

Hyperphysics: Fundamental Forces

http://hyperphysics.phy-astr.gsu.edu/hbase/forces/funfor.html

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

4.2 Newton's Second Law

Key Concept
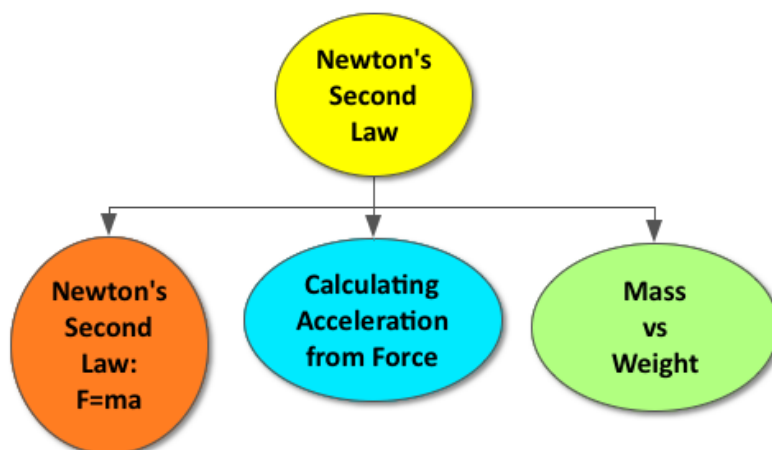
A net force on an object produces an acceleration that is dependent upon the object's mass. Newton's second law of motion states that an object's acceleration is proportional to the net force acting on an object and inversely proportional to the object's mass (F_{net} = ma). The mass of an object is a scalar quantity, measured in kilograms, referring to the amount of matter in an object. Weight is a vector quantity, measured in Newtons, depending upon "g"- the acceleration due to gravity.

Lesson Objectives

The student will:

- Define Newton's Second Law and net force.
- Calculate acceleration from force and mass.
- Calculate force from acceleration and mass.
- Calculate mass from force and acceleration.

Equations

- $\Sigma F = F_{net} = ma$

- <u>Newton's Second Law</u>: The acceleration, *a*, of an object is directly proportional to the net force, ΣF, upon it and inversely proportional to its mass, *m*.

Quick Write

Prompt students to complete a 4-minute quick write to answer the two questions below:

- How do you think the mass of an object is related to its acceleration?
- How do you think the force applied to an object is related to its acceleration?

Force (Weight vs Mass): Newton's 2nd Law

The link below describes an inquiry lab activity that prompts students to apply Newton's Second Law of Motion and examine the relationship between mass, force and acceleration. This activity also highlights the difference between mass and weight.

http://www.cpalms.org/Public/PreviewResourceLesson/Preview/51128

Peer Teaching

Give students time to answer the following two practice problems individually. Provide the answer key to the class and have students check their own work. Pair each student up and have them alternate between tutor and tutee, explaining the step-by-step guide of how to answer each question.

Prompt: NASA's Curiosity Rover landed on Mars on August 6th, 2012, in order to conduct a variety of experiments to determine if the planet could have once harbored life. The rover weighs 8990 N on Earth and 3326 N on Mars.

1. What is the mass of the Curiosity Rover?
2. Answer Key:
3. W = mg

    - W = 8990 N on Earth
    - g = 10 N/kg on Earth
    - m = ??

4. 8990 N = (m)(10 N/kg)
5. m = 899 kg
6. What is the gravitational constant "g" on Mars?
7. Answer Key:
8. W = mg

    - W = 3326 N on Mars
    - m = 899 kg (mass stays constant)
    - g = ??

9. 3326 N = (899 kg)(g)

10. g
11. *Mars*
12. = 3.7 N/kg

For more information on the Curiosity rover, check out the link below:

http://www.nasa.gov/mission_pages/msl/index.html#.VAkiW2SwJfI

Your Weight on Other Worlds

Direct students who need more help understanding the difference between mass and weight to the website below.
http://www.exploratorium.edu/ronh/weight/

Exit Slip

Pass out index cards to the students and ask them to write their response to the following prompt on the card. Collect the cards as students exit the classroom and assess.

Prompt: What does F_{net} = ma mean? What does each variable stand for? What are the units for each variable? *(Refer to sample answers).*

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook.* You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

4.3 Newton's Third Law

Key Concept
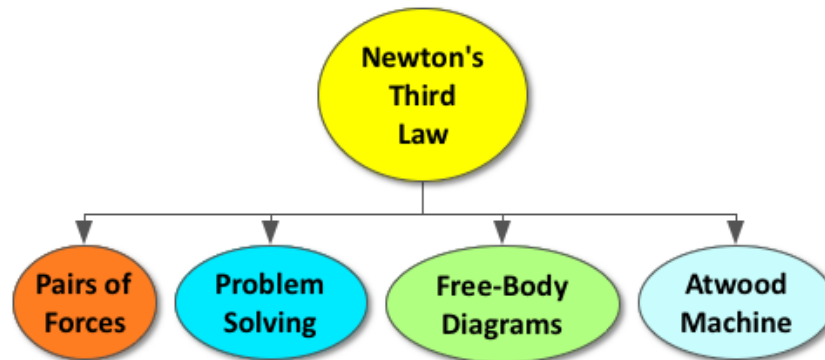
Newton's third law of motion states that whenever two objects interact, object 1 will exert a force on object 2 that is equal in magnitude but opposite in direction to the force exerted on object 1 by object 2. This is called an action-reaction pair and can be applied when solving problems. A free-body diagram is also helpful in solving problems in order to illustrate all of the forces acting on an object.

Lesson Objectives

The student will:

- Understand Newton's Third Law.
- Understand the difference between countering forces and action-reaction pairs.
- Use Newton's three laws to solve problems in one dimension.

Lesson Vocabulary

center of mass
    The point at which all of the mass of an object is concentrated.
dynamics
    Considers the forces acting upon objects.
free-body diagram (FBD)
    A diagram that shows all of the forces that act upon an object/body.

Equations

- $\Sigma F = F_{net} = ma$
- <u>Newton's Third Law</u>: Whenever two objects interact, they must exert equal and opposite forces upon each other.

Think*Pair*Share

Allow students time to think about the question below on their own, share their answer with the person next to them, and then discuss as a class.

Prompt: While driving on the highway, a semi truck hits a fly. Who experiences the greater force: the fly or the semi truck? Why? [*Correct Answer: According to Newton's third law of motion, they must experience a contact force equal in magnitude and opposite in direction.*]

Use this activity to introduce **action-reaction pairs**. Let's say the semi-truck was moving leftward (negative force vector), the fly was moving rightward (positive force vector), and the magnitude of their contact force was 900 N. The semi truck would experience a contact force of -900 N as a result of contact with the fly. The fly would experience a contact force of +900 N as a result of contact with the semi truck. The reason the fly goes "splat" and the semi truck continues moving unfazed is due to Newton's second law: F_{net} = ma. The semi truck's weight is very large (~90,000 N), so its acceleration due to the force of the fly will be extremely small. The fly's weight is very small (~0.002 N), so its acceleration will be extremely large. The fly's acceleration will actually be so large that it will cause the fly to "splat" against the window.

Push me, Pull You: Newton's Third Law [C Head] The link below describes an inquiry lab activity that prompts students to investigate Newton's Third Law of motion and addresses many misconceptions regarding action-reaction pairs.

http://physics.doane.edu/hpp/Library/Materials/A21SG.pdf

Whiteboarding: Free-Body Diagrams

Break students up into pairs and provide each pair with a whiteboard and dry-erase markers. Students should sketch a free-body diagram to address the following question:

Prompt: What forces are acting on you? *(Refer to sample answers).*

Countering Forces vs Action-Reaction Pairs

Be sure to highlight that countering forces are different from action reaction pairs.

Action-reaction force pairs meet the following criteria:

1. <u>Are the same type of force</u>

    2. <u>Act on different objects</u>
    3. Equal in magnitude
    4. Opposite in direction

Countering forces on an object at rest or moving with a constant velocity are equal in magnitude and opposite in direction, but they act on the same object and are different types of forces.

For example: If I am standing still on the Earth, the following free-body diagrams illustrate all of the forces acting on me and all of the forces acting on the Earth.
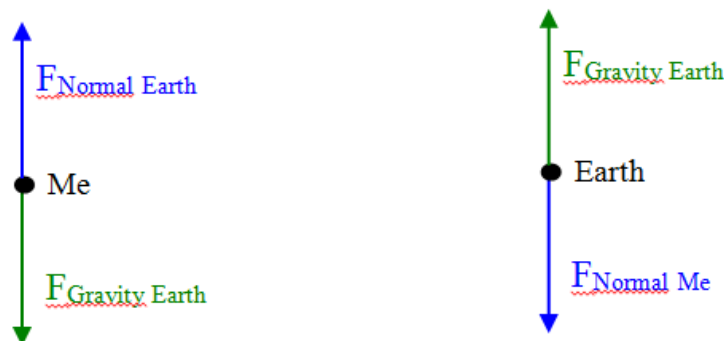
- Action-Reaction Pair #1: The $F_{Normal\ Earth}$ pushing up on me and the $F_{Normal\ Me}$ pushing down on the Earth

    - These are action-reactions pairs because they:
        * Are same type of force: Normal Force
        * Act on different objects: The Earth and Me
        * Equal in magnitude: Same Size arrows
        * Opposite in direction: Pointing different directions

- Action-Reaction Pair #2: The $F_{Gravity\ Earth}$ pulling down on me and the $F_{Gravity\ Me}$ pulling up on the Earth

    - These are action-reactions pairs because they:
        * Are same type of force: Gravitational Force
        * Act on different objects: The Earth and Me
        * Equal in magnitude: Same Size arrows
        * Opposite in direction: Pointing different directions
    - **Students often have a hard time believing that they pull up on the Earth with a force of gravity. This could be a good time to discuss what gravity is. (Here is link to a great video to aid in your discussion:

https://www.youtube.com/watch?v=mezkHBPLZ4A)

- The normal force and gravitational force on me are countering forces. They are equal in magnitude and opposite in direction, but they are NOT an action-reaction pair. The normal force and gravitational force are being exerted on the *same* object.

IOW

Prompt students to write out each of Newton's three laws of motion in their own words and include an example for each law. Students can then turn to the person next to them and compare their laws and examples.

Misconception Survey

Students should review their initial answers to the survey given at the beginning of the lesson and make any changes they feel necessary. At the end of the lesson, you should post the answer key and dispel any common misconceptions as a class.

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

Chapter Test

Copy and distribute the Chapter 4 Test using the *CK-12 Physics Intermediate Quizzes and Tests* link.

CHAPTER **5** Forces in Two Dimensions

Chapter Outline

Chapter Overview
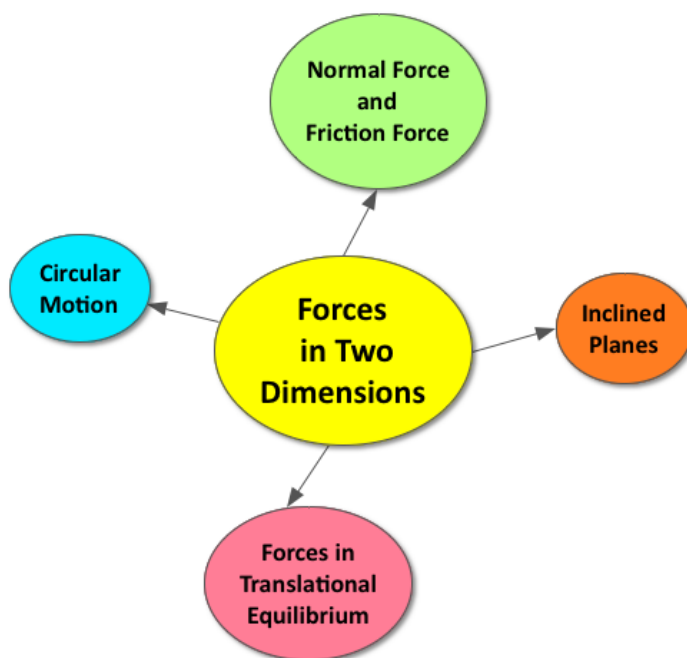
Just as two-dimensional motion refers to the simultaneous movement in both the horizontal and vertical dimensions, forces at an angle have both an x and y component. These dimensions are still independent of each other; what happens in one dimension does not have an affect on the other. Vectors and trigonometric functions can be used to analyze forces in two dimensions.

Online Resources

The Electromagnetic Repulsion of Contact Forces

The following links would aid in describing the electromagnetic repulsion of contact forces (such as normal, friction, and tension).

http://www.pbs.org/wgbh/nova/physics/fabric-of-cosmos.html

https://www.youtube.com/watch?v=yE8rkG9Dw4s

https://www.youtube.com/watch?v=yQP4UJhNn0I

https://phet.colorado.edu/sims/friction/friction_en.html

Hyperphysics

The link below is a wonderful simulation for students who are visual learners and need more practice with the normal force and the force of friction.

http://hyperphysics.phy-astr.gsu.edu/hbase/frict.html

Video Hooks

The videos below would be great hooks to get students excited about the real world applications of forces in two dimensions.

https://www.youtube.com/watch?v=K0-GxoJ_Pcg&app=desktop

https://www.youtube.com/watch?v=2V9h42yspbo

Apps

ShowMe Interactive Whiteboard

The link to the App below can be used to create voiceover whiteboard tutorials and share them online. Students can create their own explanations of concepts learned in class or teachers can create short tutorials to share with their students.

http://vimeo.com/38003641

https://itunes.apple.com/us/app/showme-interactive-whiteboard/id445066279?mt=8

TABLE 5.1: Pacing The Lessons

Lesson	Class Periods (60 min)
Lesson 5.1 Normal Force and Friction Force	3
Lesson 5.2 Inclined Planes	2
Lesson 5.3 Circular Motion	2
Lesson 5.4 Forces in Translational Equilibrium	3

5.1 Normal Force and Friction Force

Key Concept
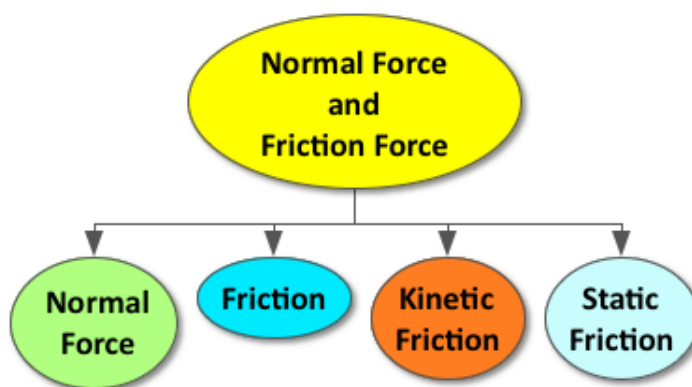
When two surfaces come into contact, a normal force (F_n) exists between them. The direction of the normal force is always perpendicular to the surfaces. Friction force is another contact force that exists when two surfaces slide past each other. The direction of the friction force is always parallel to the surfaces and opposes the direction of motion. The force of friction depends on the material of the surfaces in contact, represented by the coefficient of friction (mu, μ). The force of friction also depends on how much the surfaces are pressed against each other, which equates to the normal force between the two surfaces. The force of static friction (F_s) exists when two objects are not yet sliding against each other and the equation is $F_s = \mu_s F_n$. The force of kinetic friction exists when two objects are sliding against each other and the equation is $F_k = \mu_k F_n$. In order to get an object to start sliding, the applied force must be greater than the maximum static friction force. The force needed to get an object to start sliding is always greater than the force needed to keep an object sliding. As a result, the force of static friction is always greater than the force of kinetic friction.

Lesson Objectives

The student will:

- Understand how to solve problems involving the normal force.
- Understand how to solve problems involving friction.

Lesson Vocabulary

friction
> A force that opposes two objects sliding against each other. Friction acts in a direction along the flat surface of an object.

normal force
> The force exerted by the ground or another object that prevents an objects from going through it.

vector components
> The different parts of a two-dimensional vector. For example, a vector can be split into its component along the x-axis and its component along the y-axis.

Equations

- F_n = Normal Force
- F_s = Force of Static Friction
- F_k = Force of Kinetic Friction
- μ_s = Coefficient of Static Friction
- μ_k = Coefficient of Kinetic Friction
- $F_s = \mu_s F_n$
- $F_k = \mu_k F_n$

"What does a bathroom scale actually measure?"

You can use this question to ignite a class discussion, introducing aspects of the normal force and reviewing Newton's laws of motion. *(Refer to sample answers).*

Use this discussion to highlight that the force due to gravity on Earth never changes, but the normal force can change based on Newton's laws of motion.

Would you weigh less in an elevator?

Show this video to wrap up your discussion on the normal force and provide students some other points to consider.

http://ed.ted.com/lessons/would-you-weigh-less-in-an-elevator-carol-hedden

Optional Activity: If there is an elevator in your school that students are permitted to use, you can prompt students to stand on a bathroom scale in the elevator and witness the normal force change while the elevator accelerates up and down.

Mu Shoe Physics Lab

In this lab from the Physics Classroom, students are prompted to determine the coefficient of static friction for a variety of athletic shoes. This activity is a great way to connect the physics of friction and its real world application.

http://www.physicsclassroom.com/getattachment/lab/newtlaws/nl9tg.pdf

PhET: Forces and Motion

This simulation would be a great resource for students struggling to understand the connection between an applied force and the opposing force of static and kinetic friction.

http://phet.colorado.edu/en/simulation/forces-and-motion

3-2-1 Exit Slip

Pass out index cards to the students and ask them to write their response to the following prompt on the card. Collect the cards as students exit the classroom and assess.

Prompt: What are

- 3 things you learned?
- 2 facts you found interesting?
- 1 question you still have?

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

5.2 Inclined Planes

Key Concept
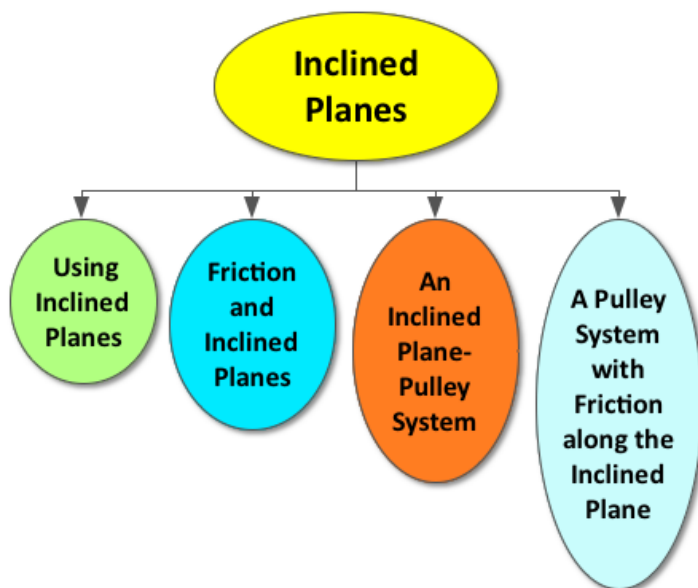
The forces acting on an object on an inclined plane are two-dimensional. It is important to always separate the forces into their corresponding horizontal (x) and vertical (y) components. Newton's laws can still be applied to an object on an inclined plane. However, students must solve for both the net force in the horizontal (x) dimension and the net force in the vertical dimension (y). These two dimensions remain independent from each other.

Lesson Objectives

The student will:

- Understand how to analyze and work with forces on inclined planes.
- Understand how to apply Newton's Second Law to the inclined plane problems.

Lesson Vocabulary

inclined plane
Any flat surface tilted at an angle to the horizontal.

Equations

- $F_x = mg \sin \theta$
- $a = g \sin \theta$

Mass Doesn't Matter

This real world application, presented by CK-12, is a great way to inspire students to learn more about the two dimensional forces involved with inclined planes.

http://www.ck12.org/physics/Inclined-Plane/rwa/Mass-Doesnt-Matter/

PhET: Ramp Forces and Motion

Prompt students to explore the forces involved with pushing an object up an inclined plane. Students are able to manipulate the angle of inclination and visualize the effect on the force vectors.

http://phet.colorado.edu/en/simulation/ramp-forces-and-motion

Whiteboarding: Problem-Solving

Divide students into groups of 3-4 and provide each group with a whiteboard and dry erase markers. Prompt each group to solve the following problem on their whiteboards using their understanding of Newton's laws of motion and forces in two dimensions.

Prompt: A 50 kg snowboarder is sliding down an inclined plane angled 20 degrees above the horizontal. The snowboarder accelerates at 2 m/s^2. What is the magnitude of the force of friction on the snowboarder? *(Refer to sample answers).*

Problem-Solving Narration

Prompt each group to create and record a two-minute narration of how to solve the inclined plane problem above.

Optional: Students can use the ShowMe App on their iPhone, iPod Touch, or iPad to do this activity. See the App descriptions in the chapter overview for more information.

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

5.3 **Circular Motion**

Key Concept
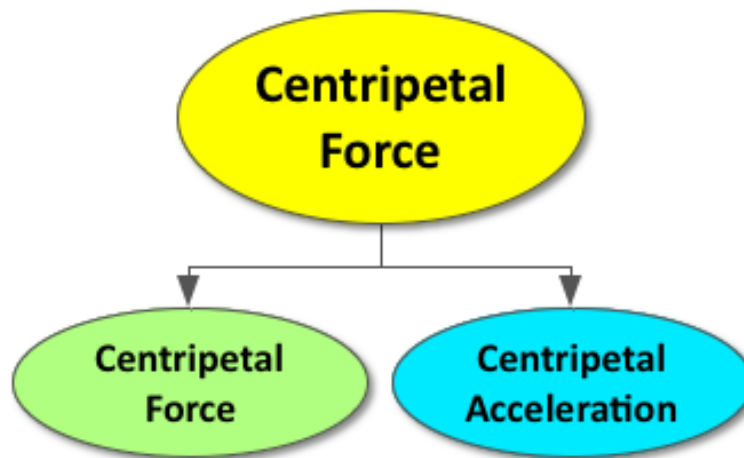
In order for an object to move in a circle, it must experience a net force pointing toward the center of the circle. This is referred to as a centripetal force. As a result of the centripetal force, objects with circular motion are always accelerating. The centripetal acceleration is also always directed toward the center of the circle. Even if the object is traveling around the circle with a constant speed, the direction of its motion is always changing. The velocity vector of an object moving in a circle is always tangent to the circle.

Lesson Objectives

The students will:

- Understand that in circular motion there is always a force (and hence an acceleration) that points to the center of the circle defined by the object motion. This force changes the direction of the velocity vector of the object but not the speed.
- Understand how to calculate the velocity of an object in circular motion using the period of motion and the distance of the object's path (circumference of the circle it traces out).

Lesson Vocabulary

centripetal acceleration
> The inward acceleration that keeps an object in circular motion.

centripetal force
> The inward force that keeps an object in circular motion

Is There Gravity in Space?

Inspire students to begin thinking about objects with circular motion, such as the International Space Station, by showing this video. Also, take some time to dispel common misconceptions regarding weightlessness or zero gravity in space as addressed in the video.

https://www.youtube.com/watch?v=d57C2drB_wc

CK-12: Newton's Cannon Simulation

Prompt students to use this simulation to explore how a satellite stays in orbit.

http://ck12-simulations.s3.amazonaws.com/simulations/physics/newtons-cannon/app/index.html?source=ck12Launcher&backUrl=http://ck12-simulations.s3.amazonaws.com/simulations/launcher-2.0/index.html&artifactID=1234

Real World Applications of Centripetal Motion

Challenge students to apply what they have learned regarding centripetal force and centripetal acceleration to explain the circular motion of a new real-world example. Break students up into groups of 3-4 and provide each group with a whiteboard. Prompt students to draw a free-body diagram including all of the forces acting on the object, the velocity vectors at a few different points on the objects path, and a sentence describing the object's acceleration.

Example of objects with circular motion:

- Tetherball
- Bobsled
- Roller Coaster Loops
- The Moon's Orbit
- Satellites

When each group has finished, place all the whiteboards at the front of the room and highlight that in every situation, the object moving in a circle meets the following criteria:

- The net force on the object is centripetal.
- The object's velocity is perpendicular to the centripetal force (tangent to the circle).
- The direction of the velocity is always changing (constant acceleration).

Points to Consider

Why does the tetherball get higher when the tetherball gets faster?

Tether Ball:

http://ck12-simulations.s3.amazonaws.com/simulations/physics/tetherball/app/index.html?source=ck12Launcher&backUrl=http://ck12-simulations.s3.amazonaws.com/simulations/launcher-2.0/index.html&artifactID=1234

What keeps a bobsled on the track?

Bobsled:

http://ck12-simulations.s3.amazonaws.com/simulations/physics/bobsled/app/index.html?source=ck12Launcher&backUrl=http://ck12-simulations.s3.amazonaws.com/simulations/launcher-2.0/index.html&artifactID=1234

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook.* You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

5.4 Forces in Translational Equilibrium

Key Concept
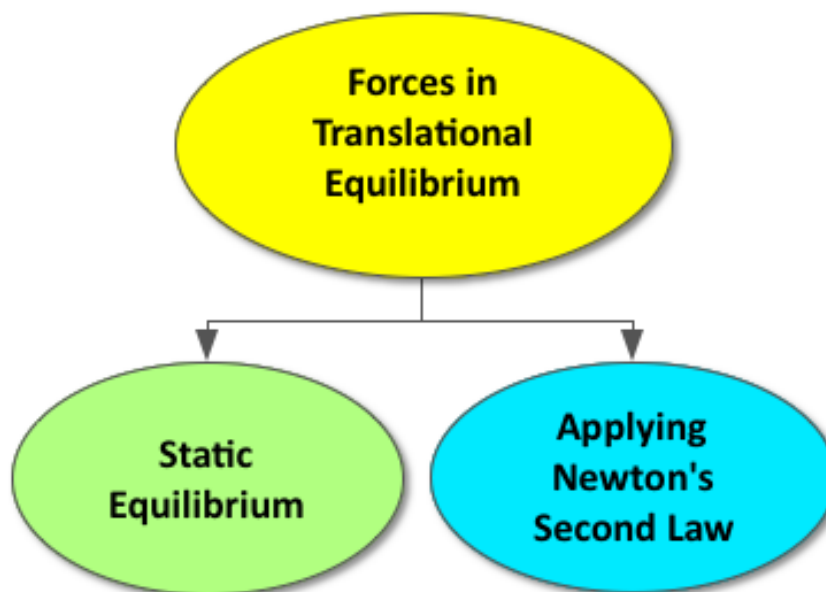
When the all the forces acting on an object in both the horizontal (x) and vertical (y) dimensions are balanced, the forces are said to be in translational equilibrium. Objects that are in static equilibrium are at rest and will remain at rest according to Newton's laws of motion.

Lesson Objectives

The student will:

- Understand how to apply Newton's Second Law under equilibrium conditions in two dimensions.

Lesson Vocabulary

static equilibrium
        Objects in static equilibrium are motionless.

A New Angle on Force

Enable students to recognize the two-dimensional forces prevalent in our everyday lives by showing them these images at the beginning of the lesson.

https://www.flickr.com/photos/physicsclassroom/galleries/72157624753355321/

Inquire

Prompt students to apply Newton's Second Law under equilibrium conditions in two dimensions with the simulation below.

http://ck12-simulations.s3.amazonaws.com/simulations/physics/portrait-gallery/app/index.html?source=ck12Launcher &backUrl=http://ck12-simulations.s3.amazonaws.com/simulations/launcher-2.0/index.html&artifactID=1234

Solution Sandwich

Have students fold a notebook paper in half. Prompt them to write the steps to solving problems regarding forces in translational equilibrium on the left side and exemplify the steps on the right side.

Relating Science to Engineering

Connect science and engineering with the project described at the following link.

http://www.teachengineering.org/view_activity.php?url=collection/cub_/activities/cub_staticcrane/cub_staticcrane_- activity1.xml

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link. link.

Chapter Test

Copy and distribute the Chapter 5 Test using the *CK-12 Physics Intermediate Quizzes and Tests* link.

CHAPTER **6**

Work and Energy

Chapter Outline

Chapter Overview
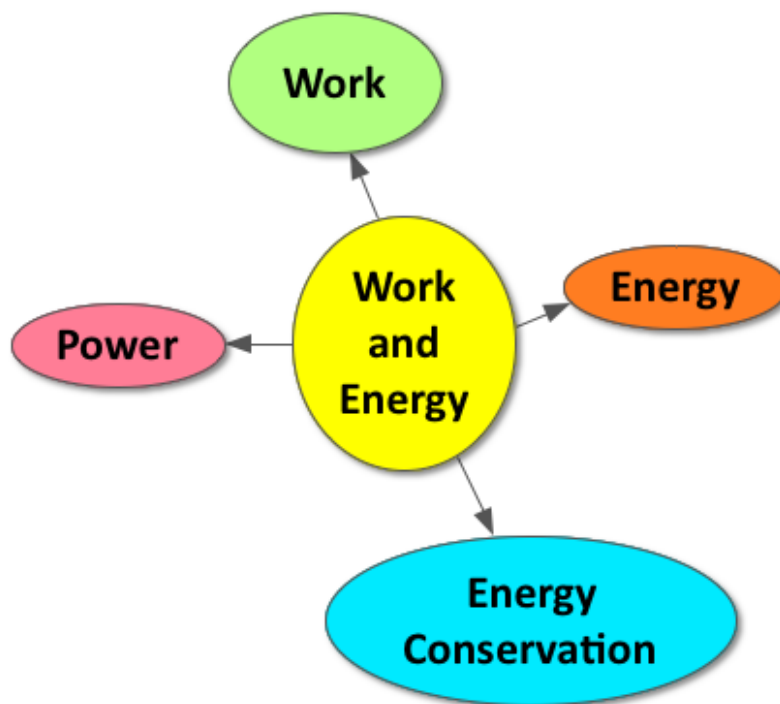
In physics, work means to apply a force over a distance. By doing work, we can transfer energy into a system. Energy, or the ability to do work, is an important concept in physics. We can store energy to do work for us later. The energy stored in motion is called kinetic energy. The energy stored due to a height above the earth is called potential energy. The energy stored in the bonds of an elastic object, such as a rubber band or spring, is called potential spring energy. Both work and energy are measured in Joules. Power is the rate at which work is done or the use of energy over time and is measured in Watts.

Online Resources

Virtual Lab

What is the relationship between work, force and distance? The link below provides an online activity that introduces students to the scientific definition of work and allows them to explore the relationship between work, force, and distance.

http://www.glencoe.com/sites/common_assets/science/virtual_labs/E13/E13.html

Simple and Complex Machines

The website below is a great resource for students who need more practice with simple machines. There are also links to student worksheets and teacher lesson plans on the site.

http://sunshine.chpc.utah.edu/Labs/Machines/index.html

PhETs

The links below provide wonderful simulations for students who are visual learners and need more practice with Conservation of Mechanical Energy.

http://phet.colorado.edu/en/simulation/the-ramp

http://phet.colorado.edu/en/simulation/energy-skate-park

CK12 Physics Interactive Simulations

The links below are great for students interested in exploring the real world applications of many of the core concepts introduced in this chapter.

http://interactives.ck12.org/simulations/physics/bow-and-arrow/app/index.html?source=ck12Launcher&backUrl=http://interactives.ck12.org/simulations/?backUrl=http://www.ck12.org/teacher/

http://interactives.ck12.org/simulations/physics/trampoline/app/index.html?source=ck12Launcher&backUrl=http://interactives.ck12.org/simulations/?backUrl=http://www.ck12.org/teacher/

http://interactives.ck12.org/simulations/physics/high-energy-particles/app/index.html?source=ck12Launcher&backUrl=http://interactives.ck12.org/simulations/?backUrl=http://www.ck12.org/teacher/

http://interactives.ck12.org/simulations/physics/malt-shop/app/index.html?source=ck12Launcher&backUrl=http://interactives.ck12.org/simulations/?backUrl=http://www.ck12.org/teacher/

Apps

Coaster Physics

Students can use this app to build a roller coaster and then see graphs depicting the transformation between kinetic and potential energy throughout their ride.

https://itunes.apple.com/us/app/coaster-physics/id393340142?mt=8

TABLE 6.1: Pacing The Lessons

Lesson	Class Periods (60 min)
Lesson 6.1 Work	2
Lesson 6.2 Energy	2
Lesson 6.3 Energy Conservation	
Lesson 6.4 Power	

6.1 Work

Key Concept
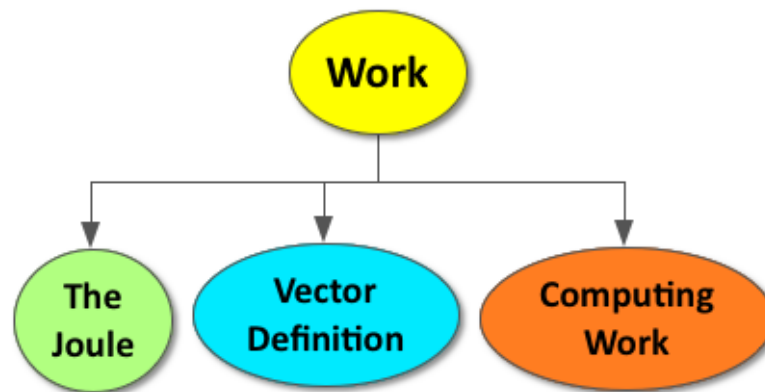
Whenever a force is applied to an object over a distance, work is done and energy is transferred. As a result, work and energy have the same units, the Joule. Force is a vector quantity, and the direction of the force on an object over a distance matters. Work can be calculated using the equation, $W = Fd * cos$, where θ is the angle between the force and the direction of the object's motion. The force required to move an object can be reduced by using a simple machine, which increases the distance over which the force is applied. The overall work will remain constant.

Lesson Objectives

The student will:

- Understand how work is defined in physics
- Be able to solve problems involving work

Lesson Vocabulary

scalar quantity
     Term used when referring only to magnitude.
work
     Force applied over a distance.

Equations

- $W = Fd * cos$

Quick Write

Prompt students to complete a 3-minute quick write to answer the two prompts below:

- List all the examples of simple machines you can think of.
- How do simple machines make our lives easier?

Ramp and Piano Simulation

Allow students to investigate the relationship between force and distance in a simple machine through this CK12 Simulation.

http://interactives.ck12.org/simulations/physics/ramp-and-piano/app/index.html?hash=bcfa0a8596ecc92590af33f22a01f6d9&artifactID=1742552&backUrl=http%3A//www.ck12.org/physics/Work/

Note: The four questions at the end of the simulation are great ways to extend the class discussion regarding the concept of force, distance, work and simple machines.

Inclined Plane Lab

Use this simple lab activity to enable students to further investigate how inclined planes allow us to manipulate the force needed to move an object a certain distance and the work involved.

http://sciencewithskinner.com/files/Eighth_Grade/MotionForces/inclinedplanes.pdf

At the end of the activity, prompt students to answer the following questions in their own words:

- How can force be manipulated using an inclined plane? *(Refer to sample answers).*

- What pattern do you observe regarding the force and distance in an inclined plane? *(Refer to sample answers).*

More Simple Machines

Challenge students to test if their conclusions regarding inclined planes apply to all simple machines.

Virtual Pulley http://www.compassproject.net/sims/pulley.html

CK12 Block and Tackle Simulation http://ck12-simulations.s3.amazonaws.com/simulations/repository/block-and-tackle/index.html#f00

Exit Slip

Pass out index cards to the students and ask them to write their response to the following prompt on the card. Collect the cards as students exit the classroom and assess.

Prompt: List all the ways you have done work today (in the scientific sense). *(Refer to sample answers).*

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook.* You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

6.2 Energy

Key Concept
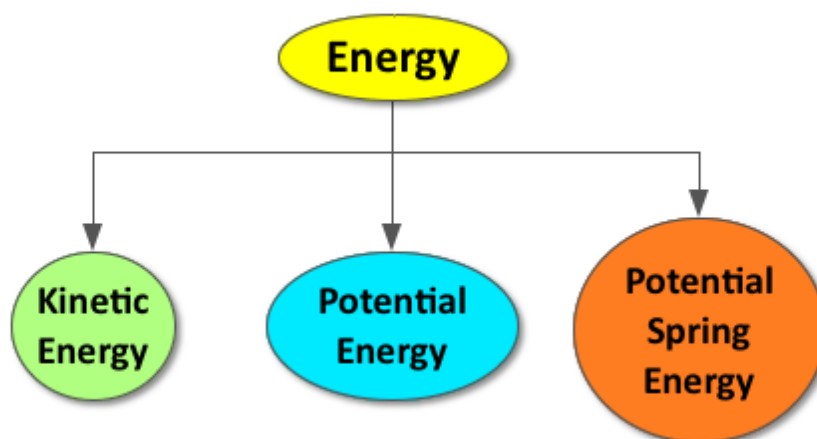
Energy is the ability to do work. When you do work on an object, you simultaneously transfer energy into the system. The energy can be stored in the system in a variety of forms and can be used to do work later. When a force is applied to move an object, the energy is transformed into kinetic energy (KE). When a force is applied to lift an object to a height above the Earth, the energy is transformed into potential energy (PE). When a force is applied to stretch a spring or other elastic object, energy is transformed into potential spring energy (PE$_s$).

Lesson Objectives

The student will:

- Understand the relationship between work and energy
- Be able to distinguish between kinetic and potential energy
- Understand the role of friction as it pertains to work and energy
- Be able to solve problems involving kinetic and potential energy and friction.

Lesson Vocabulary

energy

The ability to do an amount of work. Different forms of energy can do work indirectly.

kinetic energy

Energy of an object from its motion.

potential energy

Energy from an object's position.

Work-Energy Principle

The net work done on an object is equal to its change in kinetic energy.

Equations

- $KE = \frac{1}{2}mv^2$
- $W_{Net} = \Delta KE$
- $PE = mgh$
- $F_{spring} = k\Delta x$
- $PE_{spring} = \frac{1}{2}kx^2$

Elasticity of Rubber

Inspire students to think about why rubber stretches and the molecular structure of elastic objects by showing them the short video clip (1:25) at the link below.

https://www.youtube.com/watch?v=pWAvmQZjdXk

How does a spring scale work?

Prompt students to explore Hooke's Law and springs scales by completing the inquiry activity below.

http://www.batesville.k12.in.us/physics/phynet/mechanics/newton3/Labs/SpringScale.html

Optional: If you do not have access to the necessary lab equipment for the activity above or would rather do a virtual lab, the following two links provide online inquiry activities regarding potential spring energy.

http://www.4physics.com/phy_demo/HookesLaw/HookesLaw.html

http://phet.colorado.edu/en/simulation/mass-spring-lab

Whiteboarding

Divide students into groups of 3-4 and provide each group with a whiteboard and dry erase markers. Prompt students to create and complete the following chart on their wheteboards:

TABLE 6.2: Table 6.2 Whiteboarding

Symbol	Type of Energy	Equation	When is the energy present?	Units
W				
KE				
PE				
PE$_s$				

Sample Answer

TABLE 6.3: Table 6.2 Whiteboarding Answer

Symbol	Type of Energy	Equation	When is the energy present?	Units
W	Work	$W = Fd * \cos\theta$	When a force is applied over a distance	Joules, J
KE	Kinetic Energy	$KE = \frac{1}{2}mv^2$	When an object is in motion	Joules, J
PE	Potential Energy	$PE = mgh$	When an object is at a height above the ground (Earth's surface)	Joules, J
PE$_s$	Potential Spring Energy	$PE_{Spring} = \frac{1}{2}kx^2$	When a spring or elastic object (with an elastic constant, k) is stretched or compressed a certain distance (x)	Joules, J

Optional: Prompt students to take a picture of their whiteboards using their phones, iPads, etc for future reference. Students who take electronic notes can insert this image into their notes.

Problem Solving

Prompt students to apply the information from their chart above to solve the following problems:

A toy car has a mass of 2kg. It uses a spring with an elastic constant (k) of 40 N/m to launch into motion. When it is not being used, it rests on a shelf 1.5m above the ground.

- If the spring is compressed 0.01m, how much potential spring energy does the toy car have?
    - $PE_{Spring} = \frac{1}{2}kx^2$

- *Answer*: $\frac{1}{2}(40)(0.01^2) = 0.002\ J$

- If the toy car moves at 3 m/s, how much kinetic energy does the toy car have?
  - $KE = \frac{1}{2}mv^2$
  - *Answer*: $\frac{1}{2}(2\ kg)(3^2) = 9\ J$

- When the toy car is resting on the shelf, how much potential energy does the toy car have?
  - $PE = mgh$
  - *Answer*: $(2\ kg)(10\ N/kg)(1.5\ m) = 30\ J$

- How much work does it take to move the car from the ground onto the shelf?
  - $W = fd$
  - '*Answer*: $(20\ N)(1.5\ m) = 30\ J$

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook.* You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

6.3 Energy Conservation

Key Concept
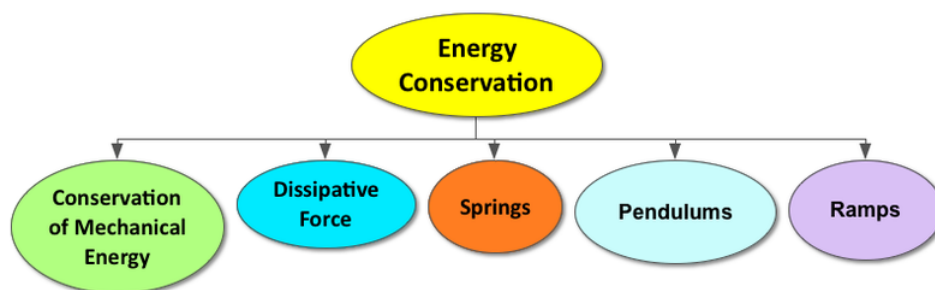
Mechanical energy is the energy due to an object's motion (kinetic energy) or an object's position (potential energy or potential spring energy). The total mechanical energy in a system is always conserved. Therefore, the total amount of kinetic and potential energy in a system will remain constant in the absence of friction.

Lesson Objectives

The student will:

- Understand the meaning of energy conservation.
- Be able to use energy conservation in solving problems.

Lesson Vocabulary

Conservation of Mechanical Energy
    The total of kinetic energy and potential energy in a system remains constant as long as there are no dissipative forces or interaction with outside the system.
Conservation Principle
    A conserved quantity is a quantity where the total cannot increase or decrease.
dissipative forces
    Forces such as friction that change mechanical energy into other types of energy, such as heat energy.

Equations

- $KE_i + PE_i = KE_f + PE_f$

Kings Dominion Mindbug: Potential and Kinetic Energy

Address the misconception (or "mindbug") that energy is used up along a roller coaster ride by showing students this short video (2:58).

https://www.youtube.com/watch?v=Bf_PAldyYxk

Roller Coaster Simulation

Allow students to explore how the Conservation of Energy applies to roller coasters. Students can investigate the relationship between the work done, potential energy, kinetic energy, heat and total energy of a roller coaster through this interactive simulation.

http://interactives.ck12.org/simulations/physics/roller-coaster/app/index.html?source=ck12Launcher&backUrl=http://interactives.ck12.org/simulations/?backUrl=http://www.ck12.org/teacher/

Roller Coaster of Doom

Divide students into groups of 3-4 and provide each group with a whiteboard and dry erase markers. Challenge each group to complete the following task:

- Create a roller coaster that meets the following parameters:

    – Maximum Cart Mass: 800kg
    – Maximum Track Height: 130m
    – Maximum Cart Speed: 50 m/s
    – At least 1 loop

- Calculate Total Mechanical Energy, Potential Energy, and Kinetic Energy at three points along your roller coaster.

Design a Virtual Roller Coaster

Students can use the following resources and apply their understanding of Conservation of Energy to design virtual roller coasters.

http://www.learner.org/interactives/parkphysics/coaster/

https://itunes.apple.com/us/app/coaster-physics/id393340142?mt=8

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

6.4 Forces in Translational Equilibrium

Key Concept
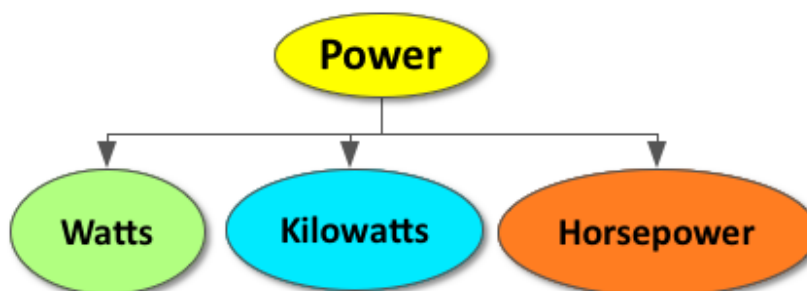
In physics, power is the rate at which work is done or the amount of energy consumed over time. Power is measured in Watts. A Kilowatt is 1000 Watts and one unit of Horsepower is equivalent to 746 Watts.

Lesson Objectives

The student will:

- Understand how power is defined in physics
- Be able to solve problems involving power

Lesson Vocabulary

power
    The rate at which work is done.

Equations

- $P_{avg} = \frac{W}{t}$

Think*Pair*Share

Allow students time to think about the question below on their own, share their answer with the person next to them, and then discuss as a class.

Prompt: Jack (mass = 60kg) runs up the hill and Jill (mass = 60kg) walks up the same hill.

- Which one does the most work? *(Refer to sample answers).*

- Which one uses the most power? *(Refer to sample answers).*

Powerhouse Lab

Prompt students to complete the inquiry lab activity below to determine the power they expend walking and running up a flight of stairs.

http://www.physicsclassroom.com/getattachment/lab/energy/e3tg.pdf

Horsepower

Using the data from the activity above, prompt students to calculate how much horsepower they expended in walking and running up the stairs.

No Simple Answer

Challenge advanced students to ponder the following question and provide their rationale, "How would riding a bicycle affect the power expended?".

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook.* You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

Chapter Test

Copy and distribute the Chapter 6 Test using the *CK-12 Physics Intermediate Quizzes and Tests* link.

CHAPTER 7

Momentum

Chapter Outline

Chapter Overview
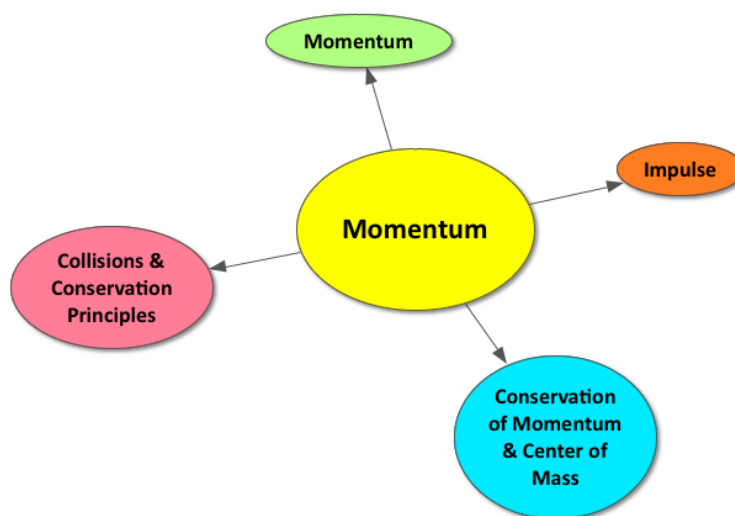
The momentum of an object depends on its mass and velocity. Momentum is a vector quantity and the direction of an object's momentum matters. When two objects collide, the momentum of each object changes due to a force exerted on each object over time, or an impulse. However, the total momentum of the system before the collision is the same as the total momentum of the system after the collision; the total momentum of a system is always conserved.

Online Resources

CK12 Momentum Study Guide

Students can download or print out this study guide for Newton's three laws of motion.

http://www.ck12.org/physics/Momentum/studyguide/Momentum-Study-Guide/

Crash Test Dummy CK12 Simulation

The link below allows students to explore the physics behind automobile collision safety systems.

http://interactives.ck12.org/simulations/physics/crash-test-dummy/app/index.html?source=ck12Launcher&backUrl=http://interactives.ck12.org/simulations/?backUrl=http://www.ck12.org/teacher/

APPS

Momentum & Collisions

This is an iBook from the Physics Classroom with student-friendly explanations of momentum and provides interactive collision problems for students who need more practice.

https://itunes.apple.com/us/book/momentum-and-collisions/id590264987?mt=13

TABLE 7.1: Pacing The Lessons

Lesson	Class Periods (60 min)
Lesson 7.1 Momentum	1
Lesson 7.2 Impulse	3
Lesson 7.3 Conservation of Momentum and Center of Mass	2
Lesson 7.4 Collisions and Conservation Principles	2

7.1 Momentum

Key Concept
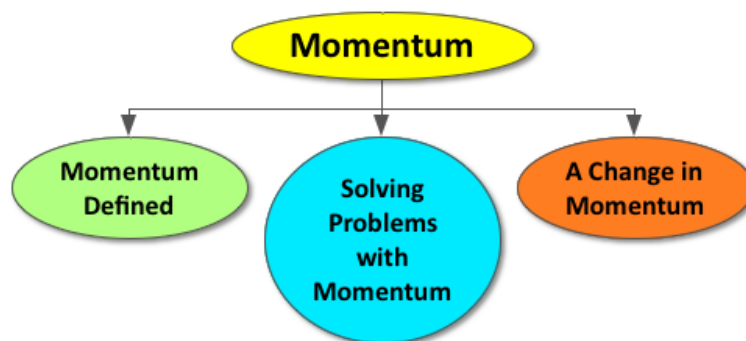
Momentum (p) is an object's tendency to stay in motion. An object's momentum is the product of its mass and velocity ($p = mv$). As a result, the momentum of an object is directly proportional to both its mass and its velocity. The standard units of momentum are $kg \cdot \frac{m}{s}$. Momentum is a vector quantity, in which the magnitude and direction of motion must be taken into consideration. The momentum of an object changes whenever the magnitude of its velocity changes, the direction of its velocity changes, or both occur.

Lesson Objectives

The students will:

- Know how momentum is defined
- Be able to solve problems using momentum

Lesson Vocabulary

momentum

An object's tendency to stay in motion, calculated as the product of its mass and velocity. Momentum has both magnitude and direction, so is a vector quantity.

Equations

- $\vec{p} = m\vec{v}$

Quick Write

Prompt students to complete a 3-minute quick write to answer the questions below:

- Provide an example of how we use the term momentum in our everyday lives.
- Do you think our everyday use of momentum is consistent with its scientific definition? *(Refer to sample answers).*

Use this prompt to highlight that the common use of the term "momentum" is very similar to its scientific definition.

Think*Pair*Share

Allow students time to think about the question below on their own, share their answer with the person next to them, and then discuss as a class.

Ask: Can a ping-pong ball (mass = 0.01 kg) and a bowling ball (5 kg) ever have the same momentum? *(Refer to sample answers).*

Whiteboarding

Provide each pair with a whiteboard and dry erase markers. Prompt each pair to provide mathematical evidence to support their claim above. *(Refer to sample answers).*

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook.* You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

7.2 Impulse

Key Concept
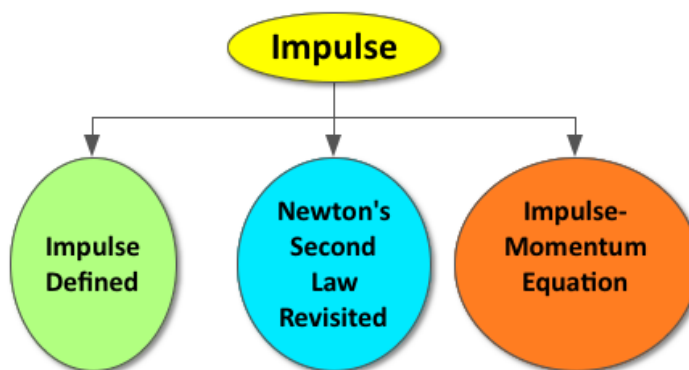
An impulse causes a change in an object's momentum and is equal to the magnitude and direction of that change ($\Delta p = p_f - p_i$). The impulse-momentum equation can be derived from Newton's Second Law and states that impulse is the product of force and the time over which the force is applied ($\Delta p = F \Delta t$). Force and time in the impulse-momentum equation are inversely proportional; by increasing one variable, you can decrease the other and the change in momentum will remain the same. There are many real-world applications for the impulse-momentum equation, such as the use of air bags and crumple zones in cars.

Lesson Objectives

The students will

- Learn the meaning of impulse force and how to calculate both impulse and impulse force in various situations.

Lesson Vocabulary

Impulse
The change in an object's momentum.

Equations

- $\Delta p = p_f - p_i$
- $\Delta p = F \Delta t$

Egg Toss

Use this fun activity to engage students in the study of impulse and allow them to explore the relationship between force and time in the impulse-momentum equation.

https://www.arborsci.com/Labs/NewCP_PDF/Mechanics/Egg_Toss.pdf

Egg Engineering –Save the Egg

Divide students into pairs and challenge them to apply their understanding of the impulse-momentum equation to complete this class project.

http://storyphysics.weebly.com/uploads/2/3/0/7/23078982/egg_drop_another_teachers_with_physics_infor.pdf

Making Real-World Connections

Challenge students to brainstorm situations in which the impulse-momentum equation is applied in the real world to decrease the force of impact by increasing the time over which the force is applied.

See the link below for some real-world examples:

http://www.physicsclassroom.com/class/momentum/Lesson-1/Real-World-Applications

Class Participation Reflection

At the end of this lesson, prompt students to reflect on their class participation by answering the following questions on a piece of paper and turning it in for your review.

1. Rate your participation in the Egg Engineering class project on a scale from 1-10. Explain the reason for your choice.
2. What was the most significant idea you contributed to your Egg Engineering project design?

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

7.3 Conservation of Momentum and Center of Mass

Key Concept
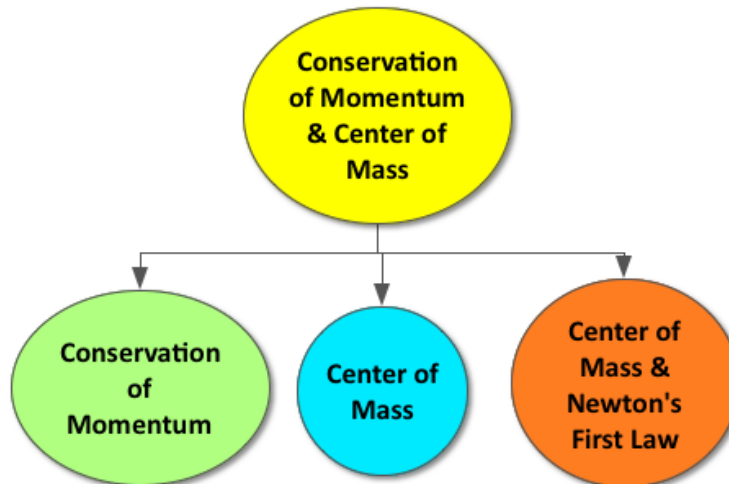
According to Newton's First Law, the total momentum of a system will stay the same if the net force on the system is zero. The total initial momentum of a system will equal the total final momentum of a system. The principle of conservation of momentum can be used to predict and analyze the resulting motion of interacting objects.

Lesson Objectives

The students will

- Understand conservation of momentum
- Be able to solve problems using the conservation of momentum
- Understand the motion of the center of mass of a system

Lesson Vocabulary

Center of mass
     The balancing point of a system, or the point at which all of the mass in a system is concentrated.
Conservation of Momentum
     The change in the total momentum of a system is zero.

Equations

- $p_i = p_f$

Circus Physics

Inspire students to think about some real world applications of the conservation of momentum by showing this video of a trapeze artist and discussing the provided questions as a class.

http://www.pbs.org/opb/circus/classroom/circus-physics/activity-guide-linear-momentum/

Momentum and Marbles

Enable students to actually visualize the conservation of momentum by completing the activity described at the link below.

http://www.fofweb.com/onfiles/seof/science_experiments/6-7.pdf

Peer Teaching

Give students time to answer the following conceptual physics problem individually. Pair students up and have them alternate between tutor and tutee, explaining the concept of conservation of momentum as it applies to the prompt below.

Prompt: Two friends, Shane (mass = 60 kg) and Brian (mass = 80 kg), perform an experiment related to momentum in their physics class. They each stand on identical skateboards, facing each other at rest, and then push off each other. Shane moves to the right and Brian moves to the left. Assume the force of friction on the floor is negligible.

Use the concepts from this lesson to answer the following questions:

1. Why did Shane and Brian move in opposite directions? *(Refer to sample answers).*

1. Why must they move at different speeds? *(Refer to sample answers).*

Teacher in Training

Prompt each student to write one physics problem related to the conservation of momentum on a piece of paper and provide the solution below it. Collect every student's question to use in one of the following ways:

- Exit Slip Question
- Warm-up Question
- Quiz/Test Question
- Extra Credit Question

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

7.4 Collisions and Conservation Principles

Key Concept
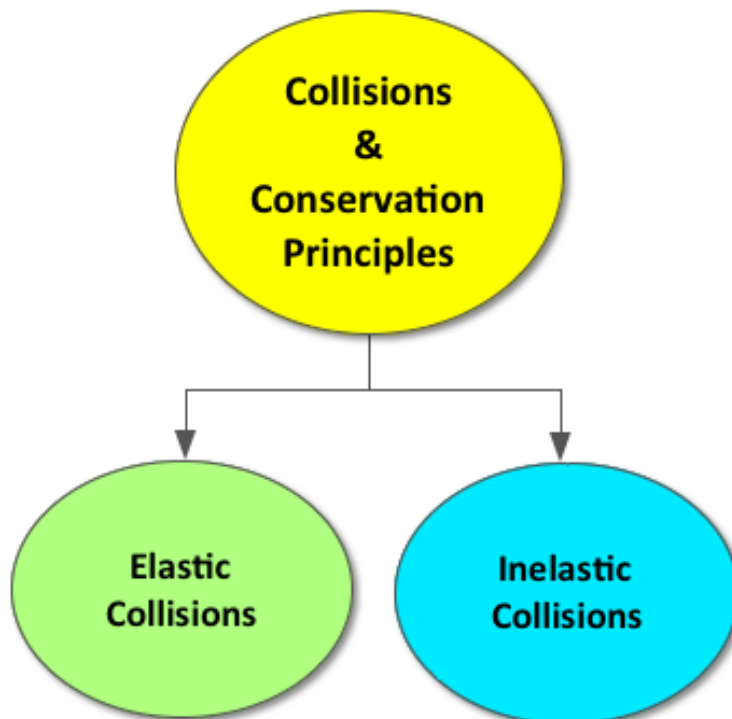
There are two types of collisions, elastic and inelastic. When two objects collide and bounce off each other, it is categorized as an elastic collision. When two objects collide and stick together, it is categorized as an inelastic collision. The difference between the two types of collisions has to do with the total kinetic energy of the system. In an elastic collision, it is assumed that the total kinetic energy of the system is conserved. In an inelastic collision, it is assumed that some kinetic energy is lost from the system and, therefore, not conserved. As a result, momentum is the best way to analyze all collisions, whether elastic or inelastic, because total momentum is always conserved.

Lesson Objectives

The students will

- Understand the difference between elastic and inelastic collisions.
- Be able to solve problems using both energy and momentum conservation.

Lesson Vocabulary

elastic collisions
    Collisions in which we assume the kinetic energy is conserved.
inelastic collisions
    Collisions where kinetic energy is not conserved.

Sport Science Explains Home Plate Collisions

Use this short video (2:29) to get students excited to learn about the physics of collisions.

http://espn.go.com/high-school/baseball/video/clip?id=6635515

Bumper Car Simulation

Allow students to explore how momentum and energy are exchanged in a bumper car collision. Use this simulation to differentiate between elastic and inelastic collisions.

http://interactives.ck12.org/simulations/physics/collisions/app/index.html?source=ck12Launcher&backUrl=http://interactives.ck12.org/simulations/?backUrl=http://www.ck12.org/teacher/

Brainstorm

Divide students up into groups of 3-4. Provide each group with a whiteboard and dry erase markers. Challenge each group to come up with a list of as many different types of collisions as possible in two minutes. *(Refer to sample answers)*.

Next, prompt students to categorize each of their collision examples on the whiteboards as elastic or inelastic.

Display all the whiteboards at the front of the classroom and engage in a discussion, highlighting the difference between elastic and inelastic collisions.

Newton's Cradle

Challenge advanced students to apply their understanding of conservation of energy and momentum to explain how a Newton's Cradle works.

Here are some links with virtual simulations of a Newton's Cradle, in case you do not have access to one in your classroom.

http://en.wikipedia.org/wiki/Newton's_cradle

http://www.school-for-champions.com/science/newtons_cradle.htm#.VCcdgStdX40'

Still Sticky

At the end of the lesson, pass out sticky notes to each student and provide them with the opportunity to write down any questions they still have or discuss concepts that are still unclear to them regarding momentum. Review the answers to common student questions with the class before the chapter test.

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook.* You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

Chapter Test

Copy and distribute the Chapter 7 Test using the *CK-12 Physics Intermediate Quizzes and Tests* link.

CHAPTER **8** # Angular Motion and Statics

Chapter Outline

Chapter Overview
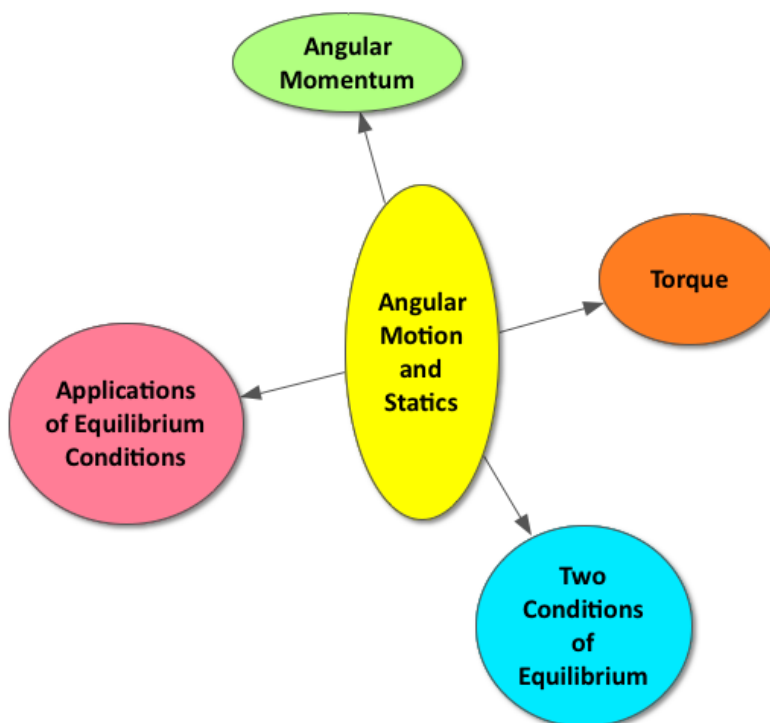
The angular momentum of a rotating object is dependent upon its rotational inertia and angular velocity. Although the rotational inertia and angular velocity of a rotating object can change, the overall angular momentum of an isolated system is conserved. For an object to begin to rotate, a torque must be applied. Torque is the product of the length of a lever arm and the perpendicular component of the force applied to the lever arm. By increasing the length of a lever arm, the force needed to turn an object can be reduced. In order for a system to achieve static equilibrium, it must be in both translational equilibrium ($\Sigma F_{net} = 0$) and rotational equilibrium ($\Sigma \tau_{net} = 0$).

Online Resources

Circular Motion Inquiry Activities

The following links provide additional inquiry activities related to circular motion.

http://www.pbs.org/opb/circus/classroom/circus-physics/activity-guide-conservation-angular-momentum/

http://www.arborsci.com/ArborLabs/PDF_Files/ASLab_102.pdf

http://serc.carleton.edu/sp/mnstep/activities/27399.html

Gyroscopes

The following links provide additional information related to gyroscopes.

http://spacestationlive.nasa.gov/educators/Physics-MC-ADCO-MC.pdf

http://www.gyroscopes.org/uses.asp

Torque

The following links provide additional information and activities related to torque.

http://tll.mit.edu/help/torque

http://teachers.egfi-k12.org/lesson-torque-in-daily-life/

PhET Simulations

The links below provide simulations for students who are visual learners and need more practice with torque.

http://phet.colorado.edu/en/simulation/balancing-act

http://phet.colorado.edu/en/simulation/torque

CK-12 Circular Motion Study Guide

Students can download or print out this study guide for circular motion.

http://www.ck12.org/physics/Torque/studyguide/Circular-Motion-Study-Guide/

TABLE 8.1: Pacing The Lessons

Lesson	Class Periods (60 min)
Lesson 8.1 Angular Momentum	3
Lesson 8.2 Torque	2
Lesson 8.3 Two Conditions of Equilibrium	2
Lesson 8.4 Applications of Equilibrium Conditions	3

8.1 Angular Momentum

Key Concept
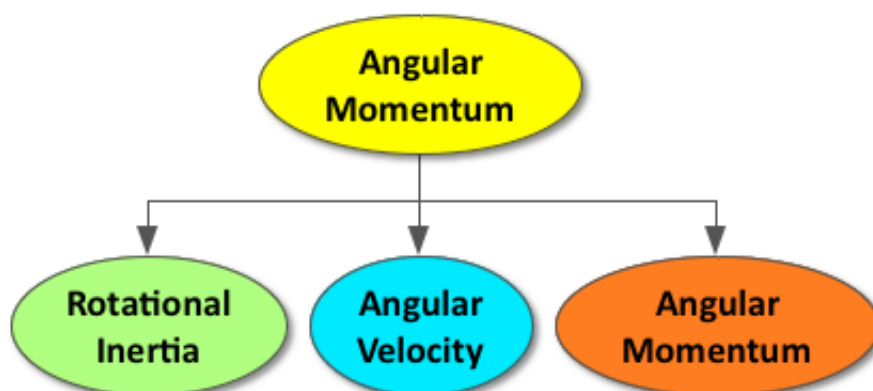
Similar to linear inertia, a non-rotating object will continue not rotating and a rotating object will continue rotating until acted upon by an outside force. The resistance to any change in rotational motion is referred to as rotational inertia, (I). The rotational inertia of a rotating object is directly proportional to the distance between its center of mass and its axis of rotation. As a result, a mass close to its axis of rotation is easier to turn than a mass far from its axis of rotation. Unlike linear inertia, the rotational inertia of a rotating object can change by simply moving the center of mass closer to or farther from its axis of rotation. Angular velocity, (ω), is the rate of rotation, measured in revolutions per second (rev/s) or radians per second (rad/s). Angular momentum is the product of rotational inertia and angular velocity ($L=I\omega$). Similar to linear momentum, the angular momentum of a system is always conserved ($I_i\omega_i=I_f\omega_f$). Unlike linear momentum, the rotational inertia can change, causing a change in angular velocity. Due to the conservation of angular momentum, rotational inertia and angular velocity are inversely proportional; as one increases, the other decreases, and the overall angular momentum remains the same.

Lesson Objectives

The student will:

- Understand what angular momentum is and how to use it in solving problems.

Lesson Vocabulary

angular momentum
> The product of rotational inertia and angular velocity.

angular velocity
> How quickly an object is turning.

axis of rotation
> The center around which an object turns, which might or might not be outside of the object.

radian
> The distance around the edge of a circle of radius 1.

revolution
> An object turning around a center that may or may not be outside of the object.

rotation
> An object turning without moving its center of mass, like a spinning top.

rotational inertia
> The difficulty required to turn an object.

Equations

- $L = I\omega$
- $I_i \omega_i = I_f \omega_f$

Spinning Pencil Inquiry

Instruct students to do the following:

1. Place a piece of scratch paper on their desks.
2. Take out a sharpened pencil
3. Try to spin the pencil (with the lead side touching the paper)

Then, discuss the following question as a class, "What things could you do to the pencil to make it spin longer?" Create a running list of student suggestions on the whiteboard and use these suggestions to introduce the concept of rotational inertia, angular velocity and the conservation of angular momentum.

Tinkering with Tops [C Head] Challenge students to design and build their own spinning tops by following the instructions at the website below.

http://www.tryengineering.com/lessons/tinkeringwithtops.pdf

Toy Gyroscopes

Provide each student with a note card and prompt them to apply their understanding of angular momentum to explain the gyroscopic effect of toys such as tops, yo-yo's or boomerangs.

If possible, build a bicycle wheel gyro or provide toy gyros for students to investigate before completing their note card.

http://www.exploratorium.edu/snacks/bicycle_wheel_gyro/

Gyroscopes in Space

Allow students to learn more about the real world applications of gyroscopes and how they are used to maintain the direction of a spacecraft, such as the International Space Station, by showing the short video (1:38) at the link below.

http://www.our-space.org/materials/states-of-matter/gyroscopes

Class Participation Reflection

At the end of this lesson, prompt students to reflect on their class participation by answering the following questions on a piece of paper and turning it in for your review.

1. Rate your participation in the "Tinkering with Tops" activity on a scale from 1-10. Explain the reason for your choice.
2. What was the most significant idea you contributed to your group?

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

8.2 Torque

Key Concept
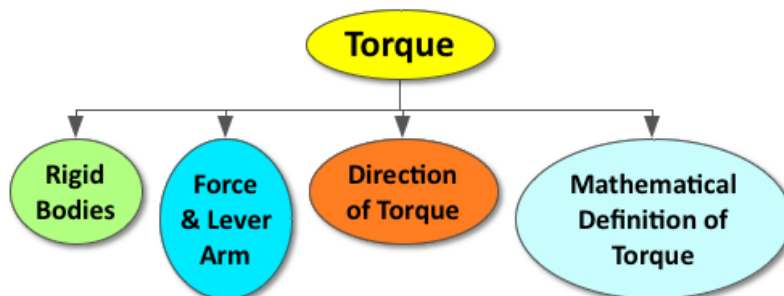
A rigid body is an idealized state in which an object experiences no deformation as a result of a net force. The difficulty related to rotating an object depends on the magnitude, direction and location of the force applied. The force needed to rotate an object can be manipulated by using a lever arm, sometimes referred to as a moment arm. A torque (τ) causes an object to rotate. Torque is the product of the length of a lever arm (r) and the force applied perpendicular to the lever arm (*Fsin*θ). Torque is a scalar quantity but causes objects to rotate in either counterclockwise (CCW) or clockwise (CW) direction. The mathematical definition of torque is $\tau = rFsin\theta$ and can be used to solve problems.

Lesson Objectives

The student will:

- Understand what torque is and how to use it in solving problems.

Lesson Vocabulary

axis of rotation
    A line drawn perpendicular to the plane of the object's rotation through the point about which the object rotates.

lever arm and moment arm
    The handle/arm of a wrench.

rigid bodies
    Objects that do not undergo any deformation when subject to a force (or forces). Rigid bodies are in an idealized state.

torque

> The component of a force applied perpendicular to a lever arm. Torque is the product of the length of a lever arm and the force applied perpendicular to a lever arm. Torque is a scalar quantity and can have clockwise or counter-clockwise direction.

Equations

- $\tau = rF\sin\theta$

Science of NFL Football: Torque and Center of Mass

Show students this short video (4:29) to get them excited to learn more about torque.

http://www.nbclearn.com/portal/site/learn/nfl/cuecard/51154/

CK-12: Seesaw Simulation

Prompt students to use this simulation to explore the concept of torque.

http://interactives.ck12.org/simulations/physics/see-saw/app/index.html?source=ck12Launcher&backUrl=http://interactives.ck12.org/simulations/

Torque Demo and Discussion

Allow students to observe the demo video at the link below and then complete the discussion questions provided alone or in pairs. Discuss the answers to the questions as a class.

http://www.pbslearningmedia.org/resource/lsps07.sci.phys.maf.torque/torque/ Points to Consider [C Head] Prompt advanced students to research the answers to the following student-generated discussion questions at the link below.

http://www.ck12.org/physics/Torque/cthink/Torque-Discussion-Questions/

Exit Slip

Pass out index cards to the students and ask them to write their response to the following prompt on the card. Collect the cards as students exit the classroom and assess.

Prompt: What are some ways you use torque in your everyday life? *(Refer to sample answers).*

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

8.3 Two Conditions of Equilibrium

Key Concept
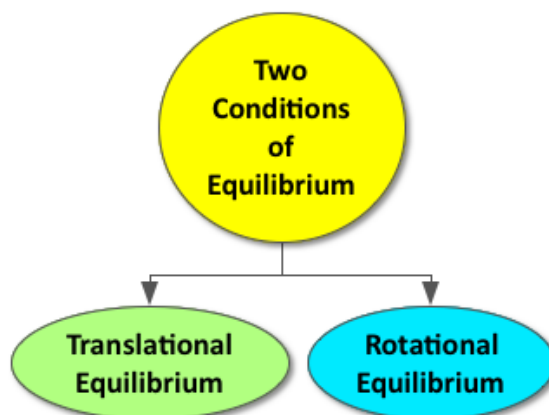
A system at rest is in static equilibrium. Static equilibrium is only achieved when a system has both translational and rotational equilibrium. As a result, both the net force and net torque of a system in static equilibrium must be zero.

Lesson Objectives

The student will:

- Understand the necessity for two conditions of equilibrium to ensure static equilibrium.

Lesson Vocabulary

rotational equilibrium
> A state in which net torque is equal to zero.

static equilibrium
> The state in which a system is stable and at rest. To achieve complete static equilibrium, a system must have both rotational equilibrium (have a net torque of zero) and translational equilibrium (have a net force of zero).

translational equilibrium
> A state in which net force is equal to zero.

Equations

- Translational Equilibrium: $\Sigma F_x = 0; \Sigma F_y = 0$
- Rotational Equilibrium: $\Sigma \tau = 0$

IOW

Prompt students to define the term "equilibrium" in their own words. Students can then turn to the person next to them and compare definitions.

∗∗Use this warm-up activity to introduce the concepts of static equilibrium, translational equilibrium, and rotational equilibrium.

Static Equilibrium Using a Meter Stick

Challenge students to place a meter stick in static equilibrium by following the lab instructions at the link below.

http://www.auburn.edu/academic/cosam/departments/physics/intro-courses/ugrad-lab/physics1500/activities/files/static%20equilibrium%20using%20a%20meterstick%20activity.pdf

SEE-I

Divide the class into groups of 3-4 students and provide each group with a whiteboard and dry erase markers. Demonstrate how to use the SEE-I method to clarify terms and show understanding (*see below for more information*). Prompt students to use the SEE-I method to describe the following scientific terms:

- Rotational Equilibrium
- Translational Equilibrium
- Static Equilibrium

Learn more about the SEE-I method by visiting the link below:

http://en.wikipedia.org/wiki/SEE-I

3-2-1 Exit Slip

Pass out index cards to the students and ask them to write their response to the following prompt on the card. Collect the cards as students exit the classroom and assess.

Prompt: What are

- 3 things you learned?
- 2 facts you found interesting?
- 1 question you still have?

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

8.4 Applications of Equilibrium Conditions

Key Concept
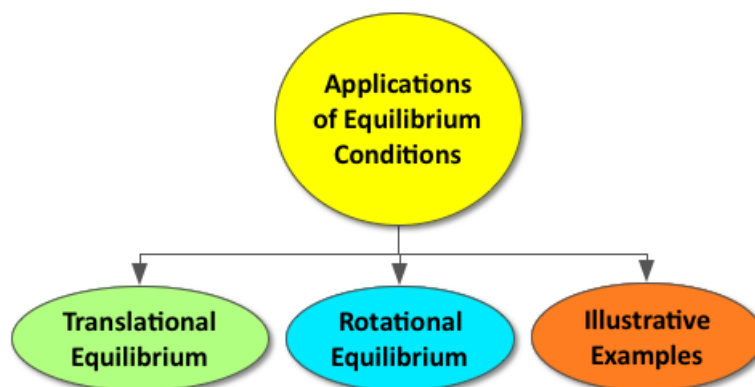
Descriptive Paragraph

Lesson Objectives

The student will:

- Use the conditions of equilibrium to solve problems.

Lesson Vocabulary

fulcrum/pivot
>   The point about which a seesaw rotates.

Equations

- Translational Equilibrium: $\Sigma F_x = 0; \Sigma F_y = 0$
- Rotational Equilibrium: $\Sigma \tau = 0$

Science and Engineering

Challenge students to consider the real-world applications of static equilibrium and apply lesson concepts to design a tower crane by following the instructions at the link below.

http://www.teachengineering.org/view_activity.php?url=collection/cub_/activities/cub_staticcrane/cub_staticcrane_-activity1.xml

Solution Sandwich

Have students fold a notebook paper in half. Prompt them to write the steps to solving problems regarding static equilibrium on the left side and exemplify the steps on the right side.

Peer Teaching

Give students some practice problems regarding translational, rotational, and static equilibrium. Pair each student up and have them alternate between tutor and tutee. Students should use their "solution sandwich" (from the activity above) to help them solve the problems.

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

Chapter Test

Copy and distribute the Chapter 8 Test using the *CK-12 Physics Intermediate Quizzes and Tests* link.

CHAPTER **9**

Newton's Universal Law of Gravity

Chapter Outline

Chapter Overview
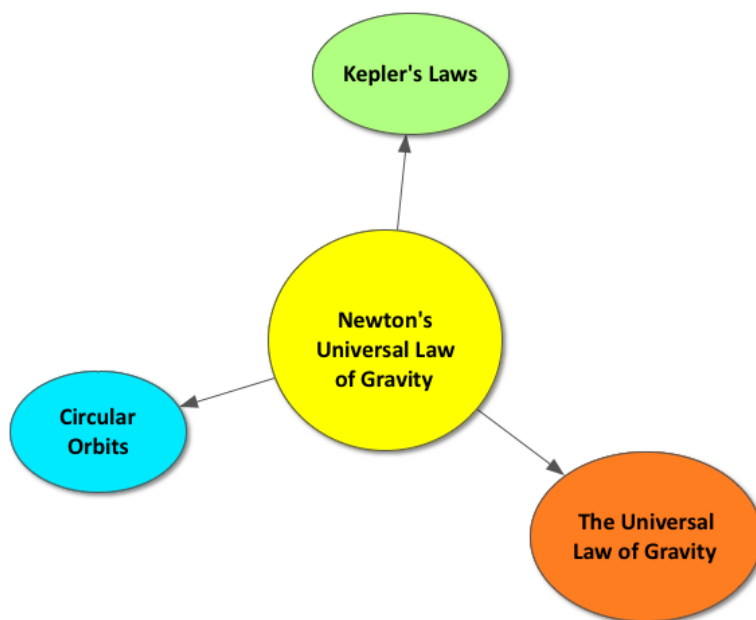
In the 17th century, Johannes Kepler wrote three laws of motion regarding the movement of the planets around the sun. Although these laws accurately described planetary motion, they did not provide an explanation as to why the planets moved as they did. Isaac Newton later proposed that the reason why planets orbited the sun was the same reason that objects fall to the ground on the Earth - simply due to the force of gravity acting on a massive object. Newton's Universal Law of Gravity states that all massive objects in the Universe pull on other massive objects with a force of gravity that is dependent on the masses of each object and the distance between their center of mass.

Online Resources

Physics Classroom: Circular Motion and Satellite Motion

This website provides a student friendly description of a variety of physical concepts, including circular motion and satellite motion.

http://www.physicsclassroom.com/class/circles/Lesson-4/Kepler-s-Three-Laws

PhETs

The links below provide alternative interactive simulations for students who are visual learners or need more practice with many of the concepts in this chapter.

My Solar System

http://phet.colorado.edu/sims/my-solar-system/my-solar-system_en.html

The Gravity Force Lab

http://phet.colorado.edu/en/simulation/gravity-force-lab

Gravity and Orbits

http://phet.colorado.edu/en/simulation/gravity-and-orbits

NASA: Earth Observatory

This website provides a great extension to the lessons in this chapter. The Earth Observatory's mission is to share the information collected from many of NASA's satellites with the general public.

http://earthobservatory.nasa.gov/?eocn=topnav&eoci=home

Apps

Circular Motion and Satellite Motion

This is an iBook from the Physics Classroom with student-friendly explanations of circular motion and provides interactive problems for students who need more practice.

https://itunes.apple.com/us/book/circular-motion-satellite/id660241927?mt=13

TABLE 9.1: Pacing The Lessons

Lesson	Class Periods (60 min)
Lesson 9.1 Kepler's Laws	3
Lesson 9.2 Newton's Universal Law of Gravity	3
Lesson 9.3 Circular Orbits	3

9.1 Kepler's Laws

Key Concept
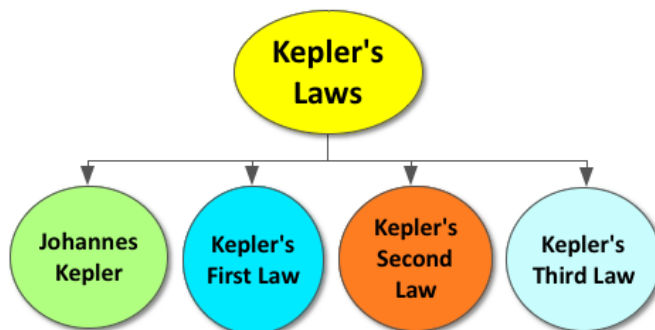
Johannes Kepler, a 17th century German mathematician and astronomer, wrote three laws of motion that describe the movement of planets around the sun. The first law describes the orbit of each planet as an ellipse with the sun as one focus point. The second law states that a planet will move at a greater rate when it is closer to the sun due to the fact that an imaginary line drawn from a planet to the sun will cover equal areas in equal time. The third law equates the square of the time for one orbital period of a planet (T) around the sun to the cube of the radius (r) between that planet and the sun ($T^2 \propto r^3$). The applications of Kepler's three laws have provided a solid foundation for modern science and can be used to solve problems involving planetary motion in physics and astronomy.

Lesson Objectives

The student will:

- Understand Kepler's Laws.
- Use Kepler's Third Law to solve problems.

Lesson Vocabulary

epicycle

geocentric
    A model of the planets in which Earth is at the center of all other planets.

heliocentric

The model of the planets in which all planets revolve around the Sun. This is the model that was eventually proven correct.

period

Equations

- $T_2 = kr_3$

Interactive Tour of the Solar System

Ignite student interest in learning about Kepler's laws of planetary motion by prompting the class to take this interactive tour of the solar system.

http://nineplanets.org/tour/

Kepler' Laws of Planetary Motion

This set of lesson plans from NASA enables students to discover Kepler's Laws by completing a variety of inquiry activities.

http://genesismission.jpl.nasa.gov/educate/scimodule/DestinationL1/DL1_PDFs/3_science/TGkeplerslaws2.pdf

IOW

Prompt students to write out each of Kepler's three laws of motion in their own words and include an example for each law. Students can then turn to the person next to them and compare their description of the laws and examples.

Planetary Orbit Simulator

The link below provides a great resource for visual learners needing more help understanding Kepler's Laws of Motion.

http://astro.unl.edu/naap/pos/animations/kepler.swf

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

9.2 Newton's Universal Law of Gravity

Key Concept
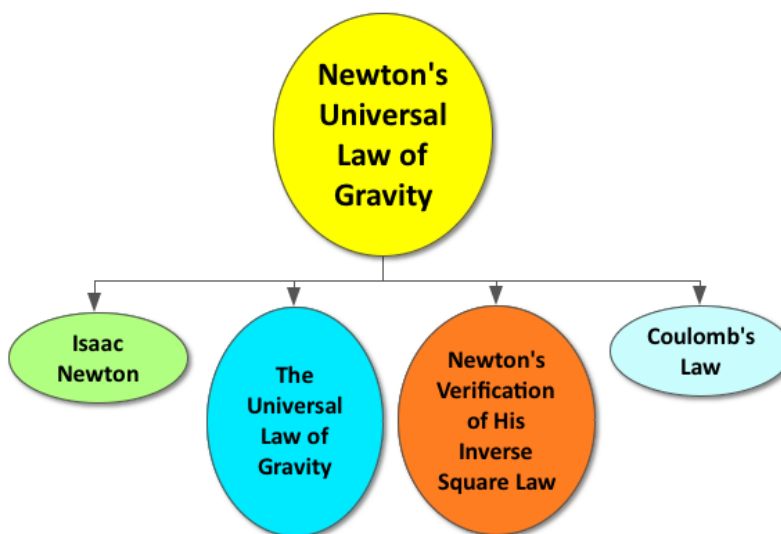
In his book, "Mathematical Principles of Natural Philosophy", Isaac Newton connected the force acting on an apple falling on the Earth and the force acting on the moon orbiting the Earth. Newton believed that all massive objects in the universe experience gravity. As a result, the force due to gravity is universal and can be defined as ($F = \frac{Gm_1m_2}{r^2}$). The Universal Law of Gravity is an inverse square law, similar to Coulomb's law for electrostatic force, ($F = \frac{kq_1q_2}{r^2}$).

Lesson Objectives

The student will:

- Understand Newton's Universal Law of Gravity.
- Use Newton's Universal Law to solve problems.

Lesson Vocabulary

- eccentricity
- empirical

Equations

- $F = \frac{Gm_1 m_2}{r^2}$
- $G = 6.67 * 10^{-11} \; \frac{N*m^2}{kg^2}$
- $F = \frac{kq_1 q_2}{r^2}$

Are Astronauts Weightless?

Begin this lesson by asking students to answer the following question, "Are astronauts weightless in space?" After collecting a few student responses, watch the short video (3:40) at the link below. Be sure to highlight Newton's Universal Law of Gravity and address the misconception that there is no gravity in space.

https://www.youtube.com/watch?v=iQOHRKKNNLQ

CK-12 Simulation: Newton's Apple

Prompt students to visualize the effects of Newton's Universal Law of Gravity on the motion of the moon and an apple by using this interactive simulation.

http://interactives.ck12.org/simulations/physics/newtons-apple/app/index.html?source=ck12Launcher&backUrl=http://interactives.ck12.org/simulations/?backUrl=https://ck12.org/student/

Whiteboard

Pair students up and challenge each group to create a whiteboard model describing the physics of the following:

- An apple as it falls to the Earth
- The moon as it orbits the Earth

The whiteboards should clearly illustrate any force acting on the objects and explain the reason for the motion of each object using words, pictures, free body diagrams and equations.

Optional: Prompt students to take a picture of their whiteboards with their phones or tablets for future reference. Students keeping an electronic notebook should insert this image into their notes.

Minute Physics: The Tides

Prompt advanced students to connect the Universal Law of Gravity and the motion of the tides by watching the short video (1:58) at the link below. https://www.youtube.com/watch?v=gftT3wHJGtg#t=55

Exit Slip

Pass out index cards to the students and ask them to answer the following prompt on the card. Collect the cards as students exit the classroom and assess.

- Prompt: Explain why "in free fall" is a better term to describe the astronauts on the International Space Station than "weightless". *(Refer to sample answers).*

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

9.3 Circular Orbits

Key Concept
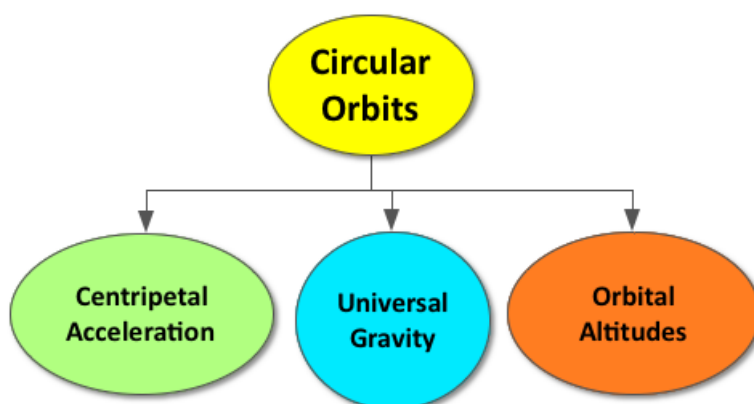
Although the orbits of the planets and moons are ellipses, the orbits of artificial satellites are circular. Problems involving circular motion require the consideration of both universal gravity and centripetal acceleration. The orbital altitudes of artificial satellites are categorized as low, medium, and high according to their distance from the surface of the Earth.

Lesson Objectives

The student will:

- Use Newton's Universal Law of Gravity and Kepler's Third Law to solve problems.

Lesson Vocabulary

- geosynchronous: An orbit where the satellite remains over the same position on the Earth.
- orbit: The path of one object revolving around the other, such as the Moon around the Earth, or the Earth around the Sun. Orbits can be circular or elliptical.

Equations

- $a_c = \frac{v^2}{r}$
- $r = R_e + h$
- $R_e = 6370\ km$

List of Satellites in Geosynchronous Orbit

As an introduction to this lesson, prompt students to read over the list of satellites in geosynchronous orbit at the link below.

http://en.wikipedia.org/wiki/List_of_satellites_in_geosynchronous_orbit

Optional: Ask students to write down 1-3 questions that arise as they read over the list. Then, select a few questions to answer as a class.

CK-12 Simulation: Clarke's Dream

Enable students to learn more about the geosynchronous orbit of a satellite and explore the best orbit for a communications satellite with this CK-12 interactive simulation.

http://interactives.ck12.org/simulations/physics/clarkes-dream/app/index.html?source=ck12Launcher&backUrl=http://interactives.ck12.org/simulations/?backUrl=https://ck12.org/student/

Peer Teaching

Provide students with practice problems involving circular motion. Pair each student up and have them alternate between tutor and tutee.

Flying Steady: Mission Control Tunes Up Aqua's Orbit

Prompt students to read this article depicting the real world applications of concepts introduced in this lesson regarding the orbital adjustment maneuver of NASA's Aqua satellite.

http://earthobservatory.nasa.gov/Features/OrbitsManeuver/

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

Chapter Test

Copy and distribute the Chapter 9 Test using the *CK-12 Physics Intermediate Quizzes and Tests* link.

CHAPTER **10**

Periodic Motion

Chapter Outline

Chapter Overview
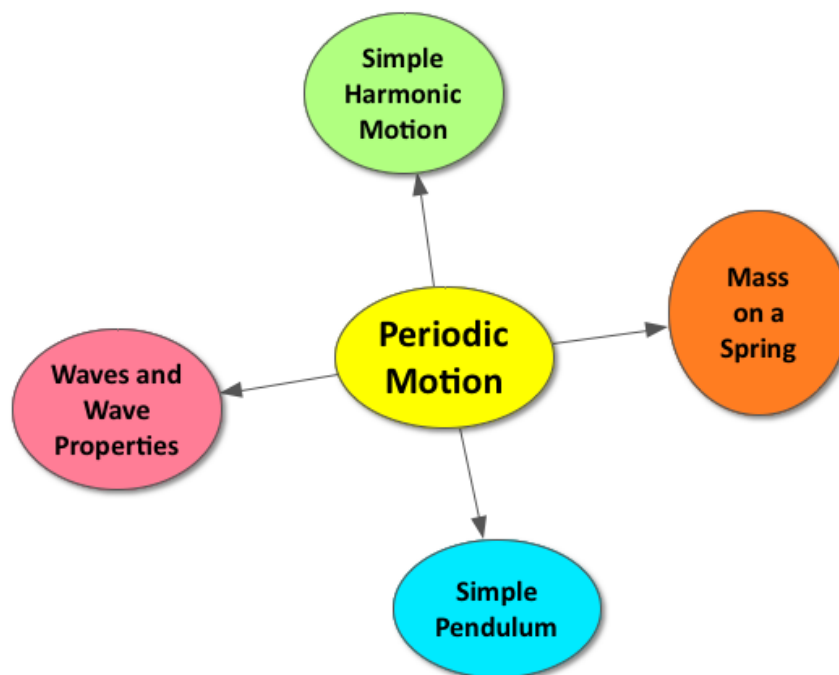
Periodic motion describes an object that repeats its path at regular time intervals. Simple harmonic motion is a type of periodic motion in which an object moves back and forth. A mass on a spring and a simple pendulum both exhibit simple harmonic motion. Properties of these systems include the period (T), the frequency, (f) and the amplitude (A). A wave also exhibits simple harmonic motion in that it causes the particles it moves through to vibrate back and forth. There are two types of waves, longitudinal and transverse. Properties of these waves include reflection, refraction, and diffraction.

Online Resources

CK12 Harmonic Motion Guide

Students can download or print out this study guide for harmonic motion.

http://www.ck12.org/physics/Springs/studyguide/Harmonic-Motion-Study-Guide/

Simple Harmonic Motion: Mass on a Spring Sensor Lab

The link below provides very detailed lab instructions to investigate the simple harmonic motion of a mass on a spring using lab sensors and computers.

http://teacher.nsrl.rochester.edu/PHYInq/Experiments/P19/P19_SHM_Mass_on_Spring.html

PBS: Virtual Pendulum

The link below provides great material for lower level classrooms (grades 5-8) or high school students needing more help with the simple harmonic motion of a pendulum.

http://www.pbslearningmedia.org/resource/phy03.sci.phys.mfw.zpendulumint/virtual-pendulum/

Circus Physics Pendulum

The following website provides amazing videos, discussion questions, practice problems and real world examples regarding pendulum motion.

http://www.pbs.org/opb/circus/classroom/circus-physics/pendulum-motion/

TABLE 10.1: Pacing The Lessons

Lesson	Class Periods (60 min)
Lesson 10.1 Simple Harmonic Motion	1
Lesson 10.2 Mass on a Spring	3
Lesson 10.3 Simple Pendulum	3
Lesson 10.4 Waves and Wave Properties	2

10.1 Simple Harmonic Motion

Key Concept
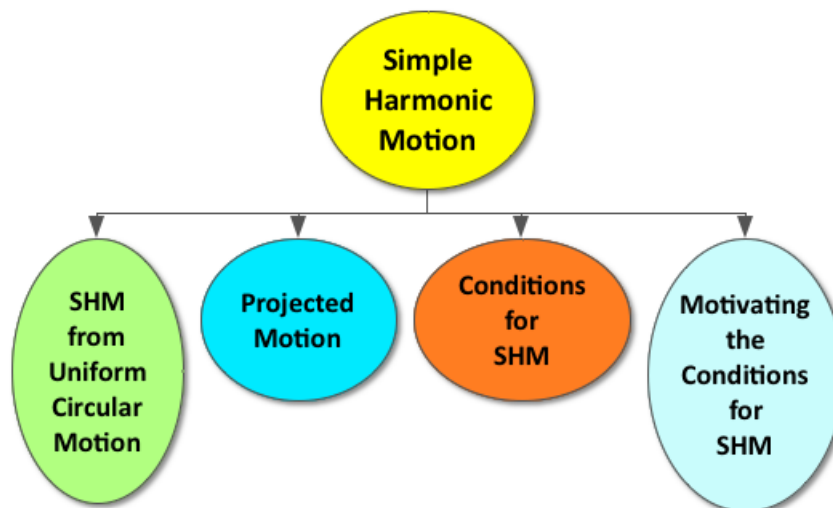
Periodic motion describes an object that moves along the same path at regular time intervals. Simple harmonic motion (SHM) is a special case of periodic motion in which an object moves back and forth. The two requirements of SHM are (1) a restorative force that is acting to return the object to its original position and (2) a point of equilibrium in which the object moves through. When an object in uniform circular motion is viewed in one dimension, it exemplifies SHM. A mass on a spring and a simple pendulum also exhibit SHM.

Lesson Objectives

The student will:

- Understand periodic motion.
- Understand simple harmonic motion.

Lesson Vocabulary

periodic motion
> Motion that repeats the same path at a regular time.

simple harmonic motion

A kind of one-dimensional (back-and-forth) periodic motion in which the farther the object moves from the center, the more it is pulled back toward the center.

Think*Pair*Share

Allow students time to think about Prompts A-C below on their own, share their answer with the person next to them, and then discuss as a class.

Prompt A: What does it mean for something to be *periodic*? *(Refer to sample answers).*
Prompt B: In one minute create a list of as many things you can think of that are periodic. *(Refer to sample answers).*
Prompt C: Based on our discussion of the term *periodic*, what do you think it means for something to have *periodic motion*? *(Refer to sample answers).*

Use this warm-up to introduce *simple harmonic motion* (SHM) as a special case of periodic motion in which an object moves back and forth, such as the motion of a child on a swing. Also, highlight the following two requirements of SHM:

1. There must be a restoring force, or a force returning the object to its original position, that is directly proportional to the displacement.
2. The object moves through a point of equilibrium.

Whiteboarding: SHM of a Child on a Swing

Break students up into groups of 3-4 and provide each group with a whiteboard and dry-erase markers. Revisit the example of the SHM of a child on a swing.

Using the child on the swing example and their whiteboards, prompt students to

- Create a sketch illustrating the SHM of a child on a swing
- Identify the restoring force
- Identify the point of equilibrium
- Sketch a graph depicting the child's position (x) over time (t)

Display all whiteboards at the front of the class and discuss common themes.

Optional: Prompt students to take a picture of their whiteboards with their phones or tablets for future reference. Students keeping an electronic notebook should insert this image into their notes.

Simple Harmonic Motion at the Exploratorium

If time allows, show the class this short video (2:55) to enable students to visualize how the SHM of a pendulum creates a sinusoidal wave.

https://www.youtube.com/watch?v=BRbCW2MsL94#t=29

Still Sticky

At the end of class, pass out sticky notes to each student and provide them with the opportunity to write down any questions they still have or discuss concepts that are still unclear to them regarding simple harmonic motion.

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

10.2 Mass on a Spring

Key Concept
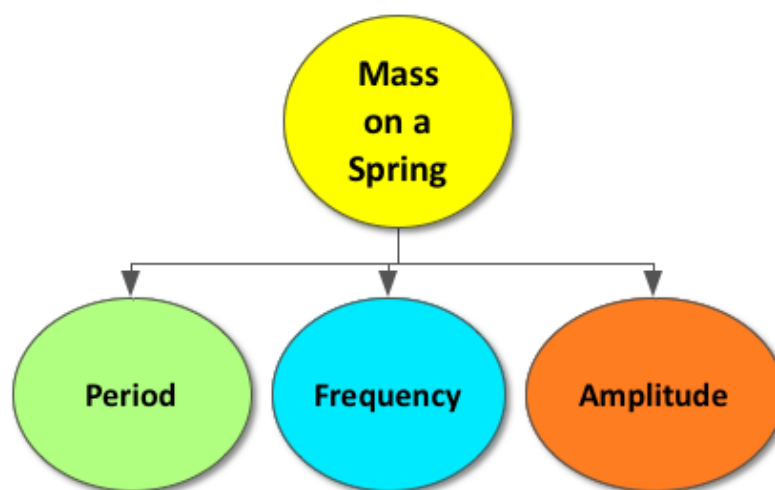
A mass on a spring has both a restoring force and moves through a point of equilibrium, making it a great example of an object with simple harmonic motion (SHM). The restoring force is directly proportional to the displacement and is pointed in the opposite direction of the displacement. As a result, the restoring force is always pulling the mass on the spring towards the point of equilibrium. The period (T) is the amount of time, in seconds, it takes for the mass-spring system to repeat its motion. The frequency (f) of the mass-spring system is the reciprocal of the period and is measured in Hertz (Hz). The amplitude (A) is the maximum distance of the mass-spring system from its point of equilibrium.

Lesson Objectives

The student will:

- Solve problems dealing with simple harmonic motion.

Lesson Vocabulary

Amplitude (A)
> The maximum distance from equilibrium of an object's periodic motion.

Frequency (f)
> The reciprocal of the period ($f = \frac{1}{T}$)

Hertz (Hz)
> Units used in place of revolutions per second, as well as cycles per second. Hertz is equivalent to $\frac{1}{s}$ cycle and revolution and has no SI units.

Period (T)
> The amount of time it takes an object to repeats its motion.

Equations

- $F_{spring} = kx$
- $f = 1/T$
- $T = 2\pi \sqrt{\dfrac{m}{k}}$

Blink Challenge

Inspire students to understand the meaning of the terms *frequency (f)* and *period (T)*, as well as derive an equation relating the two variables, by completing the class challenge below.

∗∗Highlight that a blink is an example of a cycle –you open your eyelid, close your eyelid, and open it again.

Prompt A: Try to blink as many times as possible in ten seconds. (The instructor should keep track of time and each student should keep track of how many times he or she blinks). *(Refer to sample answers).*

Prompt B: How many times did you blink per second? *(Refer to sample answers).*

> ∗∗Introduce this as the ***frequency (f)*** of blinks. Frequency is the amount of cycles per second (1/s), measured in Hertz (Hz).

Prompt C: How much time passed between each blink? *(Refer to sample answers).*

> ∗∗Introduce this as the ***period (T)*** of blinks. Period is the amount of time per cycle, measured in seconds (s).

Prompt D: Derive an equation that relates the frequency (f) and the period (T). *(Refer to sample answers).*

Mass-Spring System Inquiry

Introduce the class to a mass-spring system (have one set up at the front of the class, if possible). Then, prompt students to think about what variables affect the period (T) of the mass-spring system. Create a list on the board of these variables.

Divide students into pairs and prompt each pair to develop a hypothesis regarding one variable on the board and its effect on the period (T) of a mass-spring system. For example, "If the spring constant (k) increases, then the period of the mass-spring system will decrease". Remind students the importance of making their hypothesis a testable statement.

Allow students to test their hypothesis by using the Masses and Spring Simulation at the link below.

http://phet.colorado.edu/en/simulation/mass-spring-lab

Optional: Allow students to test their hypothesis on a real mass-spring system, if you have access to the necessary materials. An exemplary mass-spring lab experiment can be found at the link below.

http://www.pa.msu.edu/courses/2002spring/PHY251/Spring1.pdf

Whiteboarding

Prompt each pair from the inquiry activity above to create a whiteboard summarizing their hypothesis, experiment, and conclusions regarding a mass-spring system. Allow each group to share their whiteboards or display all whiteboards at the front of the class and highlight common themes.

**Be sure to highlight the following:*

- *The period (T) of a mass-spring system is only dependent on the mass (m) and the spring constant (k).*
- *As the mass of a mass-spring system increases, the period increases.'*
- *As the spring constant of a mass-spring system increases, the period decreases.*
- *As the amplitude of the mass-spring system increases, the period will stay the same.*

Motion of a Mass on a Spring

Direct students in need of additional help to the link below, which provides wonderful illustrations and explanations regarding the simple harmonic motion of a mass-spring system.

http://www.physicsclassroom.com/class/waves/Lesson-0/Motion-of-a-Mass-on-a-Spring

Class Participation Reflection

At the end of class, prompt students to reflect on their class participation by answering the following questions on a piece of paper and turning it in for your review.

1. Rate your participation in today's class on a scale from 1-10. Explain the reason for your choice.
2. What was the most significant idea you contributed to your group?

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

10.3 Simple Pendulum

Key Concept
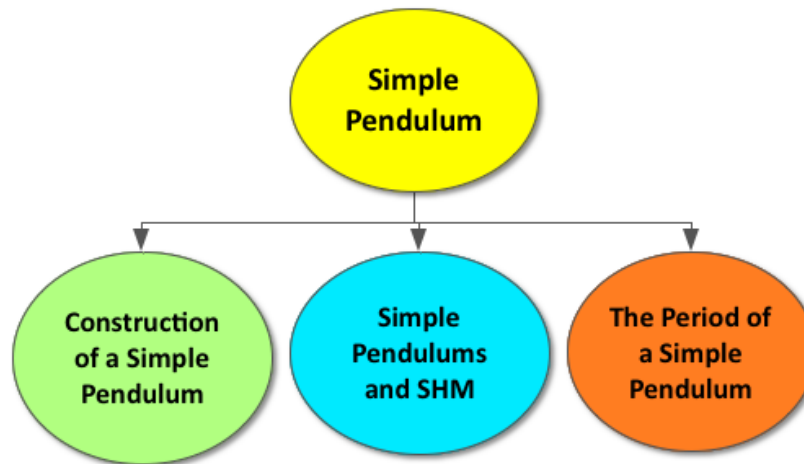
A simple pendulum is made up of a massive object hanging from a string fixed at one end. The massive object is referred to as a pendulum bob. When the pendulum bob experiences a displacement from its point of equilibrium, it will swing back and forth. A simple pendulum has both a restoring force and moves through a point of equilibrium, making it another great example of an object with simple harmonic motion (SHM). The restoring force is directly proportional to the displacement and is pointed in the opposite direction of the displacement. As a result, the restoring force is always pulling the pendulum bob towards the point of equilibrium. The period (T) is the amount of time, in seconds, it takes for a pendulum bob to complete one back and forth swing. The frequency (f) of the pendulum bob is the reciprocal of the period and is measured in Hertz (Hz). The amplitude (A) is the maximum distance the pendulum bob is moved from the point of equilibrium.

Lesson Objectives

The student will:

- Understand a simple pendulum.
- Solve problems involving a simple pendulum.

Lesson Vocabulary

simple pendulum
> Constructed by attaching any object to one end of a string and attaching the other end of the string to a fixed point, allowing them to swing back and forth.

Equations

- $T = 2\pi \ Lg$

Grandfather Clocks and Pendulums [C Head] Inspire students to gain interest in pendulums by completing the warm-up below and then discuss as a class.

∗∗Highlight that grandfather clocks are very tall (usually 6-8ft tall) clocks with a simple pendulum inside. If possible, display a picture for students to visualize or prompt them to read more information at the link below:

http://en.wikipedia.org/wiki/Longcase_clock

Prompt: A pendulum in a grandfather clock helps to keep time by swinging back and forth. When the pendulum bob reaches its maximum rightward displacement it "ticks" and when it reaches its maximum leftward displacement it "tocks". The total time it takes between a "tick" and a "tock" is exactly one second. This is how the clock keeps time.

- **What is the period (T) of the pendulum in a grandfather clock?** *(Refer to sample answers).*

- **What variables do you think affect the period (T) of the pendulum in a grandfather clock?** *Create a list of these variables on the board.*

Simple Pendulum Inquiry

Divide students into pairs and prompt each pair to develop a hypothesis regarding one variable on the board and its effect on the period (T) of a pendulum. For example, "If the length of the string increases, then the period of the pendulum will decrease". Remind students the importance of making their hypothesis a testable statement.

Allow students to test their hypothesis by using the Pendulum Simulation at the link below.

http://phet.colorado.edu/en/simulation/pendulum-lab

Optional: Allow students to test their hypothesis on a real pendulum, if you have access to the necessary materials. An exemplary pendulum experiment can be found at the link below.

http://isi.loyola.edu/lab/pendulum/pen1a.html

Whiteboarding

Prompt each pair from the inquiry activity above to create a whiteboard summarizing their hypothesis, experiment, and conclusions regarding a simple pendulum. Allow each group to share their whiteboards or display all whiteboards at the front of the class and highlight common themes.

**Be sure to highlight the following:*

- *The period (T) of a simple pendulum is only dependent on the length of the string (L) and the gravitational constant (g).*
- *As the length of the pendulum increases, the period increases.*
- *As the gravitational constant of the pendulum increases, the period decreases.*
- *As the mass of the pendulum bob increases, the period stays the same.*
- *As the amplitude of the pendulum increases, the period stays the same.*

Pendulum Motion

Direct students in need of additional help to the link below, which provides wonderful illustrations and explanations regarding the simple harmonic motion of a simple pendulum.

http://www.physicsclassroom.com/class/waves/Lesson-0/Pendulum-Motion

Exit Slip

Pass out index cards to the students and ask them to write their response to the following prompt on the card. Collect the cards as students exit the classroom and assess.

Prompt: What length pendulum will ensure that the time between a "tick" and a "tock" in a grandfather clock is exactly one second? *(Refer to sample answers).*

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

10.4 Waves and Wave Properties

Key Concept
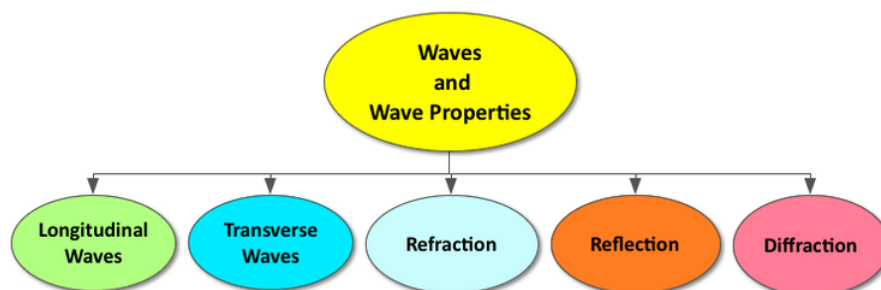
Waves transfer energy and cause particles to vibrate around a point of equilibrium. Therefore, we can classify waves as exhibiting periodic motion. Longitudinal waves cause particles to vibrate parallel to the direction of the traveling wave, such as with sound waves and earthquake P-waves. Transverse waves cause particles to vibrate perpendicular to the direction of the traveling wave, such as with light waves and earthquake S-waves. Although waves cause particles to vibrate back and forth, only energy is transferred and the particles experience no net displacement. The speed in which the wave travels depends upon the properties of the particles it travels through, commonly referred to as the medium. Waves can reflect (bounce), refract (bend), and diffract (spread out). These properties explain many everyday phenomena such as our reflection in a mirror, a ripple in a pond, and sound echoes.

Lesson Objectives

The student will:

- Be able to distinguish between types of waves.
- Be able to recognize the behavior of waves.

Lesson Vocabulary

diffraction
    The bending and stretching of waves.
longitudinal wave
    Consists of vibrations that are parallel to the wave direction.
reflection
    The process of light bouncing off boundaries between two media.

refraction
> The process of light bending.

transverse wave
> Consists of vibrations that are perpendicular to the wave direction.

Think*Pair*Share

Allow students time to think about the questions below on their own, share their answer with the person next to them, and then discuss as a class.

- What is a wave? *(Refer to sample answers)*.

- When a wave travels through a pool of water, how do the water molecules actually move? *(Refer to sample answers)*.

Stow Lake Simulation

Enable students to investigate waves and wave properties with the CK12 simulation below.

http://interactives.ck12.org/simulations/physics/stow-lake/app/index.html?source=ck12Launcher&backUrl=http://interactives.ck12.org/simulations/?backUrl=http://www.ck12.org/teacher/

SEE-I

Divide the class into groups of 3-4 students and provide each group with a whiteboard and dry erase markers. Demonstrate how to use the SEE-I method to clarify terms and show understanding (see below for more information). Prompt students to use the SEE-I method to describe the following scientific terms:

- Waves
- Longitudinal Waves
- Transverse Waves
- Reflection
- Refraction
- Diffraction

Optional: Prompt students to take a picture of their whiteboards with their phones or tablets for future reference. Students keeping an electronic notebook should insert this image into their notes.

Learn more about the SEE-I method by visiting the link below:

http://en.wikipedia.org/wiki/SEE-I

Making Waves

If possible, obtain a class set of toy slinkies. Divide students into pairs and challenge each pair to do the following:

- Move the slinky so that it creates a longitudinal wave.
- Move the slinky so that it creates a transverse wave

∗∗After you allow some time for the students to try to complete the challenge, have a class discussion about their conclusions. Highlight that in order to create a longitudinal wave, they should have moved the slinky parallel to the direction of the wave. In order to create a transverse wave, they should have moved the slinky perpendicular to the direction of the wave.

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

Chapter Test

Copy and distribute the Chapter 10 Test using the *CK-12 Physics Intermediate Quizzes and Tests* link.

CHAPTER 11 Vibrations and Sound

Chapter Outline

Chapter Overview
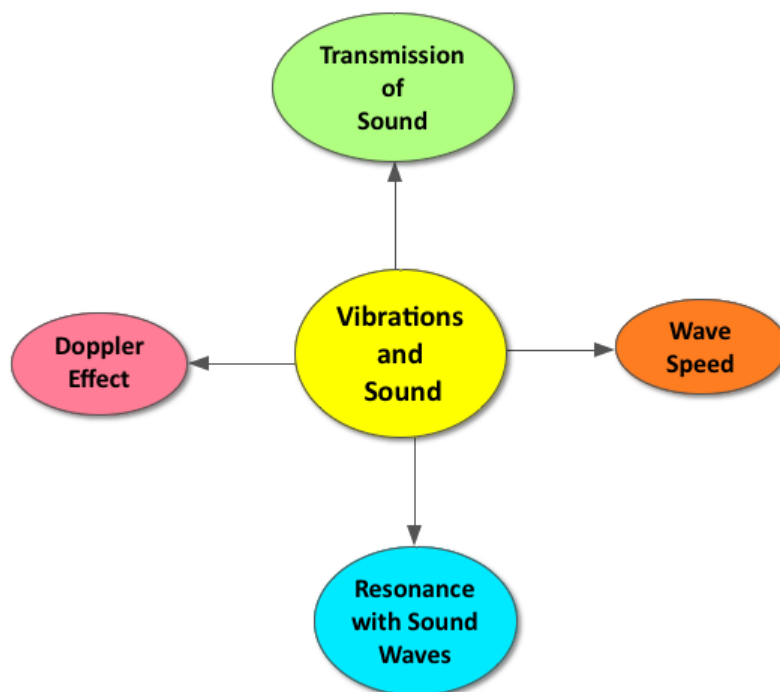
Sound waves are longitudinal waves that transfer energy from a vibrating source through a medium. Properties of a sound wave include amplitude, period, and frequency. In addition, sound waves have a wavelength and wave speed due to their movement through a medium over time. The speed of a wave in a medium is constant. When a wave travels from one medium to another, the frequency of the wave remains constant, and the wave speed and wavelength change. Sound waves in a medium can interfere to a produce wave with either a larger resultant amplitude (constructive interference) or a smaller resultant amplitude (destructive interference) in a process called superposition. Resonance occurs when a forced vibration on an object matches the object's natural frequency, causing a large increase in the amplitude of the wave. Harmonics refer to the resonance frequencies that produce standing waves. Most musical instruments made up of strings or tubes have multiple harmonics with wavelengths and frequencies that relate in a precise mathematical pattern. The Doppler effect describes the change in wave frequency as a result of the motion of the source, the receiver, or both.

Online Resources

Wolfram Demonstrations Project

Beats Working

This interactive demonstration will enable students to visualize how the similar wave frequency patterns result in beats and how these beats can be used in the process of tuning a musical instrument.

http://demonstrations.wolfram.com/BeatsWorking/

Speed of Sound

This interactive demonstrations allows students to experience how the speed of sound in air is dependent on temperature.

http://demonstrations.wolfram.com/SpeedOfSound/

Resonance in Open and Closed Pipes

This is a wonderful interactive demonstration regarding the standing waves that occur at certain harmonics in musical instruments.

http://demonstrations.wolfram.com/ResonanceInOpenAndClosedPipes/

PhETs

Wave Interference

This simulation allows students to create waves from a variety of sources, such as a dripping faucet or a radio speaker, and witness patterns of wave interference.

http://phet.colorado.edu/en/simulation/wave-interference

Resonance

This simulation is suitable for advanced students interested in discovering more regarding the concept of resonance.

http://phet.colorado.edu/en/simulation/resonance

Apps

Sound Uncovered

This is a wonderful App, by the San Francisco Exploratorium, with a variety of interactive modules enabling students to explore the concept of sound.

https://itunes.apple.com/au/app/sound-uncovered/id598835017?mt=8&ign-mpt=uo%3D2

Tone Generator

This App produces sound wave frequencies for class demonstrations regarding sound waves and wave interference.

https://itunes.apple.com/us/app/tone-generator/id457003837?mt=8

Video Physics

This App allows students to analyze the motion of an object on their iPhone, iPod Touch, and iPad. The App automatically creates position versus time and velocity versus time graphs for the object in motion and makes data sharing easy.

https://itunes.apple.com/us/app/vernier-video-physics/id389784247?mt=8

https://www.youtube.com/watch?v=ugfWRPORSNg

TABLE 11.1: Pacing The Lessons

Lesson	Class Periods (60 min)
Lesson 11.1 Transmission of Sound	3
Lesson 11.2 Wave Speed	2
Lesson 11.3 Resonance with Sound Waves	2
Lesson 11.4 Doppler Effect	2

11.1 Transmission of Sound

Key Concept
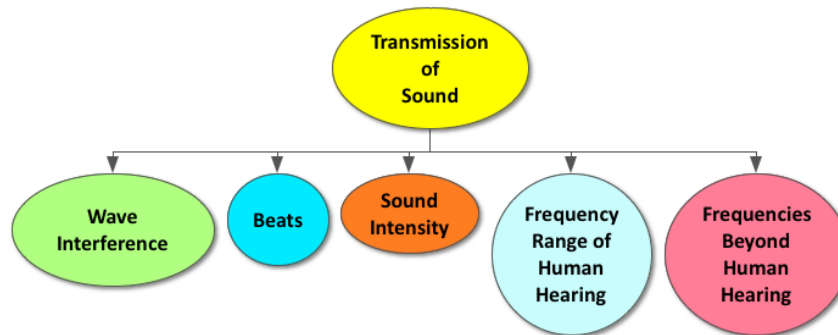
Sound waves are mechanical waves that transfer energy through a medium. They have wave properties such as amplitude, frequency, and speed. The perceived loudness of a sound is due to the amplitude of the wave. The perceived pitch of a sound is due to the frequency of the wave. The speed of sound waves varies in different mediums; the speed of sound in air is around 343 m/s. When two sound waves interfere, their amplitudes can be added together in a process called superposition. Constructive interference describes the interaction of two sound waves in phase and an increase in the resultant wave amplitude. Destructive interference describes the interaction of two sound waves out of phase and a decrease in the resultant wave amplitude. Another type of wave interference results in a beat and is caused by two waves interacting with similar frequencies. The intensity of a sound wave is defined as the average power of the sound source divided by the surface area in which the sound wave is transmitted. The frequency range of human hearing is 20-20,000 Hz. Ultrasonic sound, such as sonar, is beyond the range of human hearing.

Lesson Objectives

The student will:

- Describe how mechanical waves are transmitted.
- Explain what is meant by the superposition of waves and interference.
- Explain and evaluate sound intensity.

Lesson Vocabulary

amplitude

   The magnitude of the greatest departure from the equilibrium position or density of the wave disturbance.

frequency

>   The number of times a specified periodic phenomenon occurs within a specified interval.

 intensity

 The intensity of any wave is the time-averaged power it transfers per area through some region of space.

superposition

>   The superposition principle, also known as superposition property, states that, for all linear systems, the net response at a given place and time caused by two or more stimuli is the sum of the responses which would have been caused by each stimulus individually.

wave interference

>   A phenomenon in which two waves superimpose to form a resultant wave of greater or lower amplitude.

constructive interference

>   Occurs when waves are superimposed and form a wave with a larger amplitude than either of the original waves.

destructive interference

>   Occurs when waves are superimposed and form a wave with a smaller amplitude than either of the original waves.

wavelength

>   The distance between one peak or crest of a wave and the next corresponding peak or crest.

Equations

- A+A=2A
- A+(-A)=0
- f_{beat}=f$_2$-f$_1$
- $I = \frac{W}{A}$

Boxing

Prompt students to get out a blank sheet of paper and draw two concentric boxes on the blank page. They should write everything they know about sound waves in the larger box and everything they want to know about sound waves in the smaller box. An example is shown below.

Let's Do the Wave!

Prompt the class to do "the wave" –as if they are at a baseball game (*note: it helps if the students are sitting in rows*). Have a meter stick and a stopwatch on hand and then ask students to answer Prompt A-D as a class:

Prompt A: What determines the speed of our class wave? *(Refer#space#to#space#sample#space#answers).*

Prompt B: What determines the period of our class wave? *(Refer#space#to#space#sample#space#answers).*

Prompt C: What determines the frequency of our class wave? *(Refer#space#to#space#sample#space#answers).*

Prompt D: What determines the amplitude of our class wave? *(Refer#space#to#space#sample#space#answers).*

Use this activity to highlight the conditions necessary to create a sound wave:

- There is a medium, or interacting particles, that the sound wave moves through (the students)

- There is an original source causing the initial vibration (the first row of students to stand)
- The sound wave is transported from one place to another through particle interactions (the energy is transferred but each student experiences no net displacement).

Be sure to address that a sound wave is a longitudinal wave and the wave the students created in this activity is an example of a transverse wave.

Sound Interference

Begin by completing the following class challenge and then prompt students to create a whiteboard model of sound wave interference as outlined below.

Class Challenge: If possible, connect two speakers to a frequency generator (see below to a link for a phone App). Set the frequency generator to 343 Hz. Inform the students that the sound they are hearing has a wavelength of 1 meter. The sound waves are coming from two different speakers and are interfering. **Challenge students to walk around the room and try to locate the loud and quiet regions of sound.**

The following is a link to a frequency generator iPhone App:

https://itunes.apple.com/us/app/tone-generator/id457003837?mt=8

Whiteboard Model: Divide students into groups of 3-4 and provide each group with a whiteboard and dry erase markers. Prompt each group to create a whiteboard model that illustrates the physics behind the loud and quiet regions of sound they located around the classroom. Their whiteboards should include drawings, key terms and equations. When each group is finished, place all whiteboards at the front of the classroom and discuss common themes.

Highlight the following key concepts:

- *The perceived loudness of a sound is due to the amplitude of the wave.*
- *When two sound waves interfere, their amplitudes can be added together in a process called superposition.*
- *The loud spots around the room were a result of constructive interference, when two sound waves that were in phase interfered and produced a resultant wave with a greater amplitude.*
- *The quiet spots around the room were a result of destructive interference, when two sound waves that were out of phase interfered and produced a resultant wave with a smaller amplitude.*

Build a Speaker

If time allows, this is a wonderful activity to complete with the students. It will enable the class to witness the creation of sound wave vibrations and understand the real-world applications of class concepts. In addition, it will create a memorable experience regarding course material.

http://cse.ssl.berkeley.edu/lessons/indiv/regan/speakerlab.html

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

11.2 Wave Speed

Key Concept
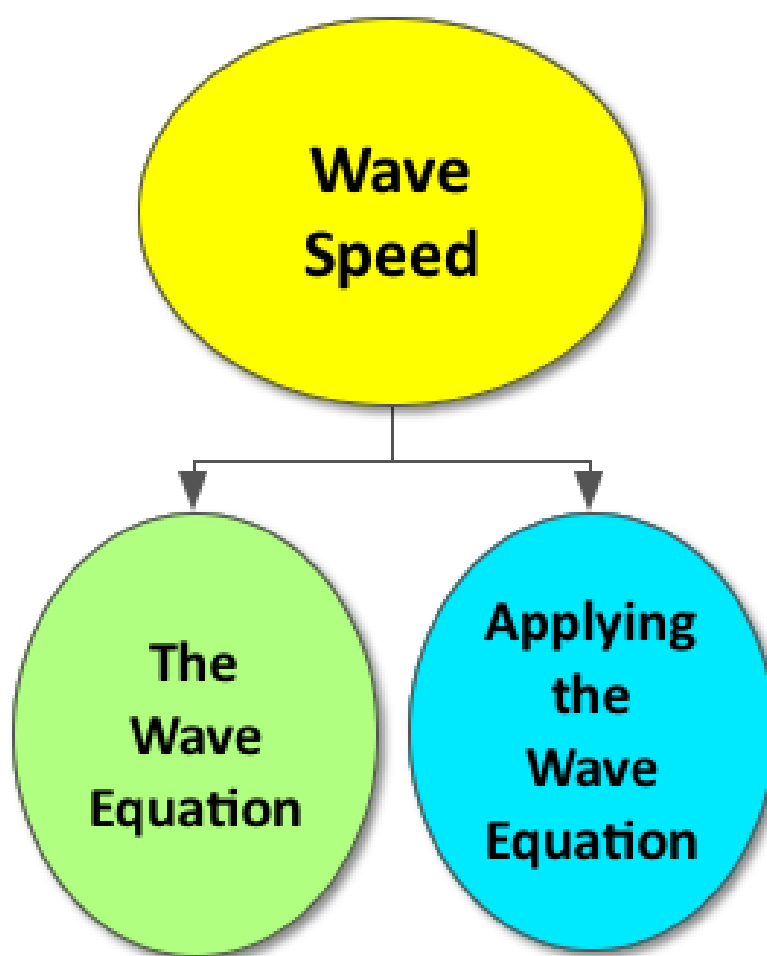
Waves exhibit properties of simple harmonic motion such as a period, frequency and amplitude. In addition to these properties, waves also exhibit a wavelength and velocity as a result of their movement through a medium. The wavelength of a moving wave is the distance, in meters, between two wave peaks. The velocity of a wave is the distance the wave travels over time and can be calculated using the equation $v = f\lambda$.

Lesson Objectives

The student will:

- Solve problems involving wavelength, wave speed, and frequency.

Lesson Vocabulary

wave equation
> Relates wavelength and wave speed. Distance is speed times time: x=vt, so wavelength is wave speed times period: λ=vT.

wave speed
> How quickly the peak of each wave is moving forward.

Equations

- $v=f\lambda$
- $\lambda=vT$

Wave Warm-up

Prompt students to match the following terms with the correct letter, as indicated on the image of the wave below.

Answer Key:

1. A
2. D
3. C
4. B

Wave Equation Inquiry Activity

Divide students into groups of 3-4 and provide each group with a slinky (*or other material to create a wave, such as a jump rope, etc*), a meter stick, masking tape, and a stopwatch. Also, provide a whiteboard and dry erase markers for data sharing.

Challenge students to use the materials to verify the wave equation: $v=f\lambda$.

Their whiteboards should include a sketch of their wave and measurements for following variables:

- wavelength (λ)
- frequency (f)
- wave speed (v)

Note: Do not provide students with any more instruction than this simple prompt. It will challenge students to think critically about their experimental design. *(Refer#space#to#space#sample#space#answers)*.

Optional: Students can the Video Physics App on their iPhone, iPod Touch, or iPad to do this activity. See the App descriptions in the chapter overview for more information.

Whiteboarding

Divide students into groups of 3-4 and provide each group with a whiteboard and dry erase markers. Challenge each group to work together to answer questions #1-4 below and display their work on the whiteboards.

The drawing above depicts a wave on a rope fixed at both ends.

1. What is the wavelength of this wave on a rope?
2. If the frequency is 100 Hz, what is the speed of the wave on the rope?
3. If the frequency is increased to 200 Hz, what is resulting wavelength? Draw what the new wave on the 6 m rope would look like.
4. If the frequency is increased to 400 Hz, what is resulting length of the wave on the rope? Draw what the new wave on the 6 m rope would look like.

`(Refer to sample answers).`

Be sure to use this activity to highlight the following:

- *How to measure one wavelength*
- *The wave speed in one medium is constant; the frequency and wavelength are inversely proportional*
- *When a wave travels from one medium to another, the frequency is constant and the wavelength and wave speed are directly proportional*

Exit Slip

Pass out index cards to the students and ask them to write their response to the following prompt on the card. Collect the cards as students exit the classroom and assess.

Prompt: Determine your distance from a storm cloud if you count 7 seconds between the time you see lightning and hear thunder. *(Refer#space#to#space#sample#space#answers)*.

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

11.3 Resonance with Sound Waves

Key Concept
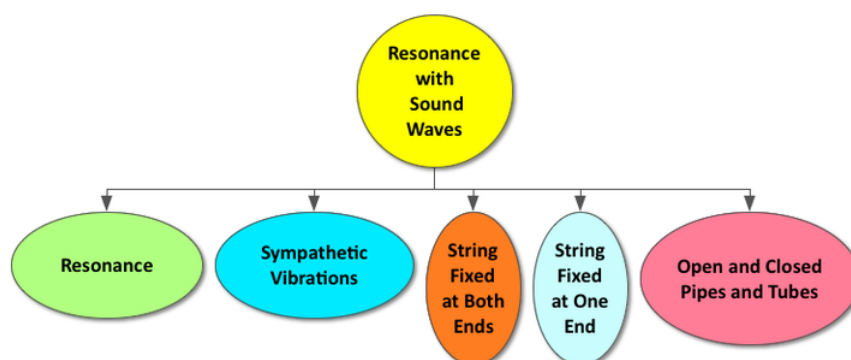
All objects vibrate with a natural frequency. This natural or resonant frequency is the frequency that requires the least amount of energy to create vibrations; it depends on what the object is made of, as well as its size and shape. When a forced vibration on an object matches the object's natural frequency, it causes a large increase in the amplitude of the wave due to a process called resonance. Resonance occurring at certain frequencies results in a standing wave pattern, comprised of nodes (areas of complete destructive interference) and antinodes (areas of complete constructive interference). The certain resonance frequencies that produce standing waves are called harmonics. Most musical instruments made up of strings or tubes have multiple harmonics whose wavelengths and frequencies relate mathematically. For example, instruments made up of strings fixed at both ends or open pipes have resonant wavelengths of $_n = \frac{2}{n}L$, where L is the length of the string or pipe and n is the harmonic (n=1,2,3 . . .). Strings fixed at only one end and closed pipes have resonant wavelengths of $_n = \frac{4}{n}L$, occurring at only odd harmonics (n=1,3,5 . . .). The frequency at which the first harmonic occurs in most instruments is referred to as the fundamental frequency and all other harmonics occur at frequencies that are multiples of this fundamental frequency ($f_n = nf_1$). Most students are surprised to learn that music is math!

Lesson Objectives

The student will:

- Understand the conditions for resonance.
- Solve problems with strings and pipes using the condition for resonance.

Lesson Vocabulary

beat frequency

natural frequency
   The frequency at which a system vibrates normally when given energy without outside interference.
resonance
   Timing force to be the same as natural frequency.
sympathetic vibrations

Equations

- $\lambda_n = \frac{2}{n}L$; n=1,2,3...
- $\lambda_n = \frac{4}{n}L$; n=1,3,5...
- $f_n = nf_1$
- v=330+0.6T

Guitar Oscillations Captured with iPhone 4

Enable students to visualize the standing waves created by strumming a guitar by beginning the lesson showing the Youtube video below.

https://www.youtube.com/watch?v=TKF6nFzpHBU

Palm Pipes Project

Complete the fun class activity below, which prompts students to investigate the different sound waves and musical notes created by vibrating the air in a palm pipe. Be sure to end class by performing a Palm Pipe Symphony!

http://www.cposcience.com/home/Portals/2/Media/post_sale_content/PFC2/ancillaries/skill_practice/20C_palm_pipes_-project_PFC2.pdf

Drawing Harmonics

Prompt each individual student to complete the following task:

- In your notes, draw the first five harmonics for a stringed instrument (such as a guitar, violin, or harp)
- Next, draw the first five harmonics for instruments made up of a pipe open at both ends (such as a flute)

- Lastly, draw the first five harmonics for instruments made up of a pipe closed at one end (such as the Palm Pipes in the inquiry activity above)

(Refer to sample answers).

Sound Uncovered

Prompt students to download this free and fun APP from the San Francisco Exploratorium and play.

https://itunes.apple.com/us/app/sound-uncovered/id598835017?mt=8

Exit Slip

Pass out index cards to the students and ask them to write their response to the following prompt on the card. Collect the cards as students exit the classroom and assess.

Prompt: What is the most surprising thing you learned today and why?

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook.* You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

11.4 Doppler Effect

Key Concept
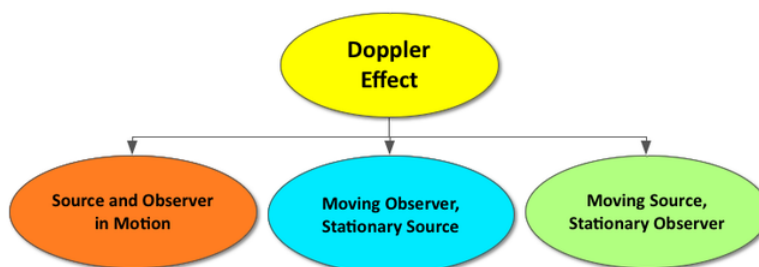
The Doppler effect describes the change in wave frequency as a result of the motion of the source, the receiver, or both. These changes can be calculated using the following equation: $f' = f\frac{v+v_r}{v+v_s}$

Lesson Objectives

The student will:

- Understand the Doppler effect.

Lesson Vocabulary

Doppler effect
   the change in wave frequency as a result of the motion of the source, the receiver, or both.

Equations

- $f' = f\frac{v+v_r}{v+v_s}$

How the Ear Works

Begin this final lesson on vibrations and sound by discussing how our ears work with the class and showing the video (3:25) at the link below.

https://www.youtube.com/watch?v=qgdqp-oPb1Q

Quick Write

Prompt students to complete a 5-minute quick write to answer the prompt below:

You are standing still at a crosswalk waiting to cross the street, when an ambulance approaches you with its siren blaring. Describe what you hear in detail at the following instances a-c described below:

(a) as the ambulance approaches you with its siren blaring

(b) as the ambulance is right next to you with its siren blaring

(c) as the ambulance drives away from you with its siren blaring

Then, attempt to explain what you hear at instances a-c using your understanding sound waves and how the ear works.

Peer Teaching

Give students some practice problems related to the Doppler effect. Pair each student up and have them alternate between tutor and tutee.

Shock Waves

Challenge students to investigate how the Doppler effect relates to shock waves and a sonic boom. If time allows, show this short (2:30) video below:

https://www.youtube.com/watch?v=-d9A2oq1N38

Boxing Review

Pass back students' papers from the Boxing warm-up activity in lesson 11.1. Allow students some time to review the items they listed in the box "What do I know about sound waves?" and prompt them to correct any mistakes. Also, challenge students to answer any of the items they listed in the box "What do I want to know about sound waves?" that they now can as a result of what they have learned in this chapter. If time allows, answer any unresolved student questions as a class.

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

Chapter Test

Copy and distribute the Chapter 11 Test using the *CK-12 Physics Intermediate Quizzes and Tests* link.

CHAPTER **12**

Fluid Mechanics

Chapter Outline

Chapter Overview
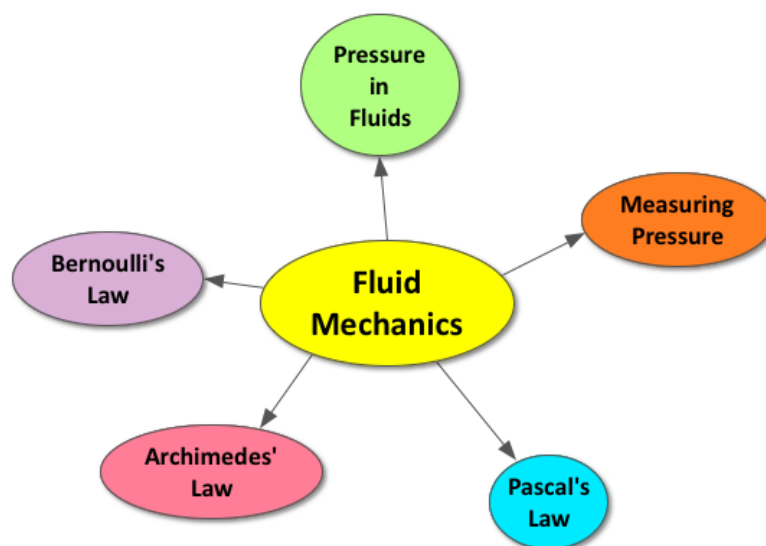
Fluid mechanics is the study of the behavior of fluid molecules, such as liquids and gases, at rest and in motion. A fluid at rest produces a hydrostatic pressure that increases with density and depth. The air molecules on Earth produce an atmospheric pressure that can be measured with a barometer. Any additional pressure added to a system on top of the atmospheric pressure is referred to as the gauge pressure. As a result, the total pressure of a system is the sum of the atmospheric pressure and the gauge pressure. According to Pascal's Law, the pressure in a fluid increases equally throughout the fluid and is utilized to create a mechanical advantage in hydraulic machinery. Archimedes' Law states that the buoyant force on a submerged object is equal to the weight of the fluid that is displaced. An object will float if the density of the object is less than the density of fluid or if the object displaces a weight of fluid equal to its own weight. In accordance with Bernoulli's Law, as the velocity of a moving fluid increases, the pressure will decrease.

Online Resources

CK12 Fluids Study Guide

Students can download or print out this study guide for fluids found at the link below.

http://www.ck12.org/physics/Buoyancy/studyguide/Fluids-Study-Guide/

Lesson: Archimedes' Principle, Pascal's Law and Bernoulli's Principle

The following link provides curriculum from Teach Engineering, with power point presentations, worksheets, and student projects.

https://www.teachengineering.org/view_lesson.php?url=collection/uoh_/lessons/uoh_fluidmechanics/uoh_fluidmechanics_lesson01.xml

PhETs

The following links provide simulations regarding fluid mechanics.

Density

http://phet.colorado.edu/en/simulation/density

Buoyancy

http://phet.colorado.edu/en/simulation/buoyancy

Balloons and Buoyancy

http://phet.colorado.edu/en/simulation/balloons-and-buoyancy

Wolfram Demonstrations Project

The following links provide interactive demonstrations regarding fluid mechanics.

Forces Exerted on an Immersed Object

http://demonstrations.wolfram.com/ForcesExertedOnAnImmersedObject/

Pascal's Principle

http://demonstrations.wolfram.com/PascalsPrinciple/

TABLE 12.1: Pacing The Lessons

Lesson	Class Periods (60 min)

TABLE 12.1: (continued)

Lesson	Class Periods (60 min)
Lesson 12.1 Pressure in Fluids	2
Lesson 12.2 Measuring Pressure	1
Lesson 12.3 Pascal's Law	2
Lesson 12.4 Archimedes' Law	2
Lesson 12.5 Bernoulli's Law	1

12.1 Pressure in Fluids

Key Concept
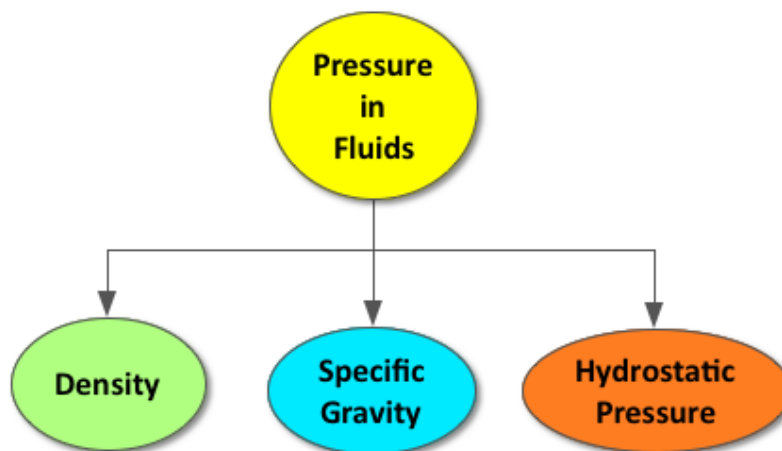
When a fluid is at rest, it produces hydrostatic pressure. The hydrostatic pressure is dependent on the density of the fluid and the depth. The density of a fluid is equal to its mass divided by its volume. The pressure of a fluid is equal to the force per unit area. The unit for pressure is the Pascal (Pa), which is equivalent to one Newton per square meter (N/m^2). The specific gravity of a fluid is equal to the ratio of the density of the fluid to the density of water and is measured in kilograms per cubic meter (kg/m^3).

Lesson Objectives

The student will:

- Understand density and be able to solve problems with density.
- Understand pressure and be able to solve problems with pressure.

Lesson Vocabulary

density
    The ratio of an object's mass divided by its volume.

pressure
> Force per unit area.

Equations

- $\rho = \frac{m}{v}$
- $sg = \frac{density}{1000 \ kg/m^3}$
- $P = \frac{F}{A}$
- $P_g = \rho g h$

Quick Write

Prompt students to complete a 3-minute Quick Write to answer the simple prompt below on an index card with their name on it. At the end of the Quick Write, collect the cards and keep them for students' review at the end of the chapter.

Prompt: Why do you think an object floats?

The Floating Egg

Use the following demonstration to engage students in an introductory discussion regarding density and its relationship to floating. (Note: There will be further discussion on the physics of floating in Lesson 12.4: Archimedes' Principle). http://www.stevespanglerscience.com/lab/experiments/floating-egg

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SEE-I

Divide the class into groups of 3-4 students and provide each group with a whiteboard and dry erase markers. Demonstrate how to use the SEE-I method to clarify concepts and show understanding (*see below for more information*). Prompt students to use the SEE-I method to describe the following three statements regarding pressure in a fluid:

- The pressure in a fluid is equal in all directions
- The pressure in a fluid increases with density
- The pressure in a fluid increases with depth

Display the completed whiteboards at the front of the class, highlighting good examples and common themes.

Learn more about the SEE-I method by visiting the link below:

http://en.wikipedia.org/wiki/SEE-I

Phet: Under Pressure

If time allows, enable students to explore pressure in a fluid using the following simulation. http://phet.colorado.edu /en/simulation/under-pressure

Exit Slip

Pass out index cards to the students and ask them to write their response to the following prompt on the card. Collect the cards as students exit the classroom and assess.

Prompt: What is the relationship between pressure and force? *(Refer to sample answers).*

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

12.2 Measuring Pressure

Key Concept
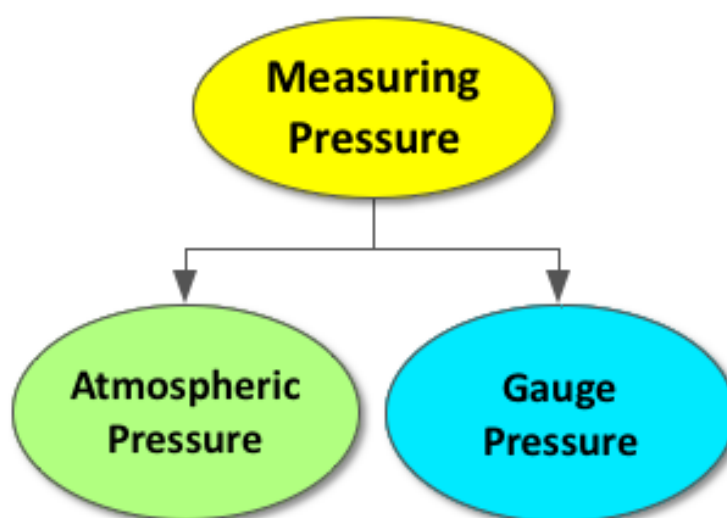
The weight of the air molecules in the Earth's atmosphere produces an atmospheric pressure. The standard pressure of the Earth's atmosphere is 101,325 Pa. The gaseous air molecules on Earth increase their density as they approach sea level, which results in an increase in atmospheric pressure. However, atmospheric pressure is not dependent on density alone. Many variables, such as climate and weather, affect the amount of atmospheric pressure exerted on a certain location. A barometer can be used to measure the atmospheric pressure. Any other type of pressure exerted on a system other than the atmospheric pressure is referred to as the gauge pressure. The total pressure on a system is the sum of the atmospheric pressure and the gauge pressure.

Lesson Objectives

The student will know:

- How atmospheric pressure is measured.
- How gauge pressure is defined.

Lesson Vocabulary

- atmospheric pressure: The pressure from the Earth's atmosphere.
- barometer: The oldest design for scientifically measuring pressure.
- gauge pressure: The pressure above the current atmospheric pressure.

Equations

- $P_{atm} = 1\ atm = 101,325\ Pa = 1.013 \times 10^5\ \frac{N}{m^2} = 101.3\ kPa$
- $P_g = pgh$
- $P_T = P_atm + P_g$

Water Glass Magic

Use this experiment to demonstrate the strength of atmospheric pressure and inspire students to gain interest in learning more about measuring pressure. http://www.physicscentral.com/experiment/physicsathome/magicwaterglass.cfm

Think*Pair*Share

Allow students time to think about the questions below on their own, share their answer with the person next to them, and then discuss as a class.

Prompt: If you convert standard atmospheric pressure at sea level from N/m^2 to lbs/in^2, it will come out to about 15 lbs of force exerted on every square inch of your body! How are you able to withstand this immense amount of pressure? *(Refer to sample answers).*

Differences in Atmospheric Pressure

Divide students into pairs and provide each pair with a whiteboard and dry erase markers. Challenge each pair to answer the question below using a combination of words, pictures, and equations.

Prompt: Explain why atmospheric pressure at sea level is greater than the atmospheric pressure in the mountains.

Display completed whiteboards at the front of the classroom, highlighting good examples and common themes.

Be sure to address the following:

- *Atmospheric pressure is due to the gravitational force on air molecules (air weight) exerted over an area (P=F/A).*

- *The amount of air molecules above an area at sea level is greater than the amount of air molecules above an area in the mountains.*
- *The air weight exerted over an area at sea level will be greater than the air weight exerted over an area in the mountains.*
- *The atmospheric pressure at sea level will be greater than the atmospheric pressure in the mountains.*

Points to Consider

If time allows, challenge students to research answers to the following questions regarding pressure.

- **How does air pressure signal changes in the weather?**
- **What is decompression sickness and how is it related to pressure?**
- **What is cabin pressure and why is it necessary?**
- **Why do your ears pop when you change altitude?**

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

12.3 Pascal's Law

Key Concept
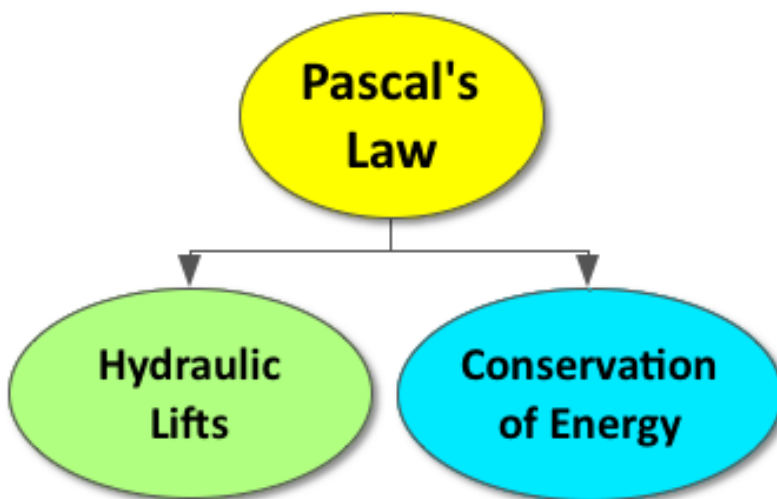
According to Pascal's Law, pressure increases equally throughout a fluid. Therefore, if the pressure at any one point in a fluid increases, then the pressure at all other points in the fluid also increase. A hydraulic lift utilizes Pascal's Law to create a large output force from a small input force by manipulating the area over which the force is applied. Although there is a mechanical advantage, a hydraulic lift still obeys the Law of Conservation of Energy.

Lesson Objectives

The student will:

- Understand and be able to solve problems using Pascal's Principle.

Lesson Vocabulary

- Pascal's Law: Increasing the pressure of fluid anywhere in a system increases the pressure everywhere in the system

Equations

- $P_{out} = P_{in}$
- $\frac{F_{out}}{A_{out}} = \frac{F_{in}}{A_{in}}$
- $\frac{A_{out}}{A_{in}} = \frac{F_{out}}{F_{in}}$

Grocery List: Hydraulic Machinery

Begin this lesson by challenging students to make a list of real-word connections by completing the prompt below. Then, discuss as a class.

Prompt: Hydraulic devices utilize fluids to do mechanical work. Please list all the ways you can think of in which hydraulics are used in our everyday lives. [Click on the following link for examples of hydraulic machinery: http://en.wikipedia.org/wiki/Hydraulic_machinery]

Pascal's Law Demonstration

Utilize the following demonstration to enable students to witness Pascal's Law in action. **Note: Be sure to highlight how Pascal's Law is used to design hydraulic machinery (as discussed in the warm-up activity above).*

http://www.sciencefair-projects.org/physics-projects/pascals-law.html

Pascal's Law and Hydraulics

Divide students into groups of 3-4 and provide each group with a whiteboard and dry erase markers. Challenge each group to complete the prompt below using a combination of words, pictures, and equations.

Prompt: Choose one example of a hydraulic machine and explain how it works in detail. Be sure to include Pascal's Law in your explanation.

Display completed whiteboards at the front of the classroom, highlighting good examples and common themes.

∗∗*Be sure to highlight the following:*

- *Hydraulic systems work because the pressure of a fluid is constant everywhere in the system. According to Pascal's Law, if the pressure anywhere increases, then the pressure everywhere increases.*
- *Pressure is the ratio of force to area (P=F/A). So, if the pressure is constant everywhere in a fluid, then the ratio of force to area must also remain constant throughout the system. This can be re-written as $F_A/A_A = F_B/A_B$, where A and B are two different points in a fluid system.*
- *Scientists and engineers utilize Pascal's Law in hydraulic systems to generate a large force over a large area by applying a small force over a small area.*
- *One example is hydraulic brakes in a car. Your foot applies a small force to a small break pad, which is transferred through the brake fluid to a large area with a large force, causing the wheels of your car to stop rotating.*

Connecting Science with Engineering

If time allows, the link below provides a detailed lesson plan in which students connect Pascal's Law with the engineering of dam and lock systems.

https://www.teachengineering.org/view_activity.php?url=collection/cub_/activities/cub_dams/cub_dams_lesson03_-activity1.xml

3-2-1 Exit Slip

Pass out index cards to the students and ask them to write their response to the following prompt on the card. Collect the cards as students exit the classroom and assess.

Prompt: What are

- 3 things you learned?
- 2 facts you found interesting?
- 1 question you still have?

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

12.4 Archimedes' Law

Key Concept
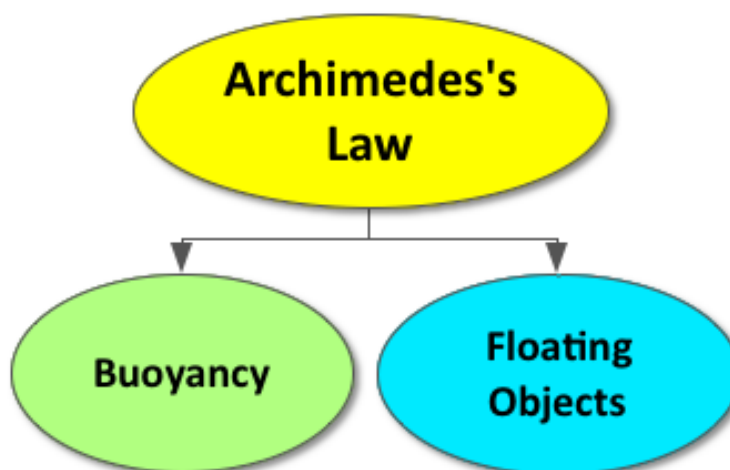
Fluid pressure increases with depth, causing the fluid pressure on a submerged object to be greater on the bottom of the object. As a result, a submerged object experiences an upward force called the buoyant force. According to Archimedes' Law, the buoyant force is equal to the weight of the fluid that is displaced by the submerged object. When an object displaces an amount of fluid equal to its own weight, it will float.

Lesson Objectives

The student will:

- Understand buoyancy and how it applies to Archimedes' Law.
- Be able to solve problems using Archimedes' Law.

Lesson Vocabulary

- buoyancy: The force that pushes upward on an object that is partially or wholly submerged in water.

Equations

- $F_b = \rho V g$

Grocery List: Floating

Begin this lesson by challenging students to make a list of real-word connections by completing the prompt below. Then, discuss as a class.

Prompt: Create a list of all the things that float on water that surprise you. [*Example: The USS Iowa is 45,000 tons and can float on water! To learn more about this historical ship, prompt students to check out the following link:* http://www.ck12.org/physics/Pressure-in-Fluids/rwa/USS-Iowa/].

CK-12 Simulation: What causes a diver to float?

Use this interactive simulation to introduce students to the buoyant force and Archimedes' Law.

http://interactives.ck12.org/simulations/physics/scuba-training/app/index.html?hash=9159120b7f044d15178e9d595ca94089&artifactID=1732571&backUrl=http%3A//www.ck12.org/physics/Pressure-in-Fluids/

Penny Boat Challenge

Divide students into groups of 3-4 and challenge each group to create a penny boat by following the instructions at one of the links provided below. Each group should also submit a written explanation of their penny boat design to demonstrate their understanding of Archimedes' Law.

The three links below provide a variety of instruction and levels regarding the penny boat challenge.

- http://www-tc.pbskids.org/fetch/parentsteachers/activities/pdf/FETCH_FloatMyBoat_AG.pdf
- http://www.eastbaystem.net/wp/wp-content/uploads/2013/04/Penny-Boat-Challenge.pdf
- http://www.edisonmuckers.org/wp-content/uploads/2012/08/Whatever-Floats-Your-Boat.pdf

Submarines

If time allows, prompt interested students to investigate how a submarine utilizes Archimedes' Law. http://www.onr.navy.mil/focus/blowballast/sub/work2.htm

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

12.5 Bernoulli's Law

Key Concept
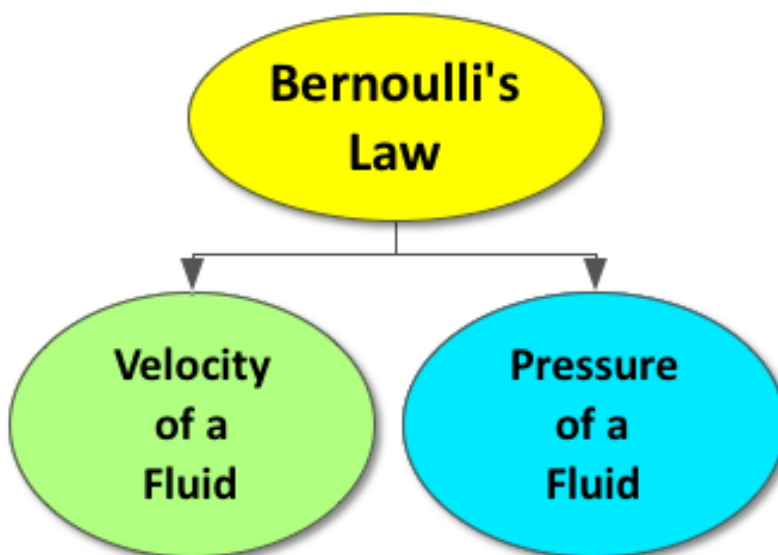
Bernoulli's Law states that as the velocity of a moving fluid increases, the pressure of the moving fluid decreases. There are many applications of Bernoulli's Law, from increasing the pressure of the water coming from a garden hose to increasing the lift force on an airplane wing.

Lesson Objectives

The student will:

- Understand Bernoulli's principle and be able to discuss its implications.

Lesson Vocabulary

- Bernoulli's Principle: A key principle connecting velocity and air. At those points in space where the velocity of a fluid is high, the pressure is low. At those points in space where the velocity of a fluid is low, the pressure is high.

Equations

- $P_1 + \frac{1}{2}pv_1^2 + \rho gh_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho gh_2$

Bernoulli Effect Demonstration

Complete one of the following demonstrations of the Bernoulli Effect to get students excited to learn more.

https://www.physics.umn.edu/outreach/pforce/circus/Bernoulli.html

Bernoulli's Principle On-Board the International Space Station

Show this video (7:17) to review the Bernoulli's Principle and its everyday applications.

http://www.nasa.gov/audience/foreducators/nasaeclips/search.html?terms=%22Launchpad%3A%20Bernoulli%27s%20Principle%20On-Board%20the%20International%20Space%20Station%22&category=0000&disp=grid

Peer Teaching

Pair students up and have them alternate between tutor and tutee, answering practice problems that employ Bernoulli's Equation ($P_1 + \frac{1}{2}pv_1^2 + \rho gh_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho gh_2$).

Teacher in Training

Prompt each student to write one physics problem related to Bernoulli's Law on a piece of paper and provide the solution below it. Collect every student's question to use in one of the following ways:

- Exit Slip Question
- Warm-up Question
- Quiz/Test Question
- Extra Credit Question

Quick Write Review

Pass back students' index cards from the Quick Write warm-up activity in lesson 12.1. Allow students some time to review their answers and prompt them to correct any mistakes. If time allows, answer any unresolved student questions as a class.

∗∗*Be sure to highlight the following:*

- *An object will float if the density of the object is less than the density of fluid or if the object displaces a weight of fluid equal to its own weight.*

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

Chapter Test

Copy and distribute the Chapter 12 Test using the *CK-12 Physics Intermediate Quizzes and Tests* link.

CHAPTER **13**

Heat

Chapter Outline

Chapter Overview
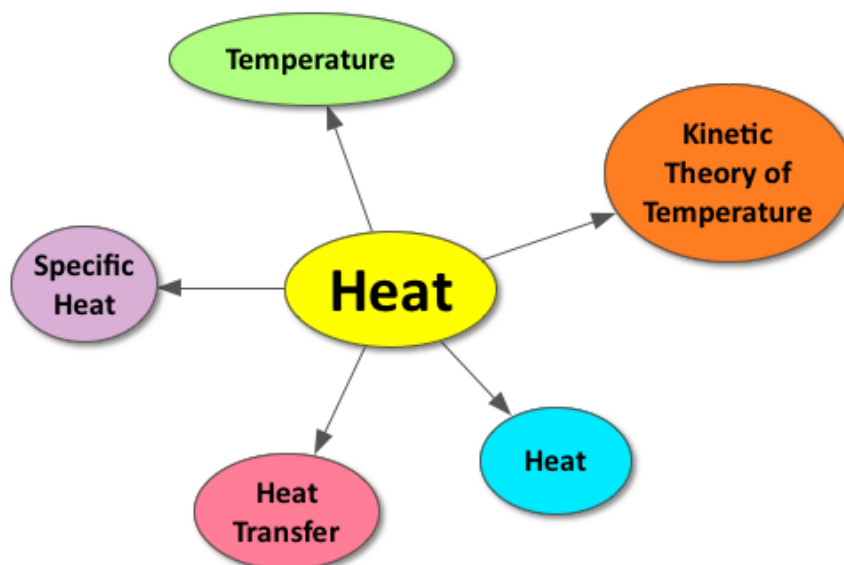
The temperature of an object is due to its atomic motion. Temperature is measured with a thermometer using one of the following scales: the Fahrenheit Scale, the Celsius Scale, or the Kelvin scale. The average kinetic energy of the atoms in an object is directly proportional to its temperature. The internal energy of an object is directly proportional to both the temperature and the amount of atoms in the object. Heat is the transfer of energy between two objects due to a difference in their temperatures. Heat is measured in calories and can be transferred by conduction, convection, or radiation. The amount of heat required to change the temperature of an object depends on its specific heat. An object with a high specific heat requires more energy to increase its temperature.

Online Resources

Investigating Heat and Temperature

This simple activity, outlined at the link below, focuses on dispelling the misconception that heat and temperature are the same thing.

http://serc.carleton.edu/sp/mnstep/activities/34783.html

Cooking Cookies with Solar Power

In this short video segment (3:10), young students assess two homemade solar cookers and review the three methods of heat transfer.

http://www.pbslearningmedia.org/resource/phy03.sci.phys.mfe.zsolar/cooking-cookies-with-solar-power/

NASA Design Squad Challenge: Feel the Heat

The link below outlines a great project in which students are tasked with creating a solar hot water heater.

http://www.pbslearningmedia.org/resource/arct14.sci.dsfeel/feel-the-heat/

Colorful Convection Currents

The video and experiment found at the link below allows students to visualize the transfer of heat by convection currents.

http://www.stevespanglerscience.com/lab/experiments/colorful-convection-currents

Infrared Gallery

The infrared images at the link below show the heat radiated from everyday objects.

http://www.pbslearningmedia.org/asset/ess05_int_irgallery/

Physics Classroom: Thermal Physics

The following link is a great resource for students of all levels regarding heat, temperature, and thermal physics.

http://www.physicsclassroom.com/class/thermalP

TABLE 13.1: Pacing The Lessons

Lesson	Class Periods (60 min)
Lesson 13.1 Temperature	2
Lesson 13.2 Kinetic Theory of Temperature	2
Lesson 13.3 Heat	1
Lesson 13.4 Heat Transfer	3
Lesson 13.5 Specific Heat	1

13.1 Temperature

Key Concept
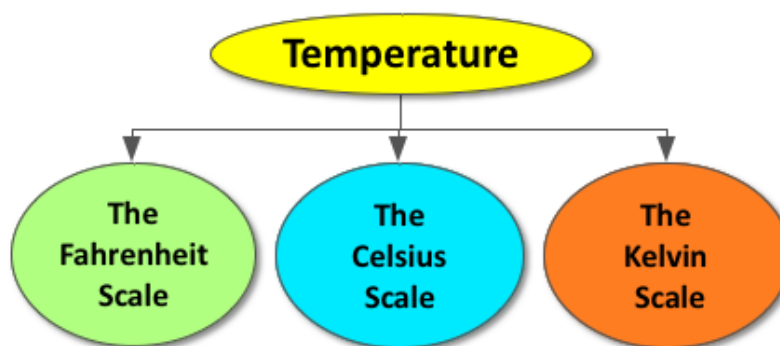
All matter is made up of atoms that vibrate back and forth. Temperature is the measure of the motion of these atoms. A thermometer measures temperature by gauging how much a liquid expands in a tube as a result of the atomic movement related to heat and energy. There are three different scales in which temperature is measured: the Fahrenheit scale, the Celsius scale, and the Kelvin scale.

Lesson Objectives

The student will:

- Explain what is meant by temperature.
- Use the centigrade (Celsius) and Kelvin temperature scales.

Lesson Vocabulary

temperature
> A measurement of the average kinetic energy of the molecules in an object or system. Temperature can be measured with a thermometer or a calorimeter.

Equations

- $T_C = (T_F - 32)/1.8$
- $T_k = T_C + 273$

Strange Temperatures

Start the lesson with this easy activity in which students begin to understand why we rely on thermometers to measure temperature and not our senses.

http://www.thenakedscientists.com/HTML/content/kitchenscience/exp/how-to-fool-your-senses/

Think*Pair*Share

Allow students time to think about prompts A-C below on their own, share their answer with the person next to them, and then discuss as a class.

Prompt A: What is temperature? *(Refer to sample answers).*

Prompt B: Why do we rely on a thermometer to measure temperature? *(Refer to sample answers).*

Prompt C: How does a thermometer measure temperature? *(Refer to sample answers).*

Converting Temperature Scales

Divide students into pairs and provide each pair with a whiteboard and dry erase markers. Challenge each group to complete the following chart using the following conversion factors:

- $T_k = T_C + 273$
- $T_C = (T_F - 32)/1.8$

TABLE 13.2: Temperature Conversions

Description	Fahrenheit Scale (˚F)	Celsius Scale (˚C)	Kelvin Scale (K)
Room Temperature	68		
Body Temperature		36.7	
Nice Day at the Beach	83		
Desert Temperature		43.4	
Snow Falling	30		
Water Boils			373
Water Freezes			273

Note: Students can also use Wolfram Alpha to aid in their conversions or check their work: http://www.wolframalpha.com/

Key:

TABLE 13.3: Temperature Conversions

Description	Fahrenheit Scale (˚F)	Celsius Scale (˚C)	Kelvin Scale (K)
Room Temperature	68	20	293
Body Temperature	98	36.7	309.7
Nice Day at the Beach	83	28.3	301.3
Desert Temperature	110	43.4	316.4
Snow Falling	30	-1.1	271.9
Water Boils	212	100	373
Water Freezes	32	0	273

Points to Consider

If time allows, challenge students to research answers to the following questions regarding temperature.

- What is the difference between heat and temperature?
- What happens on the atomic level as the temperature of an object increases?

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook.* You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

13.2 Kinetic Theory of Temperature

Key Concept
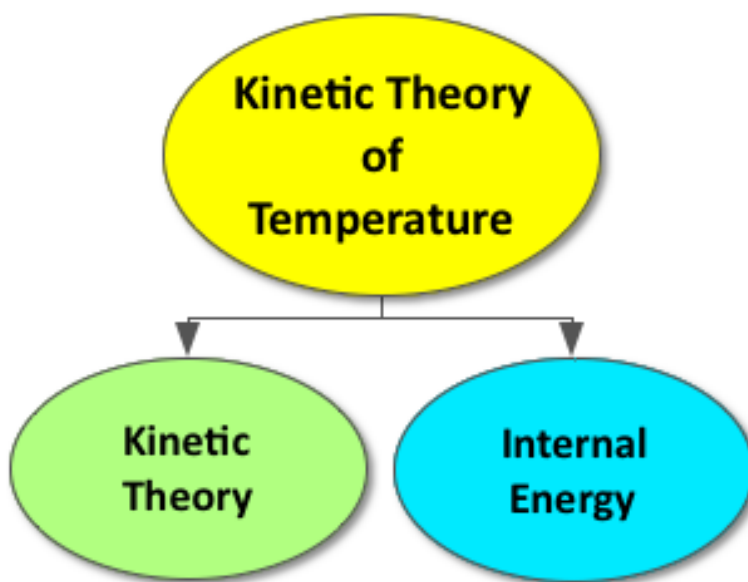
The Kinetic Theory of Temperature, developed by James Clark Maxwell, describes a mathematical relationship between the atomic motion of an ideal gas and its temperature. The equation, $KE = \frac{1}{2}mv^2 = \frac{3}{2}kT$, shows that the average kinetic energy of the atoms in a gas is directly proportional to its temperature. The internal energy, sometimes referred to as the total energy, is the product of the average kinetic energy and the number of atoms in an object: $U = N(\frac{1}{2}mv^2)$. As a result, the internal energy of an object is dependent on both the temperature and the number of atoms: $U = \frac{3}{2}NkT$.

Lesson Objectives

The student will:

- Describe the relationship between temperature and kinetic energy.

Lesson Vocabulary

internal energy
    The total kinetic and potential energy associated with the motions and relative positions of the molecules of

an object, excluding the kinetic or potential energy of the object as a whole. An increase in internal energy results in a rise in temperature or a change in phase.

Kinetic Theory

A theory concerning the thermodynamic behavior of matter, especially the relationships among pressure, volume, and temperature in gases. It is based on the dependence of temperature on the kinetic energy of the rapidly moving particles of a substance. According to the theory, energy and momentum are conserved in all collisions between particles, and the average behavior of the particles can be deduced by statistical analysis.

Equations

- Boltzmann Constant: $k = 1.38 \times 10^{-23} J/kg$
- $KE = \frac{1}{2}mv^2 = \frac{3}{2}kT$
- $U = N(\frac{1}{2}mv^2)$
- $U = \frac{3}{2}NkT$

Kinetic Theory Simulation

Begin this lesson by allowing students to investigate the connection between the kinetic energy and temperature with the simple simulation found at the link below. Prompt students to fold a piece of paper in half and write down their observations (from the simulation) regarding the relationship between kinetic energy and temperature on one side and any questions that have on another. Then, discuss as a class.

https://www.classzone.com/books/ml_science_share/vis_sim/mem05_pg101_kintheory/mem05_pg101_kintheory.html

Heating Up the Classroom

Complete the engaging inquiry activities described in detail at the link below to provide students with a meaningful learning experience regarding the relationship between kinetic energy and temperature.

http://www.iacad.org/istj/36/2/thermalenergy.pdf

Whiteboarding

Divide students into pairs and provide each pair with a whiteboard and dry erase markers. Challenge each pair to complete the prompt below using a combination of words, pictures, and equations.

Prompt: Come up with an example of two objects that have the same temperature but different internal energies. *(Refer to sample answers)*.

Display completed whiteboards at the front of the classroom, highlighting good examples and common themes.

Be sure to highlight the following:

- The internal energy (total energy) of a substance is different from the average kinetic energy.
- The average kinetic energy is directly proportional to the temperature of a substance.
- The internal energy (total energy) of a substance is directly proportional to BOTH the temperature and the number of individual atoms.

PhET: Gas Properties

If time allows, enable students to explore the effect of other variables, such as volume and pressure, on the kinetic energy of a gas using the simulation below.

http://phet.colorado.edu/en/simulation/gas-properties

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

13.3 Heat

Key Concept
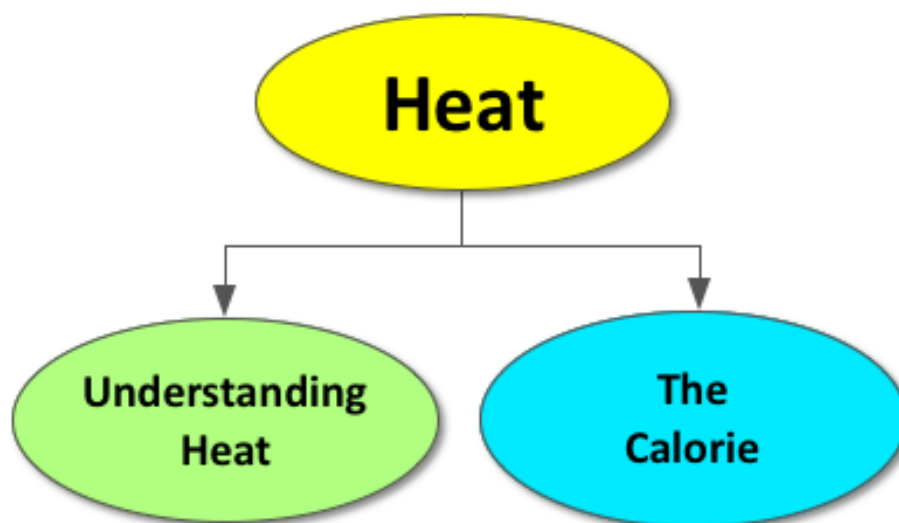
Heat is a transfer of energy from one object to another due to a temperature difference between the two objects. Heat always flows from the object with a higher temperature to the object with a lower temperature. Heat is measured in calories. One calorie is equivalent to the amount of heat required to make one gram of water rise in temperature by one degree Celsius.

Lesson Objectives

The student will:

- Explain the relationship between heat and energy transfer.
- Describe how the calorie is a measure of energy.

Lesson Vocabulary

calorie
    The amount of energy needed to increase the temperature of 1 gram of water by 1°C at standard atmospheric

pressure (101.325 kPa). This is approximately 4.2 joules.

heat

The sum of all the kinetic energies of all the molecules in an object or substance.

Equations

- $1 \, kC = 4186 \, Joules$

TED-Ed: The Chemistry of Cookies

Inspire students to relate the concept of heat with baking cookies by showing this short video (4:29) found at the link below.

http://ed.ted.com/lessons/the-chemistry-of-cookies-stephanie-warren#watch

Think*Pair*Share

Allow students time to think about the question below on their own, share their answer with the person next to them, and then discuss as a class.

Prompt: Can an object, like the cookie described in the video above, contain heat? *(Refer to sample answers).*

Use this prompt to distinguish the following terms: *heat, temperature, and energy.*

Calorie Calculations

Prompt students to convert the Calories in a food item of their choice into Joules. Then, discuss as a class.

Example: A chocolate chip cookie contains 220 Calories.

$220 \, Calories \times \frac{4186 \, J}{1 \, Calorie} = 920,920 \, J$

Work Review

Take this opportunity to review the concept of work by answering the question below.

Prompt: How many times would you have to lift a 50lb (23kg) barbell a distance of 2 meters above the floor of the gym to "work off" the calories from consuming the food item in the activity above. *(Refer to sample answers).*

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

13.4 Heat Transfer

Key Concept
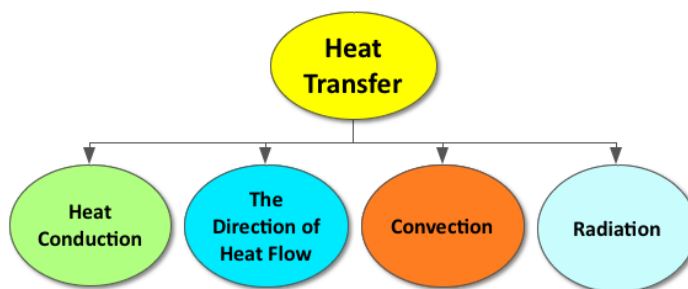
Heat is the transfer of energy from an object with higher temperature to an object with lower temperature. Heat can be transferred by conduction, convection, or radiation. Conduction is the transfer of heat through atomic collisions. Convection is the transfer of heat as a result of the movement of fluids. Radiation is the transfer of heat through electromagnetic waves, such as the heat transferred from the sun.

Lesson Objectives

The student will:

- Explain the relationship between heat and energy transfer.
- Describe how energy is transported through the processes of conduction, convection, and radiation.

Lesson Vocabulary

conduction
> The transfer of heat through matter by communication of kinetic energy from particle to particle (molecular collision), with no net displacement of the particles.

convection
> The transfer of heat from one place to another by the movement of fluids, also known as convective heat transfer.

heat
> The sum of all the kinetic energies of all the molecules in an object or substance.

radiation
> Energy emitted in the form of electromagnetic waves and covers the entire electromagnetic spectrum, extending from the radio-wave portion of the spectrum through the infrared, visible, ultraviolet, x-ray, and gamma-ray portions.

Equations

- $\frac{\Delta E}{\Delta T} = kA\frac{\Delta T}{t}$
- $\Delta T = T_2 - T_1$

Think*Pair*Share

Allow students time to think about the question below on their own, share their answer with the person next to them, and then discuss as a class.

Prompt: How does a thermos work? *(Refer to sample answers).*

Hot Cans and Cold Cans

Challenge students to connect science and engineering with the hands-on activity found at the link below. Students will be tasked with keeping one can of soda hot and one can of soda cold by applying their understanding of conduction, convection, and radiation.

https://www.teachengineering.org/view_activity.php?url=collection/duk_/activities/duk_heattransfer_smary_act/duk_heattransfer_smary_act.xml

Grocery List: Conduction, Convection, and Radiation

Divide students into pairs. Challenge each pair to make a list of real-word connections by completing the prompt below. Then, discuss as a class by creating a large chart on the board of all the real-world examples.

Prompt: Get out a sheet of paper and create a chart like the one below. Please list all the ways we use each method of heat transfer in our everyday lives.

TABLE 13.4: Heat Transfer

Conduction	Convection	Radiation

Sample Chart:

TABLE 13.5: Heat Transfer Answers

Conduction	Convection	Radiation
Boiling Water	Greenhouse	Campfire
Blanket	The second floor of a house being warmer than the first floor	Microwave

Optional: Prompt students to take a picture of the combined class chart on the board with their phones or tablets. Students keeping electronic notebooks should insert this image into their notes.

Heat Transfer

The following link is a great resource for students who need more help understanding the concepts of conduction, convection, and radiation.

http://www.pbslearningmedia.org/asset/lsps07_int_heattransfer/

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

13.5 Specific Heat

Key Concept
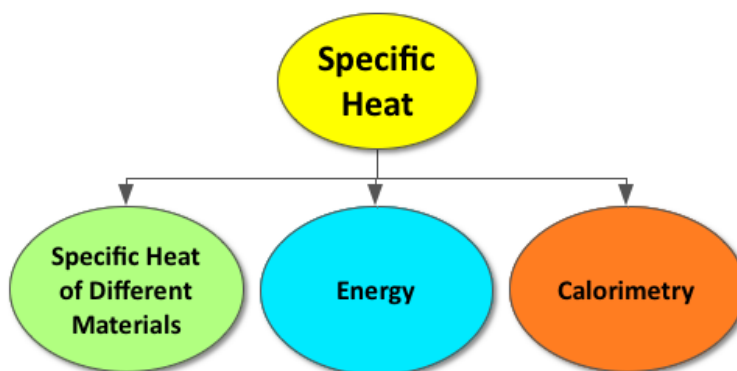
The amount of heat required to change the temperature of an object depends on the atomic structure of that object. The specific heat indicates the amount of heat necessary to raise the temperature of one gram of an object by one degree Celsius. Calorimetry is the measure of the heat transferred into or out of a system.

Lesson Objectives

The student will:

- Solve problems involving specific heat.

Lesson Vocabulary

specific heat
    The amount of heat required to raise the temperature of one gram of a substance by one Celsius degree.

Equations

- $\Delta Q = mc\Delta T$

Think*Pair*Share

Allow students time to think about the questions below on their own, share their answer with the person next to them, and then discuss as a class.

Prompt A: When boiling water to make Macaroni and Cheese, what heats up faster: the metal pot or the water? *(Refer to sample answers)*.

Prompt B: Which has the highest specific heat: the metal pot or the water? *(Refer to sample answers)*.

Specific Heat Lab

Complete the following lab activity in which students review the relationship between heat and temperature and calculate the specific heat of a variety of everyday materials.

http://d32ogoqmya1dw8.cloudfront.net/files/sp/mnstep/activities/student_handout_pdf.pdf

Peer Teaching

Pair students up and have them alternate between tutor and tutee, solving problems regarding specific heat and Calorimetry.

Teacher in Training

Prompt each student to write one physics problem related to specific heat or Calorimetry on a piece of paper and provide the solution below it. Collect every student's question to use in one of the following ways:

- Exit Slip Question
- Warm-up Question
- Quiz/Test Question
- Extra Credit Question

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

Chapter Test

Copy and distribute the Chapter 11 Test using the *CK-12 Physics Intermediate Quizzes and Tests* link.

CHAPTER **14**   # Thermodynamics

Chapter Outline

Chapter Overview
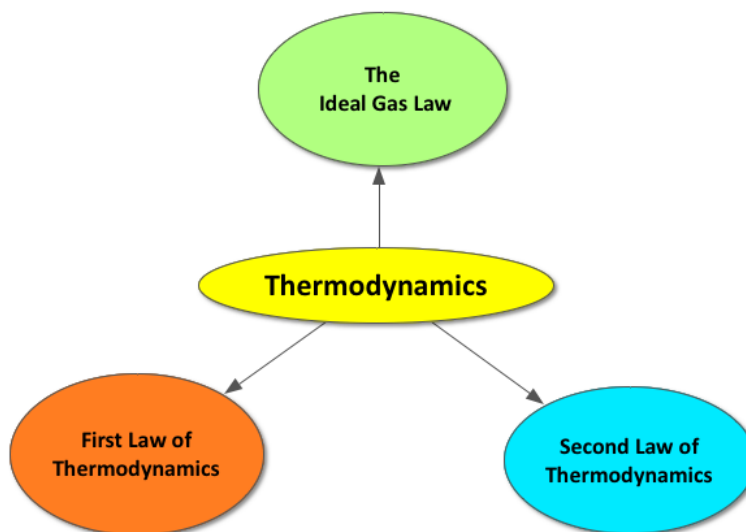
The Ideal Gas Law (PV=nRT) describes the mathematical relationship between the measurable properties of an ideal gas. Thermodynamics is the transfer of energy by heat and work. Thermodynamics depends on the conservation of energy and the flow of heat from high to low temperatures. The First Law of Thermodynamics states that the change in the internal energy of a closed system is equal to the heat into or out of a system plus the work done on the system or by the system ($\Delta U=Q+W$). The Second Law of Thermodynamics states that heat will flow spontaneously from hot to cold and that the entropy of a system will always increase.

TABLE 14.1: Pacing The Lessons

Lesson	Class Periods (60 min)
Lesson 14.1 The Ideal Gas Law	2
Lesson 14.2 First Law of Thermodynamics	2
Lesson 14.3 Second Law of Thermodynamics	2

14.1 The Ideal Gas Law

Key Concept
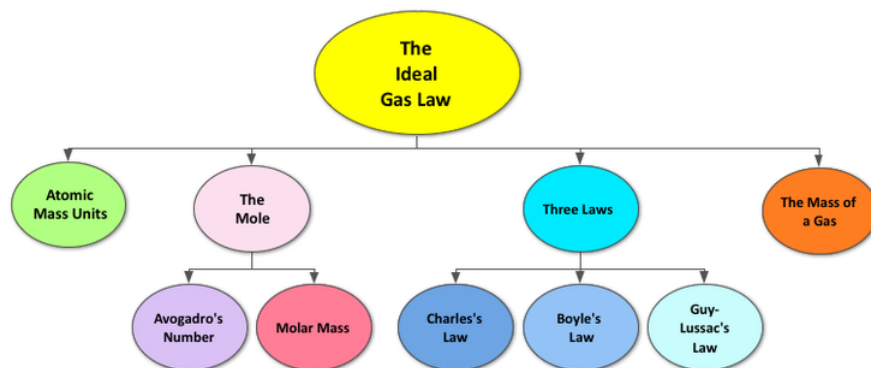
Atomic mass units are used to measure the amount of matter in an atom. One atomic mass unit (*amu*) is equivalent to the mass of one-twelfth a carbon atom. The mole (mol, N) is a basic SI unit that is equivalent to the number of atoms in 12 grams of carbon-12. Molar Mass is the mass of one mole of a substance. Avogadro's number (NA) defines the number of atoms in one mole as $6.022*10^{23}$. The gas laws describe the mathematical relationships between the variables of a gas. Boyle's Law states that if the temperature of a gas remains constant, the volume and pressure will be inversely proportional. Charles's Law states that when the volume of a gas is constant, the pressure and temperature are directly proportional. Guy Lussac's Law states that if the pressure of a gas remains constant, the volume and temperature will be directly proportional. These three laws are combined into one law, PV=nRT, referred to as the Ideal Gas Law.

Lesson Objectives

The student will:

- Explain the Ideal Gas Law.
- Solve problems using the Ideal Gas Law.

Lesson Vocabulary

Avogadro's number
> The constant, $6.022*10^{23}$, representing the number of atoms in a mole of atoms, or the number of molecules in a mole of molecules.

Boyle's Law

States that the absolute pressure and volume of a given mass of confined gas are inversely proportional, if the temperature remains unchanged within a closed system. Thus, it states that the product of pressure and volume is a constant for a given mass of confined gas as long as the temperature is constant, PV = k when T = k. The law was named after chemist and physicist Robert Boyle, who published the original law in 1662.

Charles's Law

An experimental gas law, which describes how gases tend to expand when heated. A modern statement of Charles' Law is: At constant pressure, the volume of a given mass of an ideal gas increases or decreases by the same factor as its temperature on the absolute temperature scale (i.e. the gas expands as the temperature increases). $V = kT$

Guy-Lussac's Law

The pressure of a gas of fixed mass and fixed volume is directly proportional to the absolute temperature of the gas. $\frac{P}{T} = k$

Ideal Gas Law

A law that describes the relationships between measurable properties of an ideal gas. The law states that $P \times V = n \times (R) \times T$, where P is pressure, V is volume, n is the number of moles of molecules, T is the absolute temperature, and R is the gas constant (8.314 Joules per degree Kelvin or 1.985 calories per degree Celsius). A consequence of this law is that, under constant pressure and temperature conditions, the volume of a gas depends solely on the number of moles of its molecules, not on the type of gas. This is also called the Universal Gas Law.

mole

A unit of measurement used in chemistry to express amounts of a chemical substance. A mole is defined as an amount of a substance that contains as many elementary entities (e.g., atoms, molecules, ions, electrons) as there are atoms in 12 grams of pure carbon-12 (^{12}C), which is the isotope of carbon with atomic weight 12. This corresponds to a value of $6.022*10^{23}$ elementary entities of the substance. It is one of the base units in the International System of Units, and has the unit symbol mol.

molecular mass

The mass of a molecule.

Equations

- $1\, u = 1.66 * 10^{-27}\, kg$
- $N_A = 6.022 * 10^{23} = 1\, mole$
- $PV = nRT$

Think*Pair*Share

Allow students time to think about prompts A-C below on their own, share their answer with the person next to them, and then discuss as a class.

Prompt A: How many donuts are in a dozen? [*Twelve*]

Prompt B: How many babies were born if someone had triplets? [*Three*]

Prompt C: How many individual socks are in a pair? [*Two*]

Prompt C: How many atoms are contained in a mole? [$6.022*10^{23}$]

Use this prompt to review the mole and Avogadro's number ($N_A=6.022*10^{23}$).

TED-Ed: How Big is a Mole?

Pass out index cards to each student. Prompt students to answer the following questions while watching the short video clip (4:32) at the link below on their index card. When the video is over, collect cards. Look over them, reading common questions and answers aloud to ignite a class discussion regarding the mole and Avogadro's number.

- What is one thing you found surprising?
- What is one question you still have?

http://ed.ted.com/lessons/daniel-dulek-how-big-is-a-mole-not-the-animal-the-other-one

Teacher's Note: Pay tribute to the mole and Avogadro by celebrating National Mole Day on October 23rd with your class. For more information, click on the link below:

http://www.moleday.org/

IOW: Ideal Gas Law

Prompt students to write out the Ideal Gas Law, define what each variable means and include the units of the variable. *(Refer to sample answers).*

CK-12 Simulation: Runaway Balloon

If time allows, prompt students to explore the gas laws and how they apply to a balloon at high altitude using the simulation below.

http://interactives.ck12.org/simulations/physics/runaway-balloon/app/index.html

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

14.2 First Law of Thermodynamics

Key Concept
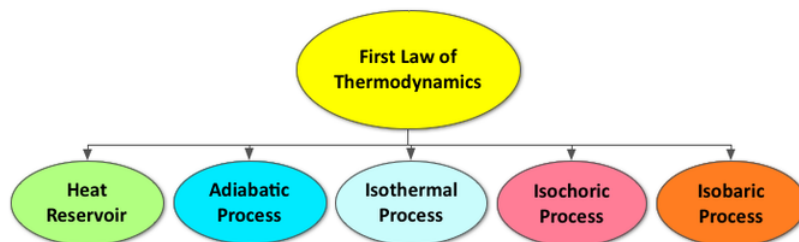
Thermodynamics deals with the transfer of energy through heat and work. The First Law of Thermodynamics states that the internal energy of a closed system is equal to the heat delivered into or out of a system, plus the work done on or by the system. A heat reservoir can be used to accept or deliver heat in order to maintain a system at a constant temperature. Whenever a system maintains a constant temperature, it is referred to as an isothermal process. An adiabatic process is one in which the system exchanges no heat with its surroundings. In an isochoric process, the volume is held constant. An isobaric process is another thermodynamic process in which pressure remains constant.

Lesson Objectives

The student will:

- Describe the First Law of Thermodynamics.
- Solve problems using the First Law of Thermodynamics.

Lesson Vocabulary

adiabatic process
    A thermodynamic process in which no heat enters or leaves the system.
heat reservoir

isobaric process
    A thermodynamic process that takes place at constant pressure.
isochoric process
    A thermodynamic process that takes place at constant volume, also known as an isovolumetric process.
isothermal process
    A thermodynamic process that takes place at constant temperature.

Equations

- $\Delta U = Q + W$

Quick Write

Prompt students to complete a 3-minute Quick Write to answer the questions below in their notebooks. Then, discuss as a class and have students correct their initial answers in their notebooks.

Prompt: What is a **system**? What is the difference between an **open, closed, and isolated system**? *(Refer to sample answers).*

Warming Hands Inquiry Activity

Prompt students to rub their hands together to generate heat. Then, discuss the following question:

Prompt: Did you create energy by rubbing your hands together? *(Refer to sample answers).*

Be sure to highlight the following:

- The First Law of Thermodynamics states that the internal energy of a closed system is equal to the heat delivered into or out of a system, plus the work done on or by the system.
- $\Delta U = Q + W$, W will be positive in this example above

SEE-I

Divide the class into groups of 3-4 students and provide each group with a whiteboard and dry erase markers. Demonstrate how to use the SEE-I method to clarify concepts and show understanding (*see below for more information*). Prompt students to use the SEE-I method to describe the following terms regarding thermodynamic processes:

- Isothermal Process
- Isobaric Process
- Isochoric Process
- Adiabatic Process

Display the completed whiteboards at the front of the class, highlighting good examples and common themes.

Learn more about the SEE-I method by visiting the link below:

http://en.wikipedia.org/wiki/SEE-I

Making Real-World Connections

Challenge students to research some real-world applications of the four thermodynamic processes listed above.

See the links below for examples of ways we rely on the thermodynamic processes in the real world:

- The adiabatic process and diesel engines:
    - http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/diesel.html
- The isothermal process and phase changes:
    - http://en.wikipedia.org/wiki/Isothermal_process
- The isochoric process and the Otto Cycle of an automobile engine:
    - http://en.wikipedia.org/wiki/Otto_cycle

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

14.3 Second Law of Thermodynamics
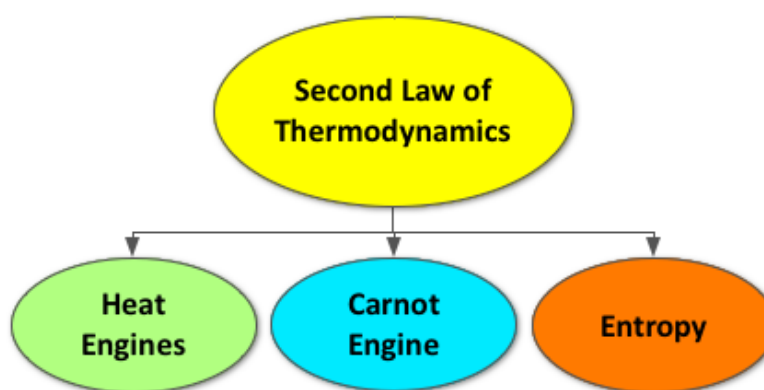
Key Concept

The Second Law of Thermodynamics states that heat will flow spontaneously from hot to cold. A heat engine uses thermal energy to do work. No heat engine is 100% efficient and, as a result, some thermal energy is always lost to the surroundings. A Carnot Engine is an ideal heat engine with reversible processes that operate with maximum efficiency. This conceptual engine showed how substances that produce the highest temperatures when burning in a heat engine produce greater efficiency. With reference to entropy, the Second Law of Thermodynamics states that entropy of a system will always increase.

Lesson Objectives

The student will:

- Understand the second law of thermodynamics.
- Understand how to calculate the efficiency of a heat engine.
- Understand how a Carnot engine operates.
- Understand that entropy is a measure of disorder.

Lesson Vocabulary

heat engine

reversible process

irreversible process

efficiency

Carnot engine

entropy

Equations

- $e = \frac{w}{Q_H} \times 100$
- $e = \left(1 - \frac{Q_L}{Q_H}\right) \times 100$
- $e = \left(1 - \frac{T_L}{T_H}\right) \times 100$

Think*Pair*Share

Allow students time to think about the prompt below on their own, share their answer with the person next to them, and then discuss as a class.

Prompt: Would it be possible for a glass of water sitting on a table at room temperature to spontaneously freeze? Why or why not? *(Refer to sample answers).*

CK-12 Simulation: Heat Engine

Allow students to explore how a heat engine works using this interactive simulation.

http://interactives.ck12.org/simulations/physics/heat-engine/app/index.html

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IOW: Internal Combustion Process

Prompt students to describe each phase of the internal combustion process listed below in their own words.

1. Intake

2. Compression
3. Ignition
4. Expansion
5. Exhaust

Internal Combustion Engine

Allow students to learn more about the four-stroke combustion cycle (Otto Cycle) of a car engine by referencing the links below:

http://auto.howstuffworks.com/engine1.htm

http://en.wikipedia.org/wiki/Internal_combustion_engine#4-stroke_engines

http://www.grc.nasa.gov/WWW/k-12/airplane/icengine.html

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

Chapter Test

Copy and distribute the Chapter 11 Test using the *CK-12 Physics Intermediate Quizzes and Tests* link.

CHAPTER **15**   # Electrostatics

Chapter Outline

Chapter Overview
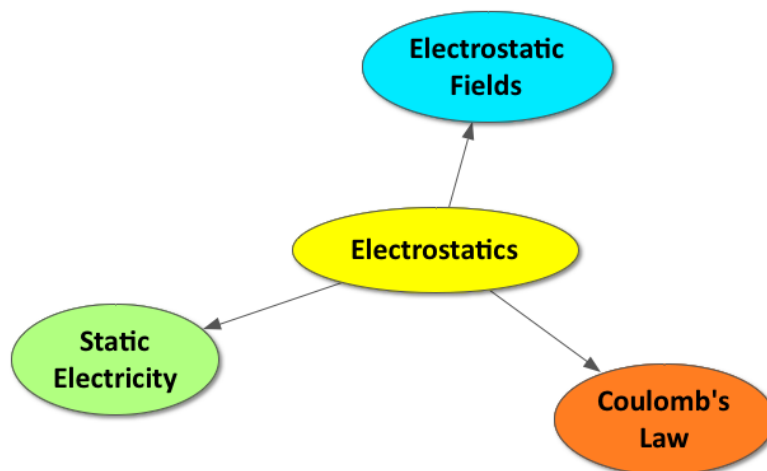
Electrostatics describes the movement of electrons from one object to another, creating an overall imbalance of charge. According to the law of conservation of electric charge, electrons are neither created nor destroyed, but simply transferred. Conductors allow electrons to move freely, whereas insulators do not. Objects can gain static electricity through friction, conduction, or induction. The units of charge are measured in coulombs (C). Coulomb's law defines the force between two charged particles as directly proportional to the product of the charges and inversely proportional to the square of the distance between the charges. Each individual charged particle creates an electric field. The force on a small, positive test charge is used to calculate the magnitude and direction of this electric field and lines can be drawn to illustrate the field.

Online Resources

Physics Classroom: Static Electricity

This website provides a student friendly description of a variety of physical concepts, including static electricity.
http://www.physicsclassroom.com/class/estatics

Static Electricity Gallery

The link to the Physics Classroom Gallery below provides wonderful images illustrating static electricity. https://www.flickr.com/photos/physicsclassroom/galleries/72157624896741488/

Action at a Distance

The link to the Physics Classroom Laboratory provides instruction for an inquiry activity regarding electrostatics. http://www.physicsclassroom.com/getattachment/lab/estatics/se1tg.pdf

PhETs

The links below provide alternative interactive simulations for students who are visual learners or need more practice with many of the concepts in this chapter.

John Travoltage

http://phet.colorado.edu/en/simulation/travoltage

Electric Field of Dreams

http://phet.colorado.edu/en/simulation/efield

CK-12 Simulations

The following links provide more interactive simulations that enable students to explore Coulomb's law and real world applications of electrostatics.

Coulomb's Law: Are force fields real?

http://interactives.ck12.org/simulations/physics/coulombs-law/app/index.html?referrer=ck12Launcher&backUrl=http://interactives.ck12.org/simulations/?backUrl=http://www.ck12.org/teacher/

Why do buildings have lightning rods?

http://interactives.ck12.org/simulations/physics/lightning-rod/app/index.html?referrer=ck12Launcher&backUrl=http://interactives.ck12.org/simulations/?backUrl=http://www.ck12.org/teacher/

Astronomy Picture of the Day (APOD): Lightning captured at 7,207 images/second

This short (30 second) video clip captures lighting striking at ~7,000 images/s.

http://apod.nasa.gov/apod/ap120723.html

TABLE 15.1: Pacing The Lessons

Lesson	Class Periods (60 min)
Lesson 15.1 Static Electricity	2

TABLE 15.1: (continued)

Lesson	Class Periods (60 min)
Lesson 15.2 Coulomb's Law	2
Lesson 15.3 Electrostatic Fields	2

15.1 Static Electricity

Key Concept

Energy is the ability to do work, or apply a force over a distance. Energy can be transferred into a system through work. Potential energy is the energy that is stored in a system. When a force is applied to lift a massive object to a height above the Earth, the energy stored in the system is referred to as gravitational potential energy (PE_g).

Lesson Objectives

The student will:

- Review and understand gravitational potential energy.

Lesson Vocabulary

gravitational potential
 The potential energy per unit mass, represented by V_g.

Equations

- $PE_g = mgh$
- $V_g = gh$

Quick Write

Prompt students to complete a 5-minute quick write to answer the prompt below:

Prompt: What does the term "potential" mean to you? How is it used in everyday language? How is it used in physics? How does its meaning in our everyday language compare to its meaning in physics?

Gravitational Potential Energy Review

Engage the class in a discussion reviewing gravitational potential energy as outlined below.

Set up: Have an object resting at a height above the Earth in front of the classroom and define the system.

Example: An empty water bottle on a desk. Define the "system" as the empty water bottle and the Earth.

Prompt A: Does this system have energy? [*Yes*]

Prompt B: What kind of energy? [*Gravitational Potential Energy*]

Prompt C: How did the energy get there? [*Someone did work and applied a force to move the water bottle a distance above the Earth*]

Prompt D: How could I increase the gravitational potential energy of this system? [*Increase the mass of the water bottle (fill it with water, etc) or increase its height above the Earth*].

Whiteboard Model: Gravitational Potential Energy

Divide students into pairs and provide each pair with a whiteboard and dry erase marker. Challenge each group to create a model of a system with gravitational potential energy. Their whiteboard should include the following:

- An illustration of a system with gravitational potential energy
- The equation for gravitational potential energy and all the variables in their system correctly labeled
- A sentence describing how to increase the gravitational potential energy in their system.

Example:

- An image of a hill with a boulder on top.
- The equation for gravitational potential energy is $PE_g = mgh$. The boulder represents the mass (m), the hill provides the height (h), and the gravitational constant (g) comes from the Earth's gravitational field.
- The higher the hill and the more massive the boulder, the greater the gravitational potential energy will be.

If time allows, prompt students to circulate the room, observing their classmate's whiteboard models.

Optional: Prompt students to take a picture of their whiteboards using their phones, iPads, etc for future reference. Students who take electronic notes can insert this image into their notes.

Wolfram Demonstrations Project: Potential Energy from Objects in Daily Life

Allow students to review gravitational potential energy by exploring the simulation found at the link below.

http://demonstrations.wolfram.com/PotentialEnergyOfObjectsFromDailyLife/

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

15.2 Coulomb's Law

Key Concept
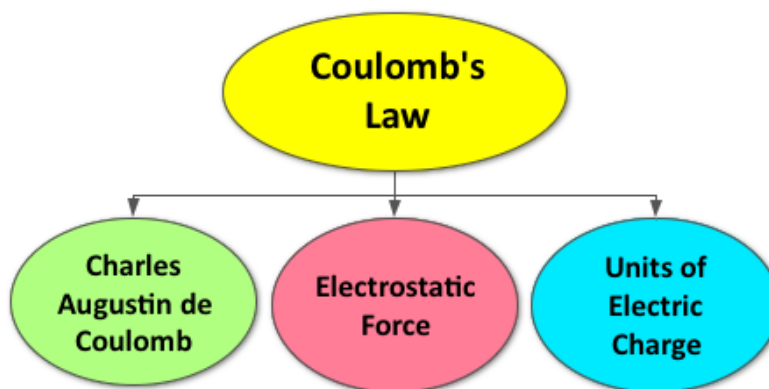
Charles Augustin de Coulomb developed a law defining the electrostatic force between two charged particles. Coulomb's law states that the force between two charges is directly proportional to the product of two charges and inversely proportional to the square of the distance between the two charges. As a result of his contribution to physics, the units of charge are measured in coulombs (C).

Lesson Objectives

The student will:

- Understand Coulomb's Law.
- Understand how to solve problems using Coulomb's Law.

Lesson Vocabulary

Coulomb's Law
   A constant of proportionality equal to $k = 8.99 \times 10^9 \frac{N \cdot m^2}{C^2}$.
Coulomb's Constant
   The force between two charges is directly proportional to the product of the charges and inversely proportional to the square of the distance between the two charges.

Equations

- $F = k\frac{q_1 q_2}{r^2}$
- $q_{e^-} = -1.60 \times 10^{-19}$

Inspire

As students walk into the classroom, have balloons sticking to the wall all around the classroom as a result of electrostatic force. [If this is not possible, simply demonstrate for the class how a balloon will stick to a wall after rubbing it with wool or animal fur.] This should spark interest in the lesson on electrostatic force.

Think*Pair*Share

Allow students time to think about the following prompt below on their own, share their answer with the person next to them, and discuss as a class.

Prompt: Which is stronger, gravitational force or electrostatic force? Why? *(Refer#space#to#space#sample#space#answers)*.

Peer Teaching

Give students some practice problems regarding Coulomb's law. Pair each student up and have them alternate between tutor and tutee.

IOW: Coulomb's Law

Prompt students who are struggling with this lesson to write out the Coulomb's law, define what each variable means and include the units of the variable. Also, allow them to review the inverse square law and highlight the fact that doubling the distance between two charged particles will decrease the electrostatic force on each particle by a factor of four.

`(Refer to sample answers).`

For more help, guide students to the link below:

http://www.regentsprep.org/regents/physics/phys03/acoulomb/default.htm

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

15.3 Electrostatic Fields

Key Concept

A capacitor is a parallel plate conductor, made up to two parallel conducting plates separated by a distance. Although the two plates of a parallel plate capacitor are charged, the overall charge on a capacitor is zero. Capacitance is the ratio of charge to voltage on a capacitor, measured in farads (F). The capacitance is directly proportional to the area of the plates and inversely proportional to the distance between the plates of a capacitor. Capacitors are used to store electric potential energy and play many important roles in common electronic devices.

Lesson Objectives

The student will:

- Understand capacitance.
- Understand how to solve problems involving capacitance.

Lesson Vocabulary

capacitance
    The constant ratio of charge to voltage, which is a property of all capacitors.
capacitor
    Common name for a parallel plate conductor.
farad
    The unit of capacitance, which equals coulombs per volts.

Equations

- $Q = CV$
- $\frac{1\,C}{V} = 1\,F$
- $C = \varepsilon_0 \frac{A}{d}$
- $\varepsilon_0 = 8.85 \times 10^{-12} \frac{C^2}{N \cdot m^2}$

Grocery List: Capacitors

Begin this lesson by challenging students to make a list of real-word connections by completing the prompt below. Then, discuss as a class.

Prompt: Capacitors store electric potential energy and can deliver it in short bursts, as needed. Please list all the ways you can think of in which capacitors are used in our everyday lives. *(Refer#space#to#space#sample#space#answers).*

PhET: Capacitor Lab

Allow students to investigate capacitors at the link below. Prompt students to work in pairs and create a list of observations regarding the simulation. Then, discuss these observations as a class.

http://phet.colorado.edu/en/simulation/capacitor-lab

IOW

Prompt students to write out the two equations regarding capacitance, define what each variable means, and include units for each variable.

Example: $C = \frac{Q}{V}$

C = Capacitance, measured in farads (F)

Q = the charge on the capacitor, measures in coulombs (C)

V = the voltage difference between the capacitor plates, measured in volts (V)

Example: $C = \varepsilon_0 \frac{A}{d}$

C = Capacitance of a parallel plate capacitor, measured in farads (f)

ε_0 = permittivity of free space, $8.85 \times 10^{-12} \frac{C}{N \cdot m^2}$

A = area of one capacitor plate in square meters (m^2)

d = the distance between the parallel capacitor plates, measured in meters (m)

Relating Science to Engineering

The following link provides an activity regarding piezoelectric generators and capacitors for more advanced students.

https://www.teachengineering.org/view_activity.php?url=collection/uoh_/activities/uoh_piezo/uoh_piezo_lesson01_-activity1.xml

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

CHAPTER 16

Electric Potential

Chapter Outline

Chapter Overview

Potential energy is the energy that is stored in a system. Just as a massive object at a height above the earth has gravitational potential energy, a charge on a voltage has electric potential energy. A voltage is an electric potential difference, often provided by a battery. Capacitors are used to store electric potential energy and play many important roles in electronic devices. A dielectric can improve the capacitance of a parallel plate capacitor. A battery does work on a capacitor system and this energy is transformed into electric potential energy.

Online Resources

Hyperphysics: Capacitor Concepts

This is a great website for advanced students wanting to learn more about capacitor concepts.

http://hyperphysics.phy-astr.gsu.edu/hbase/electric/capcon.html#c1

Teach Engineering

This website provides standards-aligned engineering lessons for science classrooms. Many of the lessons relate to capacitors, electric potential energy, and circuits.

https://www.teachengineering.org/

TABLE 16.1: Pacing The Lessons

Lesson	Class Periods (60 min)
Lesson 16.1 Reviewing Gravitational Potential Energy	1
Lesson 16.2 Electric Potential	3
Lesson 16.3 Capacitance	3
Lesson 16.4 Dielectrics	3
Lesson 16.5 Electrical Energy Storage	2

16.1 Reviewing Gravitational Potential Energy

Key Concept

Energy is the ability to do work, or apply a force over a distance. Energy can be transferred into a system through work. Potential energy is the energy that is stored in a system. When a force is applied to lift a massive object to a height above the Earth, the energy stored in the system is referred to as gravitational potential energy (PE_g).

Lesson Objectives

The student will:

- Review and understand gravitational potential energy.

Lesson Vocabulary

gravitational potential
    The potential energy per unit mass, represented by V_g.

Equations

- $PE_g = mgh$
- $V_g = gh$

Quick Write

Prompt students to complete a 5-minute quick write to answer the prompt below:

Prompt: What does the term "potential" mean to you? How is it used in everyday language? How is it used in physics? How does its meaning in our everyday language compare to its meaning in physics?

Gravitational Potential Energy Review

Engage the class in a discussion reviewing gravitational potential energy as outlined below.

Set up: Have an object resting at a height above the Earth in front of the classroom and define the system.

Example: An empty water bottle on a desk. Define the "system" as the empty water bottle and the Earth.

Prompt A: Does this system have energy? [*Yes*]

Prompt B: What kind of energy? [*Gravitational Potential Energy*]

Prompt C: How did the energy get there? [*Someone did work and applied a force to move the water bottle a distance above the Earth*]

Prompt D: How could I increase the gravitational potential energy of this system? [*Increase the mass of the water bottle (fill it with water, etc) or increase its height above the Earth*].

Whiteboard Model: Gravitational Potential Energy

Divide students into pairs and provide each pair with a whiteboard and dry erase marker. Challenge each group to create a model of a system with gravitational potential energy. Their whiteboard should include the following:

- An illustration of a system with gravitational potential energy
- The equation for gravitational potential energy and all the variables in their system correctly labeled
- A sentence describing how to increase the gravitational potential energy in their system.

Example:

- An image of a hill with a boulder on top.
- The equation for gravitational potential energy is PE_g=mgh. The boulder represents the mass (m), the hill provides the height (h), and the gravitational constant (g) comes from the Earth's gravitational field.
- The higher the hill and the more massive the boulder, the greater the gravitational potential energy will be.

If time allows, prompt students to circulate the room, observing their classmate's whiteboard models.

Optional: Prompt students to take a picture of their whiteboards using their phones, iPads, etc for future reference. Students who take electronic notes can insert this image into their notes.

Wolfram Demonstrations Project: Potential Energy from Objects in Daily Life

Allow students to review gravitational potential energy by exploring the simulation found at the link below.

http://demonstrations.wolfram.com/PotentialEnergyOfObjectsFromDailyLife/

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.
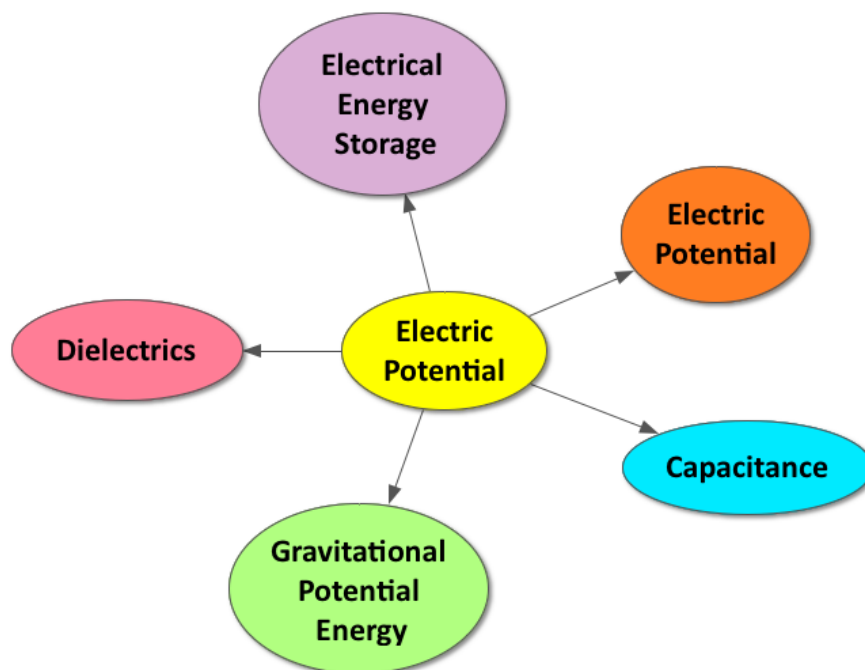
16.2 Electric Potential

Key Concept
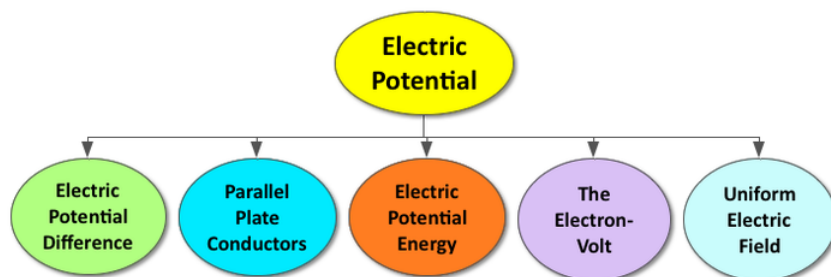
Electric potential is the energy per unit charge, measured in Volts. An electric potential difference is referred to as a voltage. Just as a massive object placed at a height above the Earth stores gravitational potential energy, a charge placed on a voltage stores electrical potential energy. A parallel plate conductor creates a uniform electric field. An electron-volt is defined as 1.6×10^{-19} J, or the change in potential energy experienced by a single electron moving through an electric potential difference of 1 V.

Lesson Objectives

The student will:

- Understand how to solve problems using electric potential energy.
- Understand how to solve problems using voltage differences.
- Understand how to solve problems in a uniform electric field.

Lesson Vocabulary

electric potential
Energy per unit charge.
electric potential difference
The difference in electric potential between two points within an electric field.
voltage
The amount of work done by the electric field per unit charge in moving a charge between two points in the electric field, $\Delta V = \frac{W}{q}$, also known as a change in potential energy.

Equations

- $PE_e = qEx$
- $U = qV$
- $\Delta V = \frac{W}{q}$
- $V = Ed$

Think*Pair*Share

Allow students time to think about the prompt below on their own, share their answer with the person next to them, and then discuss as a class.

Prompt: Which of the following scenarios would require work?

A.To push two positive charges closer together.

B.To separate two positive charges.

Answer: A- pushing two positive charges closer together requires work. Like charges repel and if you place one positive charge in the electric field of another positive charge, it will experience a repelling force directed outward. In order to overcome that repelling force, work must be done.

PhET: Battery Voltage

Allow students to investigate battery voltage at the link below. Prompt students to work in pairs and create a list of observations regarding the simulation. Then, discuss these observations as a class.

http://phet.colorado.edu/en/simulation/battery-voltage

∗∗Be sure to highlight the following:

- *Batteries do work on charges to put them where they don't want to be (Batteries make charges go against the electric field and place negative charges close to other negative charges).*
- *The energy to do the work comes from a chemical reaction inside the battery.*
- *Batteries do not provide charge; they simply provide energy.*
- *Batteries follow the law of conservation of charge –charges are neither created nor destroyed, simply transferred.*
- *Batteries are neutral –they contain the same amount of protons as electrons. However, all the electrons are concentrated at one side/terminus (-) and the protons at the other (+).*
- *A typical AA battery has an electric potential difference of 1.5 V between its positive and negative terminals.*

Whiteboard Model: Battery Analogy

Divide students into pairs and provide each pair with a whiteboard and dry erase markers. Challenge students to create an analogy between gravitational potential energy and electrical potential energy by completing the following

sentence using words, pictures, and equations:

- **A battery is like a . . .**

Example:

- *A battery is like a mountain.*
- *A mountain provides a gravitational potential (Vg=gh) just as a battery provides an electric potential (V=Ex).*
- *When work is done to place a boulder on top of a mountain, gravitational potential energy is stored. When work is done to place a charge on a voltage, electric potential energy is stored.*
- $PE_{electric}=(Q)(V); PE_{gravitational}=(m)(V_g)$

∗∗Be sure to check students' analogies before they begin to whiteboard to address any misconceptions. Their battery should be analogous to something that provides a height difference. Display completed whiteboards at the front of the classroom, highlighting good examples and common themes.

Optional: Prompt students to take a picture of their whiteboards using their phones, iPads, etc for future reference. Students who take electronic notes can insert this image into their notes.

Lemon Battery

If time allows, provide students with a memorable experience regarding batteries by following instructions at the link below. http://hilaroad.com/camp/projects/lemon/lemon_battery.html

Exit Slip

Pass out index cards to the students and ask them to write their response to the following prompt on the card. Collect the cards as students exit the classroom and assess.

Prompt: Complete the sentence below using the concepts discussed in today's lesson.

Voltage is to electric potential energy as _____ is to gravitational potential energy.

[*Answer: height*]

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

16.3 Capacitance

Key Concept

A capacitor is a parallel plate conductor, made up to two parallel conducting plates separated by a distance. Although the two plates of a parallel plate capacitor are charged, the overall charge on a capacitor is zero. Capacitance is the ratio of charge to voltage on a capacitor, measured in farads (F). The capacitance is directly proportional to the area of the plates and inversely proportional to the distance between the plates of a capacitor. Capacitors are used to store electric potential energy and play many important roles in common electronic devices.

Lesson Objectives

The student will:

- Understand capacitance.
- Understand how to solve problems involving capacitance.

Lesson Vocabulary

capacitance
    The constant ratio of charge to voltage, which is a property of all capacitors.
capacitor
    Common name for a parallel plate conductor.
farad
    The unit of capacitance, which equals coulombs per volts.

Equations

- $Q = CV$
- $\frac{1}{V}C = 1\ F$
- $C = \varepsilon_0 \frac{A}{d}$
- $\varepsilon_0 = 8.85 \times 10^{-12} \frac{C^2}{N \cdot m^2}$

Grocery List: Capacitors

Begin this lesson by challenging students to make a list of real-word connections by completing the prompt below. Then, discuss as a class.

Prompt: Capacitors store electric potential energy and can deliver it in short bursts, as needed. Please list all the ways you can think of in which capacitors are used in our everyday lives. *(Refer to sample answers).*

PhET: Capacitor Lab

Allow students to investigate capacitors at the link below. Prompt students to work in pairs and create a list of observations regarding the simulation. Then, discuss these observations as a class.

http://phet.colorado.edu/en/simulation/capacitor-lab

IOW

Prompt students to write out the two equations regarding capacitance, define what each variable means, and include units for each variable.

Example: $C = \frac{Q}{V}$

C = Capacitance, measured in farads (F)

Q = the charge on the capacitor, measures in coulombs (C)

V = the voltage difference between the capacitor plates, measured in volts (V)

Example: $C = \varepsilon_0 \frac{A}{d}$

C = Capacitance of a parallel plate capacitor, measured in farads (f)

ε_0 = permittivity of free space, $8.85 \times 10^{-12} \frac{C}{N \cdot m^2}$

A = area of one capacitor plate in square meters (m^2)

d = the distance between the parallel capacitor plates, measured in meters (m)

Relating Science to Engineering

The following link provides an activity regarding piezoelectric generators and capacitors for more advanced students.

https://www.teachengineering.org/view_activity.php?url=collection/uoh_/activities/uoh_piezo/uoh_piezo_lesson01_-activity1.xml
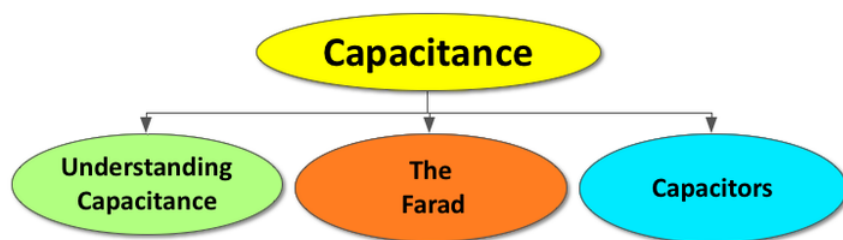
Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook.* You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

16.4 Dielectrics

Key Concept
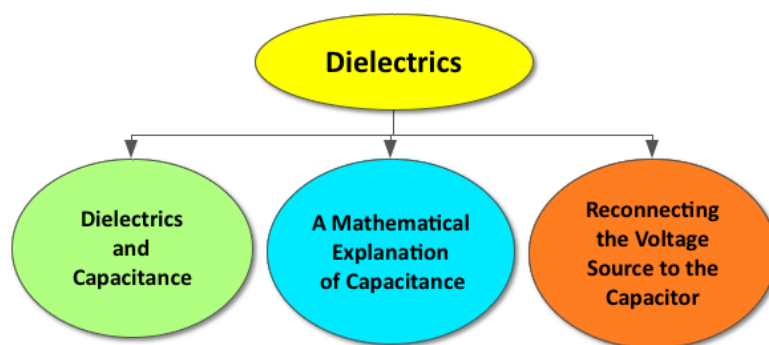
A dielectric refers to the insulating material between the two parallel plates of a capacitor. The polarization of charges in the dielectric material creates an electric field that opposes the electric field between the two conducting plates of the capacitor. As a result, electrostatic repulsion is decreased and the overall capacitance is increased. Each dielectric material increases the capacitance by a certain value, referred to as the dielectric constant (k).

Lesson Objectives

The student will:

- Understand what a dielectric is and how it affects the capacitance of a capacitor.
- Solve problems involving capacitors with dielectrics.

Lesson Vocabulary

dielectric constant
    The factor by which the dielectric increases the capacitance. The dielectric constant is particular to each dielectric material.
dielectric material
    An insulating material placed between the conducting plates of a capacitor.
polarization
    A process similar to induction, in which the molecules of the inductor align such that the positive end of the molecules will be attracted to the negative conducting plate and the negative end of the molecules will be

attracted to the positive conducting plate. An electric field is created inside the dielectric that is opposite to the electric field between the two conducting plates of the capacitor.

Equations

- $C = k\varepsilon_0 \frac{A}{d}$

Think*Pair*Share

Allow students time to think about the prompt below on their own, share their answer with the person next to them, and then discuss as a class.

Prompt: Do you think an insulator could help increase the capacitance of a capacitor? Why or why not? [**Answers will vary. Use this prompt to introduce the class to dielectric materials and their dielectric constant.]

PhET: Capacitor Lab

Prompt students to review what they learned in the previous lesson regarding capacitors by revisiting this simulation.

http://phet.colorado.edu/en/simulation/capacitor-lab

This time, challenge students to complete the following inquiry activity regarding how the design of a capacitor affects its ability to store energy. Be sure to encourage students to focus on the affect of a dielectric on the capacitance of a capacitor.

http://phet-downloads.colorado.edu/files/activities/3455/Capacitor_Student_directions_intro.pdf

Whiteboarding: Capacitor Creation

Divide students into groups of 3-4 students and provide each group with a whiteboard and dry erase markers. Challenge each group to apply their knowledge of parallel plate capacitors and dielectrics to design a hypothetical capacitor that will store maximum electrical potential energy. They should create a sketch of the capacitor and have numerical evidence to support their design.

Display completed whiteboards at the front of the classroom, highlighting good examples and common themes.

The following link provides dielectric constants for some common dielectrics:

http://www.ck12.org/book/CK-12-Physics--Intermediate/section/16.4/#x-ck12-dGFibGU6ZGllbGVjdHJpY2NvbnN0YW50W50

SEE-I

Prompt students who need more help with the concepts introduced in this chapter to use the SEE-I method to describe one or more of the following scientific terms:

- Electric potential
- Electric potential energy
- Electric Field
- Voltage
- Capacitors
- Dielectrics

Learn more about the SEE-I method by visiting the link below:

http://en.wikipedia.org/wiki/SEE-I

Exit Slip

Pass out index cards to the students and ask them to write their response to the following prompt on the card. Collect the cards as students exit the classroom and assess. Prompt **: What is one reason that capacitors are built with dielectrics between their plates?** *(Refer to sample answers).*

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook.* You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

16.5 Electrical Energy Storage

Key Concept
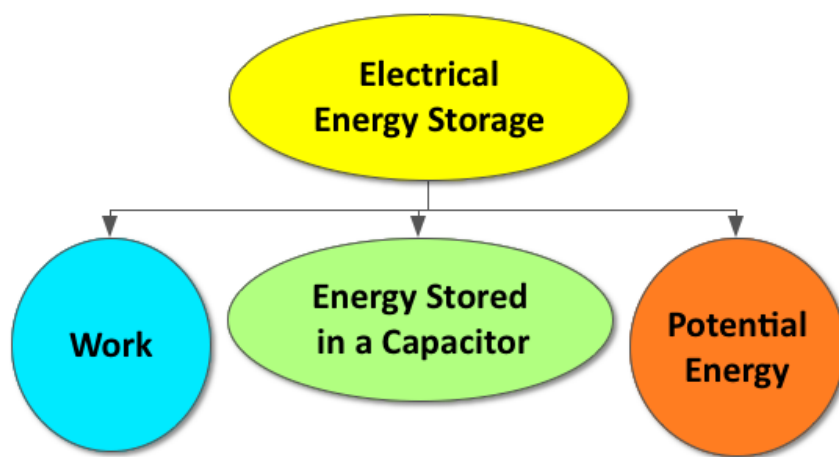
A battery does work on a capacitor system in order to separate charges, generating one positively charged plate and one negatively charged plate. The energy transferred into the capacitor system by the battery is stored as electric potential energy.

Lesson Objectives

The student will:

- Understand how energy is stored in a capacitor.
- Solve problems involving energy stored in capacitors.

Equations

- $PE_{cap} = \frac{1}{2}QV_f$
- $PE_{cap} = \frac{1}{2}CV^2$
- $PE_{cap} = \frac{1}{2}\frac{Q^2}{C}$

Review Game

Divide students into groups of 4-6 and provide each group with a brown bag filled with pieces of paper with the following words:

- Electric Field
- Electric Potential
- Voltage
- Battery
- Electric Potential Energy
- Charge
- Electrons
- Protons
- Capacitor
- Capacitance
- Dielectrics

A student from each group should start the game by picking a word from the bag. They must describe this word to the rest of their group without using the actual word. Once the group has guessed correctly, the person sitting next to them has a turn. The group that guesses the most words in 3 minutes wins.

CK-12 Simulation: Neon Lights

Allow students to explore capacitors and electric potential energy further with this simulation regarding a flashing neon light.

http://interactives.ck12.org/simulations/physics/flashing-neon-light/app/index.html?referrer=ck12Launcher&backUrl=http://interactives.ck12.org/simulations/

Peer Teaching

Give students some practice problems regarding electrical energy storage. Pair each student up and have them alternate between tutor and tutee.

Dispelling Misconceptions

Be sure to spend some time addressing the following misconceptions regarding batteries:

Misconception: A battery provides charge.

A battery provides the energy to move a charge from a low potential to a high potential, establishing an electric potential difference or a voltage. Batteries do work on charges.

Misconception: A battery no longer works when it runs out of charge.

A battery no longer works when it runs out of energy. The chemical reaction that produces energy has gone to completion in a dead battery.

Misconception: Some batteries are rechargeable because you can add more charge to them.

Some batteries can be re-energized because the chemical reaction that produces the energy inside the battery is made to be reversible.

Still Sticky

At the end of the chapter, pass out sticky notes to each student and provide them with the opportunity to write down any questions they still have or discuss concepts that are still unclear to them regarding electric potential. Review the answers to common student questions with the class before the chapter test.

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

Chapter Test

Copy and distribute the Chapter 16 Test using the *CK-12 Physics Intermediate Quizzes and Tests* link.

CHAPTER 17

Circuits

Chapter Outline

Chapter Overview
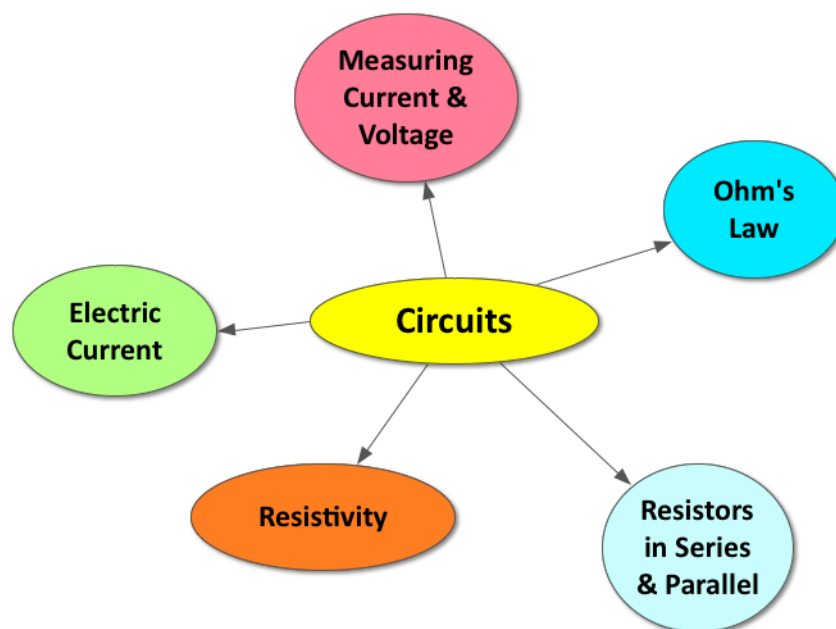
Electric current is the flow of charge that moves through a circuit as a result of a potential difference. Resistors are made of material with resistivity that resist the current in a circuit. Resistors can be connected in series or in parallel. According to Ohm's law, the current is directly proportional to the potential difference (voltage) and inversely proportional to the resistance in an electrical circuit. A voltmeter measures the voltage and an ammeter measures the current of an electrical circuit.

Online Resources

Fun with Electricity

The following link provides electricity lesson plans designed by NSF and University of Wyoming.

http://www.uwyo.edu/scienceposse/resources/lesson-plans/former-fellow-lesson-plans/luke-dosiek/luke-diosiek-fun-with-electricity-circuits.pdf

Physics Classroom: Current Electricity

This website provides a student-friendly description of a variety of physical concepts, including current electricity

http://www.physicsclassroom.com/class/circuits

Teach Engineering

This website provides standards-aligned engineering lessons for science classrooms.

Ohm's Law 1: https://www.teachengineering.org/view_activity.php?url=collection/wpi_/activities/wpi_ohm_1/ohm1_act_joy.xml

Ohm's Law 2: https://www.teachengineering.org/view_activity.php?url=collection/wpi_/activities/wpi_ohm_2/wpi_-ohm2_act_joy.xml

The Science of Everyday Life: Electrical Circuits

The following link is a great resource for students who need more help with the concepts introduced in this chapter.

http://scienceofeverydaylife.com/views/other.cfm?guidAssetId=D1507F6E-09C3-4E7B-B1E9-16708E402009

CK-12 Simulation: Touch Screen

Allow students to investigate how a capacitive touch screen works using this interactive simulation.

http://interactives.ck12.org/simulations/physics/touch-screen/app/index.html?referrer=ck12Launcher&backUrl=http://interactives.ck12.org/simulations/?backUrl=http://www.ck12.org/teacher/

TABLE 17.1: Pacing The Lessons

Lesson	Class Periods (60 min)
Lesson 17.1 Electric Current	2
Lesson 17.2 Ohm's Law	3
Lesson 17.3 Resistivity	2
Lesson 17.4 Resistors in Series and Parallel	4
Lesson 17.5 Measuring Current and Voltage	2

17.1 Electric Current

Key Concept
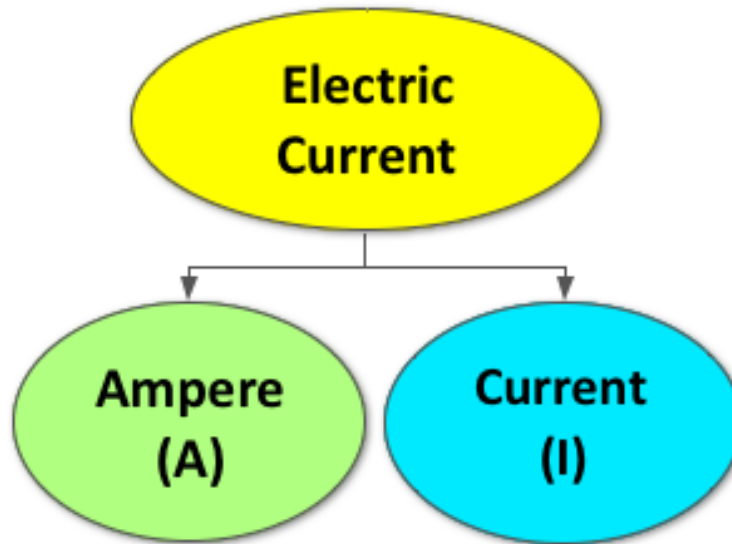
Electric current (I) is the flow of charge, measured in coulombs/second or Amperes (A). An electrical circuit is a closed loop of conducting material through which a current can flow.

Lesson Objectives

The student will:

- Understand how electric current is defined.
- Solve problems involving electric current.

Lesson Vocabulary

electric current
> A flow of charges under the influence of an electric field, such as between the terminals of a battery. The rate $I = \frac{\Delta Q}{\Delta t}$ at which charges flow within a conducting wire past any point in the wire.

Equations

- $I = \frac{\Delta Q}{\Delta t}$

Circuit Construction

To get students excited to learn more about circuits, begin this chapter by allowing students to build a circuit. Divide students into pairs and provide each pair with the necessary materials to build a circuit (ex: D cell battery, connecting wire, small bulb). Challenge students to use the materials to light the bulb.

Once the bulb is lit, prompt students to make a sketch of their circuit in their notebooks or take a picture of their circuit and insert it into their electronic notebooks. Compare and contrast each group's circuit configuration as a class, highlighting good examples and common themes. If time allows, engage the class in a discussion regarding the requirements of an electric circuit.

If time allows, provide students with a couple of switches and have them try to complete the activities described in the link below.

http://theselsproject.org/wp-content/uploads/2013/04/Circuit-Activities-bat_bulb_wire-etc.pdf

If you are unable to gather the materials for a building an actual circuit, the link to the following PhET allows students to build virtual circuits.

http://phet.colorado.edu/en/simulation/circuit-construction-kit-dc

CK-12 Simulations: Flashlight

Allow students to investigate how electricity flows in a simple circuit by using the great introductory simulation at the link below. Prompt students to work in pairs and create a list of observations regarding the simulation. Then, discuss these observations as a class.

http://interactives.ck12.org/simulations/physics/flashlight/app/index.html?referrer=ck12Launcher&backUrl=http://interactives.ck12.org/simulations/?backUrl=http://www.ck12.org/teacher/

Conservation of Energy in Circuits

Challenge students to apply their understanding of energy conservation to answer the prompt below.

Prompt A: Describe the transformation of energy in a simple circuit, made up of a loop of wire connecting a battery and a bulb. *(Refer to sample answers).*

Prompt B: Describe the transformation of energy in a more complex circuit, like the one that allows a blender to work when plugged into a wall socket (120V). *(Refer to sample answers).*

∗∗Highlight the following: ∗In order to current to flow, charges have to be placed on an electric potential (voltage). ∗The charges come from the wire and the electric potential (voltage) comes from a battery or outlet. ∗When charges

are placed on an electric potential (voltage), they have electric potential energy. ∗The role of an electrical circuit is to transform electric potential energy into some other form of energy (light, heat, motion, etc).

Points to Consider:

- Do you think current will flow in a closed circuit without a voltage source? Provide your rationale.
- Do you think current will flow through an open circuit? Provide your rationale.

Misconception Survey

The following statements highlight common misconceptions regarding electrical circuits. Prompt students to take the survey at the beginning of this chapter. Before the end of the chapter, students should review their initial answers and make any changes they feel necessary. At the end of the chapter, you should post the answer key and dispel any common misconceptions as a class (see Lesson 17.5: Assess & Reassess).

Circle T/F to indicate of the following statements are true or false:

- (T / F) Current is used up as it flows through a circuit.
- (T / F) A battery provides the charges in an electrical circuit.
- (T / F) A wall socket provides the charges in an electrical circuit.
- (T / F) A light bulb turns on immediately because current flows through the circuit at the speed of light.

(**All of the above statements are FALSE and should unveil common student misconceptions regarding acceleration).

For more common misconceptions, see the link below that highlights student difficulties with electric circuits:

http://www.physicsclassroom.com/class/circuits/Lesson-2/Common-Misconceptions-Regarding-Electric-Circuits

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

17.2 Ohm's Law

Key Concept
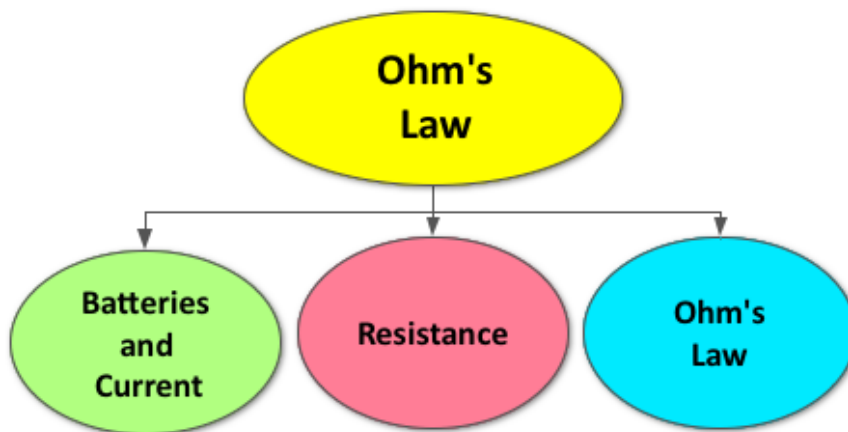
Conventional current is defined as the direction that positive charge would flow. A direct current will flow through a conducting wire connected to both terminals of a battery, from the positive terminal to the negative terminal, as a result of the potential difference. Electrical resistors resist the flow of current in a circuit. According to Ohm's law, the current is directly proportional to the potential difference (voltage) and inversely proportional to the resistance in an electrical circuit.

Lesson Objectives

The student will:

- Understand how conventional current is defined.
- Understand what is meant by electrical resistance.
- Understand how to solve problems using Ohm's law.

Lesson Vocabulary

Ohm's law
   $R = \frac{V}{I}$ meaning that resistance is equal to the proportion of velocity to current.
resistance
   The effect of the movement of electrons through a wire, which is not smooth.

Equations

- $R = \frac{V}{I}$

Think*Pair*Share

Allow students time to think about the prompt below on their own, share their answer with the person next to them, and then discuss as a class.

Prompt: Identify the essential parts of a simple electrical circuit and describe what each part supplies. *(Refer to sample answers).*

∗∗Be sure to dispel the common misconception that the battery/voltage source provides the charges. Also, introduce the role of a resistor. Lastly, re-emphasize the transformation of electrical potential energy into other forms of energy through an electric circuit.

Ohm's Law Lab

Students are prompted to collect data and derive Ohm's Law from their graphs in the inquiry lab activity described at the link below.

http://ct-stem.northwestern.edu/assets/OhmsLaw.pdf

Whiteboard Model: Circuit Analogy

Divide students into pairs and provide each pair with a whiteboard and dry erase markers. Challenge students to create an analogy for an electrical circuit (equipped with a voltage source, current, and a resistor) using words, pictures, and equations.

Example: An electrical circuit is similar to the flow of water from a water tower, to a water wheel, to a pump that puts it back up into the water tower.

- *The voltage (V) is like the tall water tower, at a height above the ground.*
- *The battery is like the water pump, moving water from the ground up to the tall water tower.*
- *The current (I) is like the amount of water flowing through a particular point in the pipes over time.*
- *A resistor (R) is like the water wheel, transforming energy from one form to another (in this case, gravitational potential energy to the mechanical motion (kinetic energy) of the water wheel.*

∗∗Be sure to check students' analogies before they begin to whiteboard to address any misconceptions. Display completed whiteboards at the front of the classroom, highlighting good examples and common themes.

Optional: Prompt students to take a picture of their whiteboards using their phones, iPads, etc for future reference. Students who take electronic notes can insert this image into their notes.

PhET: Ohm's Law

The simulation at the link below is a great resource for students who need more practice with Ohm's Law.

http://phet.colorado.edu/en/simulation/ohms-law

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

17.3 Resistivity

Key Concept
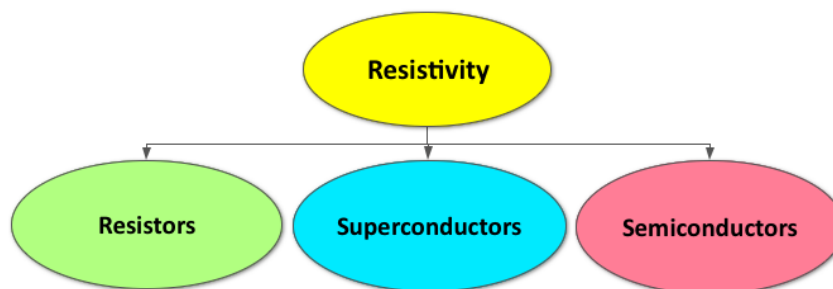
The resistivity of a material is the measure of its resistance to the flow of charge in a circuit. Resistivity is a constant of proportionally (ρ), measured in units Ω. The resistance of a wire is directly proportional to the length of the wire (L) and the resistivity of the material the wire is made of (ρ) and inversely proportional to the cross-sectional area of the wire (A). Semiconductors allow a limited flow of electrical charge. Superconductors refer to materials that loose all electrical resistance at extremely low temperatures (close to absolute zero).

Lesson Objectives

The student will:

- Understand how to solve problems involving resistivity.
- Understand how to read the resistor code.

Lesson Vocabulary

resistivity
   A constant of proportionality which depends upon the material used to make the wire, expressed in units .
resistor
   Electric components whose only purpose is to add resistance to a circuit.
semiconductors
   Materials that fall between the two extremes of conductors and insulators. Semiconductors permit a limited amount of electron flow and are very useful in constructing electronic devices.
superconductors
   Materials that lose resistance when cooled to near absolute zero.

Equations

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

Think*Pair*Share

Allow students time to think about the prompt below on their own, share their answer with the person next to them, and then discuss as a class.

Prompt: Which bulb do you think has greater resistance: A 25W light bulb or a 100W light bulb? Why? *(Refer to sample answers).*

Physics Classroom: Round vs Oblong –The Greatest Resistance? Lab

Students will compare the resistance of two bulbs and apply their understanding of Ohm's law in the inquiry activity described at the link below.

http://www.physicsclassroom.com/getattachment/lab/circuits/c5tg.pdf

SEE-I

Divide the class into groups of 3-4 students and provide each group with a whiteboard and dry erase markers. Demonstrate how to use the SEE-I method to clarify concepts and show understanding (*see below for more information*).

Prompt students to use the SEE-I method to describe **resistance**.

Display the completed whiteboards at the front of the class, highlighting good examples and common themes.

Learn more about the SEE-I method by visiting the link below:

http://en.wikipedia.org/wiki/SEE-I

Resistor Color Code

Divide students into pairs and provide each pair with a variety of resistors. Challenge each group to use the resistor color code to determine each resistor's resistance in Ohms.

If possible, provide materials for building a simple circuit (D battery, connecting wire, bulb) and allow students to see the affect of including the resistor in their circuit. (For example, a very small resistor should decrease the brightness of the bulb or a large resistor will prevent the bulb from lighting altogether).

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

17.4 Resistors in Series and Parallel

Key Concept
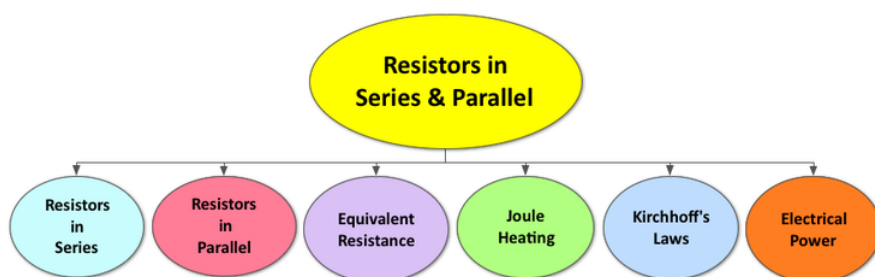
Circuit diagrams consist of symbols illustrating the configuration of batteries, resistors, capacitors, and/or switches in an electrical circuit. Resistors can be connected in series or in parallel. When a current passes through a resistor, there is a decrease in electric potential, commonly referred to as a voltage drop. Resistors in series experience the same current and resistors in parallel experience the same voltage drop. The equivalent resistance is the total resistance of the circuit. The equivalent resistance of a series circuit is always greater than the resistance of any one resistor in the circuit. The equivalent resistance of a parallel circuit is always less than the resistance of any one resistor in the circuit. Electrical power is the rate of energy consumption in an electrical circuit, measured in joules/second or Watts. The power of an electrical circuit is the product of the voltage and the current. Joule heating is the rate that a resistor transforms energy. Kirchhoff's laws can also be used to analyzed circuits. Capacitors can be included in a circuit to store and release charge.

Lesson Objectives

The student will:

- Be able to distinguish between a series and parallel circuit.
- Solve problems involving circuits with resistors.

Lesson Vocabulary

joule heating
    The rate at which the energy (power) is dissipated through a resistor.
parallel circuit
    A circuit in which the current has more than one pathway available.

series circuit
A circuit in which the current has just one pathway between the positive and negative terminal of the battery.

Equations

- $V_{total} = I(R_{equivalent})$
- $R_{series-equivalent} = R_1 + R_2 + ...$
- $I_{in} = I_{out}$
- $R_{parallel-equivalent} = \frac{R_1 R_2}{R_1 + R_2}$
- $P_{electric-power} = IV$
- $P_{electric-power} = I^2 R$

Quick Write

Prompt students to complete a 3-minute Quick Write to answer the questions below. Then, discuss as a class.

Prompt: Why do you think all the lights in a strand of Christmas tree lights go out when only one bulb is broken? Why do you think the kitchen ceiling lights remain lit when only one bulb is broken?

CK-12 Simulations: Dollhouse

Allow students to investigate how electricity flows through their house using the simulation at the link below. Prompt students to work in pairs and create a list of observations regarding the simulation. Then, discuss these observations as a class.

http://interactives.ck12.org/simulations/physics/dollhouse/app/index.html?referrer=ck12Launcher&backUrl=http://interactives.ck12.org/simulations/?backUrl=http://www.ck12.org/teacher/

Drawing Circuit Diagrams

Introduce/review the circuit symbols. Then, challenge students to draw diagrams for the following circuits using the symbols.

- A circuit with one battery and one bulb.
- An open circuit with one battery, one bulb, and one switch.
- A circuit with two bulbs and a battery in series.
- A circuit with one battery, two resistors, and one bulb in series.
- A circuit with two bulbs and a battery in parallel.

Light-House Project

If time allows, the project outlined in detail at the link below challenges students to design and build a circuit for their dream house.

http://www.trashforteaching.org/wp-content/uploads/2013/08/Light_House_Project_Plans.pdf


Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

17.5 Measuring Current and Voltage

Key Concept
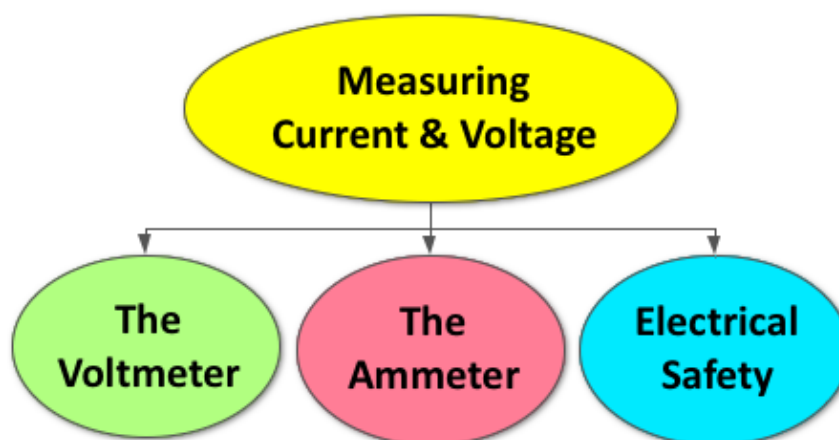
A voltmeter measures the voltage of an electrical circuit and must be connected in parallel with the circuit. An ammeter measures the current of an electrical circuit and must be connect in series with the circuit. Fuses or circuit breakers are connected in series with most house circuits as a safety precaution. Grounding is another way of preventing electrical fires.

Lesson Objectives

The student will:

- Understand how an ammeter is used.
- Understand how a voltmeter is used.

Lesson Vocabulary

- ammeter: A device used to measure currents.
- voltmeter: A device used to measure voltages.

Grocery List: Circuits in Series & Parallel

Review the concepts introduced in Lesson 17.4 by challenging students to make a list of real-word connections by completing the prompts below. Then, discuss as a class.

Prompt A: List as many examples of electrical devices that use a series circuit as you can. *(Refer to sample answers).*

Prompt B: List as many examples of electrical devices that use a parallel circuit as you can. *(Refer to sample answers).*

CK-12 Simulation: Galvanometer

Allow students to use the simulation below to investigate how we measure current and voltage.

http://interactives.ck12.org/simulations/physics/galvanometer/app/index.html?referrer=ck12Launcher&backUrl=http://interactives.ck12.org/simulations/?backUrl=http://www.ck12.org/teacher/

Peer Teaching

Give students time to answer the following practice problems individually. Provide the answer key to the class and have students check their own work. Pair each student up and have them alternate between tutor and tutee, explaining the step-by-step guide of how to answer each question.

> **Prompt: The ConAir 1875 hairdryer has an electrical resistance of 7.68 Ω.**

Question #1; How much power does this hairdryer consume when plugged into your bathroom outlet (120 V)?

Step 1: Find the current (I)

V=IR

120V=(I)(7.68)

I=15.63A

Step 2: Solve for power

P=IV

P=(15.63A)(120V)

P=1875 W (just like the name!)

Question #2: Your friend comes over with the same hairdryer. Can you both plug them in and use them if your bathroom circuit breaker trips when the bathroom draws 28A of current?

Two of these hair dryers will draw 31.26 A of current (15.63A x 2 = 31.26 A). If you both plug the hairdryers into your bathroom outlet and turn them on, the circuit breaker will trip and you will not be able to use the outlet.

Mulitmeters

Challenge advanced students to learn more about multimeters at the link below.

http://www.doctronics.co.uk/meter.htm

If possible, purchase some simple multimeters and allow students to measure the voltage and resistance of across a range of circuit configurations.

Misconception Survey

Students should review their initial answers to the survey given at the beginning of the chapter and make any changes they feel necessary. At the end of this lesson, you should post the answer key and dispel any common misconceptions as a class.

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

Chapter Test

Copy and distribute the Chapter 17 Test using the *CK-12 Physics Intermediate Quizzes and Tests* link.

CHAPTER **18**

Magnetism

Chapter Outline

Chapter Overview
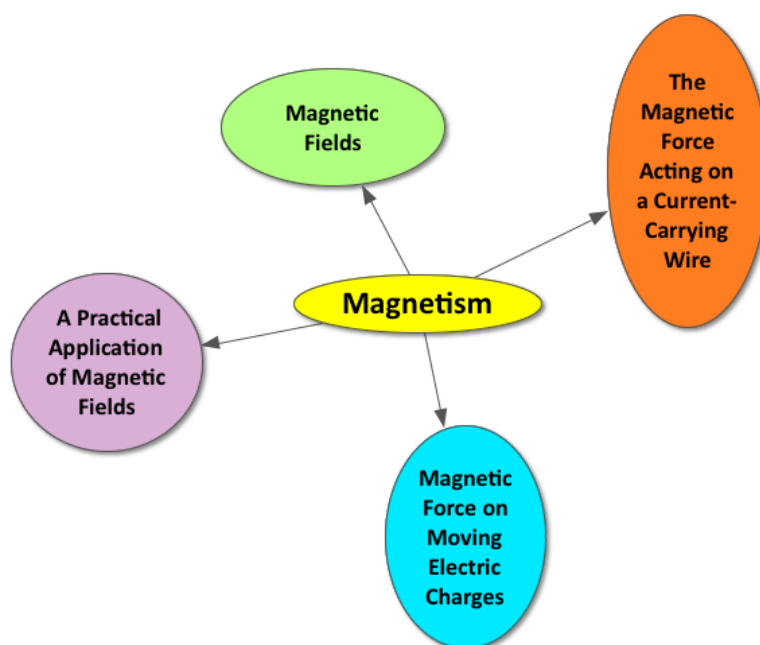
A magnetic field surrounds a moving charge. A group of atoms with aligned magnetic fields are referred to as magnetic domains. A magnet is a material in which all the magnetic domains are aligned. Every magnet has a north pole and a south pole; like poles repel and opposite poles attract. The moving charges in the Earth's core produce a large magnetic field, looping from the magnetic north pole to the magnetic south pole. A magnetic field also surrounds the moving electric charges in a current-carrying wire. The direction of the magnetic field in a current-carrying wire can be determined by using the first Right Hand Rule. When a current-carrying wire or a moving charge enters a magnetic field, it experiences a force. The second Right Hand Rule can be used to determine the direction of the magnetic force on a current-carrying wire or a moving electric charge. An electric motor uses this principle to transform electric potential energy into mechanical energy.

Video Hooks

The videos below would be great hooks to get students excited about the real-world applications of magnetism.

- https://www.youtube.com/watch?v=f3BNHhfTsvk
- https://www.youtube.com/watch?v=77EG-Bn2qCg
- https://www.youtube.com/watch?v=pGcZvSG805Y

TABLE 18.1: Pacing The Lessons

Lesson	Class Periods (60 min)
Lesson 18.1 Magnetic Fields	4
Lesson 18.2 The Magnetic Force acting on a Current-Carrying Wire	3
Lesson 18.3 Magnetic Force on Moving Electric Charges	1
Lesson 18.4 A Practical Application of Magnetic Fields	3

18.1 Magnetic Fields

Key Concept
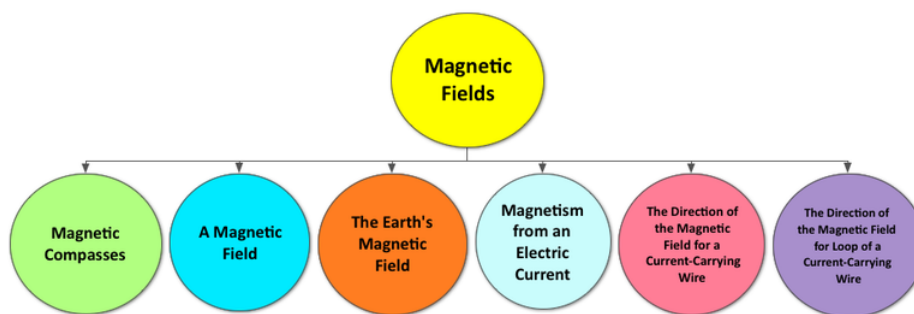
Moving charges create magnetic fields. When the magnetic fields surrounding the atoms in a material permanently align to create magnetic domains, the material is described as a magnet. Every magnet has a north pole and a south pole, with a magnetic field looping from the north pole to the South Pole. Like poles repel and opposite poles attract. The moving charges in the Earth's core create a large magnetic field around the Earth. The direction of this magnetic field is from the magnetic north pole (the geographic south pole) to the south pole (the geographic north pole). The current in an electrical wire creates a magnetic field around the wire. The direction of this magnetic field depends on the direction of the current and can be determined using the first Right Hand Rule. The magnetic field of a current-carrying wire can be greatly increased by coiling the wire to form a loop, commonly referred to as a solenoid.

Lesson Objectives

The student will:

- Know how to determine the direction of a permanent magnetic field.
- Know that a current-carrying wire creates a magnetic field.
- Know how to determine the direction of the magnetic field produced by a current-carrying wire.

Lesson Vocabulary

magnetic domains
> Certain regions of a material that align with the Earth's external magnetic field. These regions are responsible for the magnetic properties of the material.

magnetic poles
> The two end of a magnet, known as the north pole and the south pole. Like poles repel each other, and opposite poles attract each other. Magnetic poles always come in pairs.

magnetism

> Certain materials, because of their atomic structure, will have their atoms align parallel to an external magnetic field.

right-hand rule

> Used to determine the directio of the magnetic field around a wire. Point the thumb of the right hand in the direction of the (conventional) current and then curl the fingers into a fist. The fingers curl in the direction of the magnetic field around the wire.

Quick Write

Place a variety of objects made of each of the following types of materials on the students' desks before they enter the classroom:

- Objects made of permanently magnet material (ex: bar magnets)
- Objects made of temporarily magnet material (ex: paper clips)
- Objects made of non-magnetic material (ex: pieces of paper)

Allow some time for students to explore the objects and then prompt the students to complete a 5-minute Quick Write to answer the simple question below on an index card with their name on it. At the end of the Quick Write, collect the cards and keep them for students' review at the end of the chapter.

Prompt: Why do you think some materials are magnetic and others are not?

∗∗*Use this warm-up activity to introduce the following concepts:*

- *Moving charges create magnetic fields.*
- *Just as a gravitational field (g) surrounds a massive object and a voltage field (V) surrounds a charge, a magnetic field (B) surrounds a moving charge.*
- *Magnetic domains are groups of atoms in which all the magnetic fields are aligned.*
- *Materials in which all domains are aligned are permanently magnetic (ex: iron bar magnet).*
- *Materials in which the domains become aligned only in the presence of a permanent magnet are referred to as temporary magnets (ex: aluminum paper clip).*
- *Materials that have no domains are non-magnetic (ex: a piece of paper).*
- *Magnetic fields always have two poles: a north pole and a south pole; like poles repel and opposite poles attract.*

If time allows, show the following video (6:25) from Minute Physics called "Magnets: How do they work?" found at the link below:

https://www.youtube.com/watch?v=hFAOXdXZ5TM#t=81

PhET: Faraday's Electromagnetic Lab

Allow students to investigate the magnetic field created by the moving charges in a current-carrying wire using the _Electromagnet_ tab in the simulation below. Prompt students to work in pairs and create a list of observations regarding the Electromagnet simulation. Then, discuss these observations as a class.

http://phet.colorado.edu/en/simulation/faraday

∗∗*Be sure to highlight the following concepts in your class discussion:*

- *As the amount of current increases, the strength of the magnetic field increases.*
- *As the number of loops in the coil of wire increases, the strength of the magnetic field increases.*
- *As the direction of the current changes, the direction of the magnetic field changes.*

Whiteboard Model: Magnetic Fields

Divide students into groups of 3-4 and provide each group with a whiteboard and dry erase markers. Challenge each group to compare the magnetic field surrounding the Earth and the magnetic field surrounding a solenoid using words, pictures, and equations.

Display completed whiteboards at the front of the classroom, highlighting good examples and common themes.

**Be sure to highlight the following Big Idea:

- *The metal charges in the liquid of the Earth's outer core move like the charges in a solenoid, generating a giant magnetic field.*

If time allows, show the following video (2:47) from Discovery TV on the Earth's magnetic protection:

https://www.youtube.com/watch?v=AtDAOxaJ4Ms

Also, the following PhET simulation nicely illustrates the Earth's magnetic field:

http://phet.colorado.edu/en/simulation/magnet-and-compass

Peer Teaching

Provide students with practice problems requiring them to use the first Right Hand Rule to determine the direction of the magnetic field surrounding a current-carrying wire. Pair each student up and have them alternate between tutor and tutee.

Exit Slip

Pass out index cards to the students and ask them to write their response to the following prompt on the card. Collect the cards as students exit the classroom and assess.

Prompt: What happens to a permanent magnet that breaks in half? [*Sample Answer: The magnetic domains remained aligned, maintaining a north pole and a south pole, with a magnetic field looping from the north pole to the south pole.*]

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

18.2 The Magnetic Force acting on a Current-Carrying Wire

Key Concept
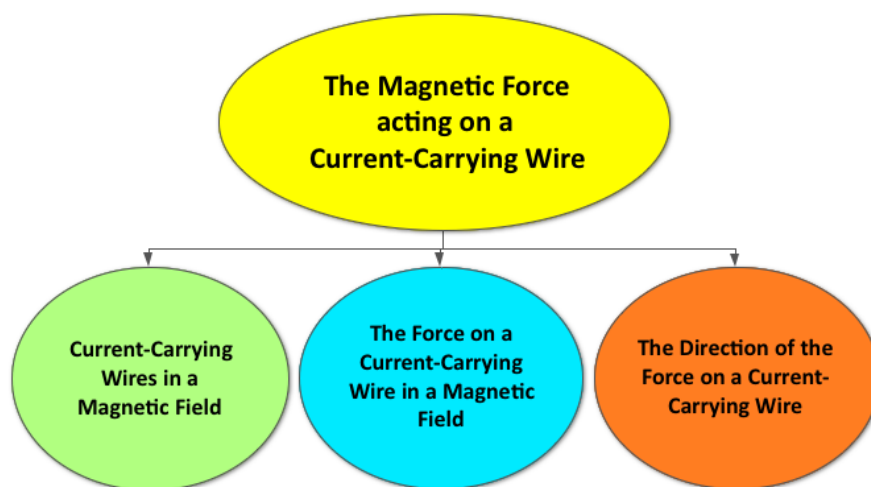
A magnetic field exerts a force on a current-carrying wire. The magnitude of the force is equal to the product of the current, the length of the wire, the magnetic field, and the sine of the angle between the direction of the current and the direction of the magnetic field F = ILB sinθ . The direction of the force can be determined using the second Right Hand Rule.

Lesson Objectives

The student will:

- Know under which conditions a current-carrying wire experiences a force when placed in a magnetic field.
- Use the right-hand rule to determine the force on a current-carrying wire in a magnetic field.
- Solve problems involving the force on a current-carrying wire in a magnetic field.

Equations

- $F = ILB \sin\theta$

The Telegraph

Inspire students to want to learn more about the practical applications of understanding the force on a current-carrying wire in a magnetic field by starting the lesson with this historical video.

https://www.youtube.com/watch?v=pkafFxtc8A8

If time allows, divide students into groups of 3-4. Provide each group with the materials and instructions described at the link below to build a simple telegraph.

http://www.ces.ncsu.edu/depts/fourh/old/greenlight/afterschool/telegraph_lesson_%28finished%29.pdf

CK-12 Simulation: The Telegraph

Allow students to investigate how electromagnetism can be used to communicate in the simulation below. Prompt students to work in pairs and create a list of observations regarding the simulation. Then, discuss these observations as a class.

http://interactives.ck12.org/simulations/physics/telegraph/app/index.html?referrer=ck12Launcher&backUrl=http://interactives.ck12.org/simulations/?backUrl=http://www.ck12.org/teacher/

∗∗*Be sure to highlight the following Big Idea in your class discussion:*

- *A current-carrying wire experiences a magnetic force from a magnetic field.*
- *The magnetic force on a current-carrying wire is used in a telegraph to transmit information through the Morse code.*

Peer Teaching

Provide students with practice problems requiring them to determine the magnitude and direction of the magnetic force on a current-carrying wire, using the equation and the second Right Hand Rule. Pair each student up and have them alternate between tutor and tutee.

Real World Applications

Challenge students to research some real-world examples of the magnetic force on a current-carrying wire in a magnetic field. Some examples include:

- How do speakers work?

http://www.physics.org/article-questions.asp?id=54

- How do Maglev Trains work?

https://www.youtube.com/watch?v=iaElPV0FWJ0&feature=related

3-2-1 Exit Slip

Pass out index cards to the students and ask them to write their response to the following prompt on the card. Collect the cards as students exit the classroom and assess.

Prompt: What are

- 3 things you learned?
- 2 facts you found interesting?
- 1 question you still have?

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

18.3 Magnetic Force on Moving Electric Charges

Key Concept
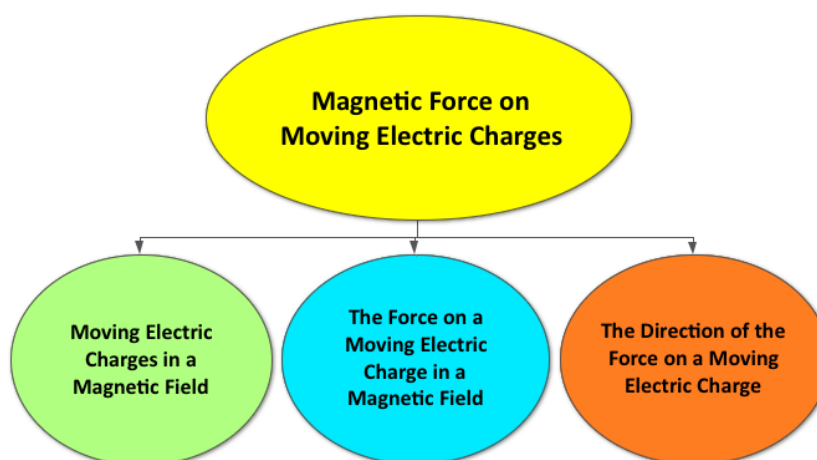
Moving charges experience a magnetic force when they enter a magnetic field at an angle. The magnitude of the force is equal to the product of the charge, the velocity of the charge, the magnetic field and the sine of the angle between the direction the charge is moving and the direction of the magnetic field $F_{on-one-charge}$ = qvB sinθ). The direction of the force can be determined using the second Right Hand Rule.

Lesson Objectives

The student will:

- Know under which conditions a moving electric charge experiences a force when placed in a magnetic field.
- Use the right-hand rule in order to determine the force on a moving electric charge in a magnetic field.
- Solve problems involving the force acting on a moving electric charge in a magnetic field.

Equations

- $F_{on-one-charge} = qvB\sin\theta$

NOVA: Space Storms

Inspire students to want to learn more about the practical applications of understanding the force on a moving electric charge in a magnetic field by starting the lesson with this video on space storms, narrated by Neil DeGrasse Tyson.

http://www.pbs.org/wgbh/nova/space/space-storms.html

Peer Teaching

Provide students with practice problems requiring them to determine the magnitude and direction of the magnetic force on a moving electric charge, using the equation $F_{on-one-charge} = qvB \sin\theta$ and the second Right Hand Rule. Pair each student up and have them alternate between tutor and tutee.

Real World Applications

Challenge students to research real-world examples of the magnetic force on a moving electric charge in a magnetic field. Some real-world examples include:

- Animal Magnetism:

http://www.pbs.org/wgbh/nova/nature/magnetic-impact-on-animals.html

- The Mass Spectrometer:

http://demonstrations.wolfram.com/TheMassSpectrometer/

Still Sticky

At the end of class, pass out sticky notes to each student and provide them with the opportunity to write down any questions they still have or discuss concepts that are still unclear to them regarding simple harmonic motion.

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

18.4 A Practical Application of Magnetic Fields

Key Concept
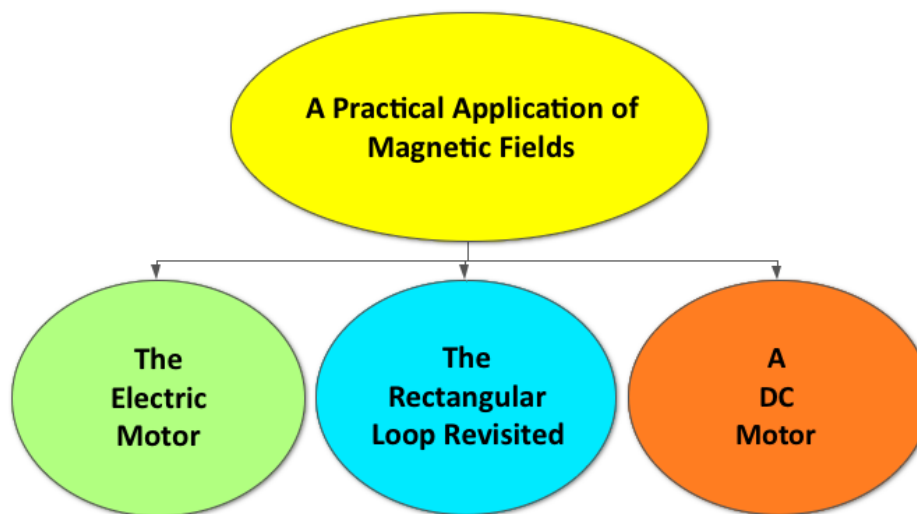
The electric motor utilizes the physical principle that a magnetic field exerts a force on a current-carrying wire to transform electric potential energy into mechanical energy. The electric motor is incorporated into in many electrical devices we rely on in our everyday lives.

Lesson Objectives

The student will:

- Understand the basic operation of an electric motor.

Lesson Vocabulary

brushes
> A device that conducts current between stationary wires and moving parts

commutator
> A device used to periodically reverse the direction of current in a motor

electric motor
> A device which converts electrical energy into mechanical work.

Equations

- $\tau = IAB \sin \theta$

Grocery List: Electric Motors

Begin this lesson by challenging students to make a list of real-word connections by completing the prompt below. Then, discuss as a class.

Prompt: Electric motors convert electrical potential energy into mechanical energy by applying the physical principle that magnetic fields exert a force on a current-carrying wire. Please list all the ways you can think of in which we use electric motors in our everyday lives.

[Sample list: Washing machines, lawn mowers, blenders, and fans are all common examples of an electric motor.]

Build an Electric Motor

Divide students into groups of 3-4. Provide each group with the materials and instructions described at the link below to build a simple electric motor.

http://www.msichicago.org/online-science/activities/activity-detail/activities/build-an-electric-motor/browseactivities/0/

Whiteboarding: The Electric Motor

Divide students into groups of 3-4 (preferably the same group as in the Build a Motor activity described above) and provide each group with a whiteboard and dry erase markers. Challenge each group to create a whiteboard model illustrating how an electric motor works using a combination of words, pictures, and equations.

Display completed whiteboards at the front of the classroom, highlighting good examples and common themes.

The following link nicely illustrates how an electric motor works:

http://electronics.howstuffworks.com/motor1.htm

Peer Teaching

Provide students with practice problems requiring them to use the second Right Hand Rule to determine the direction of the magnetic force from a magnetic field on the loop of wire in a simple electric motor. Pair each student up and have them alternate between tutor and tutee.

Quick Write Review

Pass back students' index cards from the Quick Write warm-up activity in lesson 18.1. Allow students some time to review their answers and prompt them to correct any mistakes. If time allows, answer any unresolved student questions as a class.

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook.* You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

Chapter Test

Copy and distribute the Chapter 18 Test using the *CK-12 Physics Intermediate Quizzes and Tests* link.

CHAPTER **19**   # Electromagnetism

Chapter Outline

Chapter Overview
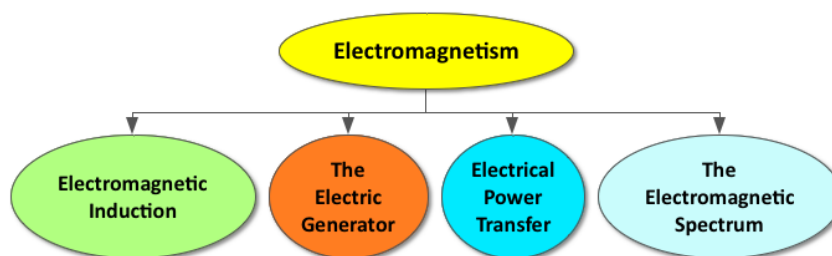
The study of electromagnetism is founded upon the following two physical principles (1) moving electric charges create magnetic fields and (2) moving magnetic fields push electric charges. Electromagnetic induction is the process of using a changing magnetic field to generate a current through a coil of wire. An electric generator relies on electromagnetic induction to convert mechanical energy into electric potential energy. Power companies utilize large generators to produce high voltages and depend on transformers to decrease the voltage for our electrical outlets.

Online Resources

PhETs

The links below provide alternative interactive simulations for students who are visual learners or need more practice with many of the concepts in this chapter.

Radiating Charge: http://phet.colorado.edu/en/simulation/radiating-charge

Radio Waves and Electromagnetic Fields: http://phet.colorado.edu/en/simulation/radio-waves

NASA: The Electromagnetic Spectrum

The following website provides a student friendly description of the electromagnetic spectrum.

http://imagine.gsfc.nasa.gov/science/toolbox/emspectrum1.html

The Electromagnetic Spectrum: Frontline

This website, from PBS Learning Media, provides a great video explanation of the electromagnetic spectrum for visual and auditory learners.

http://www.pbslearningmedia.org/resource/phy03.sci.phys.energy.emspectrum/the-electromagnetic-spectrum-frontline/

Wolfram Demonstrations Project

The following link provides an interactive demonstration regarding electromagnetic waves.

http://demonstrations.wolfram.com/ElectromagneticWave/

Apps

Color Uncovered

This is a wonderful App, by the San Francisco Exploratorium, with a variety of interactive modules enabling students to explore the concept of light.

https://itunes.apple.com/us/app/color-uncovered/id470299591?mt=8

TABLE 19.1: Pacing The Lessons

Lesson	Class Periods (60 min)
Lesson 19.1 Electromagnetic Induction	2
Lesson 19.2 The Electric Generator	2
Lesson 19.3 Electrical Power Transfer	2
Lesson 19.4 The Electromagnetic Spectrum	3

19.1 Electromagnetic Induction

Key Concept
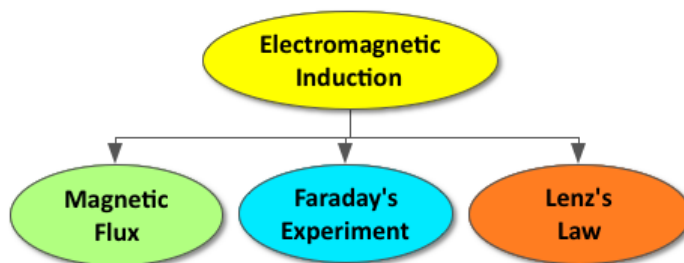
A changing magnetic field will generate a current through a coil of wire in a process called electromagnetic induction. The number of magnetic field lines that pass through the coil of wire is referred to as the magnetic flux ( ), measured in webers (Wb). Faraday's law of induction states that the induced voltage in a coil of wire is equal to the product of the number of loops in the coil and the rate of change in the magnetic flux. According to Lenz's law, this induced current will flow in a direction that opposes a change in the magnetic flux.

Lesson Objectives

The student will:

- Understand magnetic flux.
- Understand Faraday's law of induction.
- Understand Lenz's law.

Lesson Vocabulary

electromagnetic induction
   Both a current and a voltage may be produced by changing a magnetic field.
induced current
   A current created by the changing magnetic field.
magnetic flux
   The product of the magnitude of the magnetic field vector , the magnitude of the area vector , and the cosine of the angle between them.
primary coil
   The coil that is always attached to the battery and the iron ring in Faraday's Experiment.

secondary coil

    The coil attached to a galvanometer and the iron ring in Faraday's Experiment.

Equations

- $\phi = BA\,cos\theta$
- $V = -N\frac{\Delta\phi}{\Delta t}$

Quick Write

Prompt students to complete a 5-minute Quick Write to answer the questions below on an index card with their name on it. At the end of the Quick Write, collect the cards and keep them for students' review at the end of the chapter.

- How are magnetism and electricity related?
- How do we generate voltage without using batteries?
- Where does the electricity in my house come from?

PhET: Faraday's Electromagnetic Lab

Allow students to investigate electromagnetic induction using the Pickup Coil tab in the simulation below. Prompt students to work in pairs and create a list of observations regarding the Pickup Coil simulation. Then, discuss these observations as a class.

http://phet.colorado.edu/en/simulation/faraday

Be sure to highlight the following concepts in your class discussion:

- *Moving charges (current) generate a magnetic field (Ch. 18 review)*
- *Moving magnetic fields (magnetic flux) generate a current*
- *In the pickup coil simulation, mechanical energy (the moving magnet) is transferred to electric potential energy (current in the coil of wire) and then to light/heat in the light bulb (resistor)*

IOW

Prompt students who are struggling with this lesson to describe magnetic flux, Faraday's law of induction, and Lenz's law in their own words. They should define each variable in the corresponding equations and include the units of every variable.

Sample: Magnetic Flux:

- Φ=Magnetic Flux (Webers, Wb)
- B=Magnetic Field (Teslas, T)
- A=area of the coiled wire, (meters squared, m^2)
- cos =cosine of the angle between the area vector and the magnetic field vector (must be greater than zero)

Wolfram Demonstrations Project

Allow advanced students to explore the magnetic flux through a loop of wire and examine Faraday's law with an oscilloscope using the links below:

Magnetic Flux through a loop of wire

http://demonstrations.wolfram.com/MagneticFluxThroughALoopOfWire/

Showing Faraday's law with an oscilliscope:

http://demonstrations.wolfram.com/ShowingFaradaysLawWithAnOscilloscope/

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

19.2 The Electric Generator

Key Concept
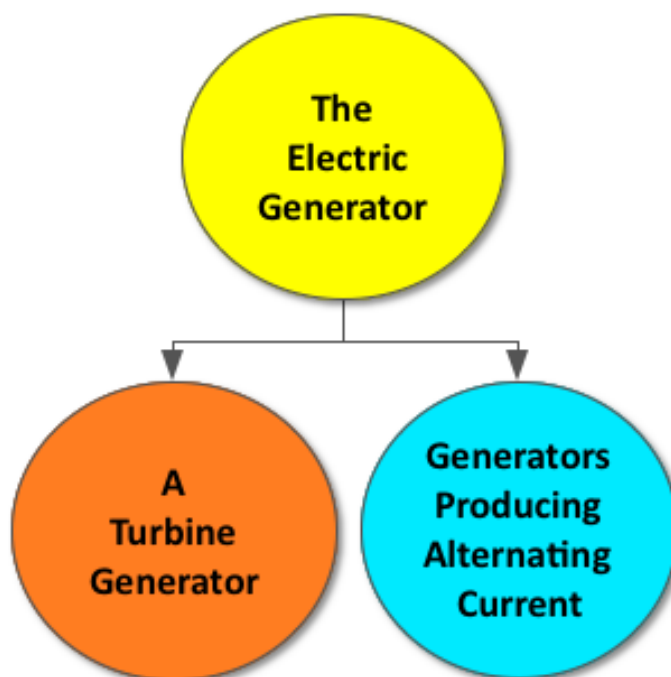
An electric generator relies on electromagnetic induction to convert mechanical energy into electric potential energy. A turbine generator utilizes wind, water, or steam to move a coil of wire in a magnetic field, inducing a voltage and, subsequently, a current through the wire. Electric generators are used to induce the voltage in standard electrical outlets and typically produce an alternating current.

Lesson Objectives

The student will:

- Understand how a generator produces an electric current.

Lesson Vocabulary

alternating current
>   The induced current reverses direction at regular intervals. Electric generators produce an alternating current. Generating alternating current is much more energy efficient (and therefore cheaper) than using direct current.

electric generator
>   A device which converts mechanical energy into electrical energy.

Hand Crank Generators

If possible, provide the class with a set of hand crank generators and some small light bulbs. Allow the students to try to use the hand crank generator to light the bulb.

Engage the class in a discussion centered around the following questions:

- **What are the circuit requirements for the light bulb to shine?** [Sample answer: A voltage source and a closed circuit in which current can flow continuously through].
- **What is providing the voltage source if we are not using a battery?** [Sample answer: The hand crank must be moving a coil around a magnet (or vice versa) to create an induced voltage via electromagnetic induction (Lesson 19.1)].

PhET: Faraday's Electromagnetic Lab

Allow students to investigate electromagnetic induction using the *Generator* tab in the simulation below. Prompt students to work in pairs and create a list of observations regarding the *Generator* simulation. Then, discuss these observations as a class.

http://phet.colorado.edu/en/simulation/faraday

Be sure to highlight the following concepts in your class discussion:

- *The materials necessary to generate electricity are a coil of wire and a magnet. The coil of wire and the magnet must be moving relative to each other.*
- *The flowing water turns the magnet, but it would not matter of it turned the coil instead. The main requirement is that the magnet and the coil move relative to each other.*
- *The potential energy of the water is transformed into kinetic energy (turning the magnet), which is then transformed to electrical potential energy (inducing a current through the wire) and, finally, to light/heat energy in the bulb.*
- *Similar generators are used to induce the voltage in the electrical outlets in your home.*

Whiteboarding: Generators

Divide students into groups of 3-4 students and provide each group with a whiteboard and dry erase markers. Prompt each group to research one of the following types of generators below:

1. Hydroelectric Dam
2. Fossil Fuel Power Plant
3. Windmill
4. Nuclear Power Plant
5. Geothermal Power Plant
6. Water Wave Generator
7. Kite Generator

Then, they should present their research on their whiteboards to share with the rest of the class. Their whiteboards should include the following:

- A simple illustration of how the generator works
- A sentence describing the transfer of energy in the generator

Display whiteboards at the front of the classroom, highlighting good examples and common themes.

Optional: Prompt students to take a picture of the whiteboards with their phones or tablets. Students keeping electronic notebooks should insert these images into their notes.

The link below provides a good explanation of various types of generators:

http://www.duke-energy.com/about-energy/generating_electricity.asp

Power Plants

Challenge advanced students to research power plants in your specific state and share their research with the class.

For example, here are some links with information on a variety of power plants in the state of California:

- CA Hydroelectric Power Plant: http://en.wikipedia.org/wiki/O%27Shaughnessy_Dam_(California)
- CA Nuclear Power Plant: http://en.wikipedia.org/wiki/Diablo_Canyon_Power_Plant
- CA Wind Power Plants: http://en.wikipedia.org/wiki/Wind_power_in_California

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

19.3 Electrical Power Transfer

Key Concept
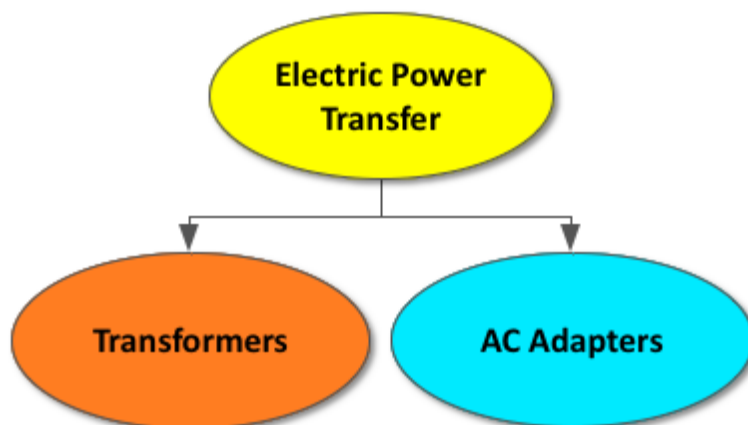
Power companies have large generators that produce immense potential differences of thousands of volts. A transformer is an electromagnetic device that can be used to reduce this large voltage to a smaller amount. The standard voltage of an electrical outlet in the United States is 120V. An AC adapter is a common transformer that changes an alternating current into a direct current, as well as steps down the voltage from a standard outlet to an amount less than 120V.

Lesson Objectives

The student will:

- Understand how transformers operate.

Lesson Vocabulary

transformer
  A device that transfers electrical energy between two circuits using electromagnetic induction, usually with a change in voltage.

Think*Pair*Share

Allow students time to think about prompts A-D below on their own, share their answer with the person next to them, and then discuss as a class.

Prompt A: What is electrical power? [*Sample Answer: The rate in which electrical potential energy is transformed into other types of energy, such as light, heat, or motion (Energy/second).*]

Prompt B: What are the units for electrical power? [*Sample Answer: 1 Watt = 1 Joule/second*]

Prompt C: Does your local power company actually provide "power"? [*Sample Answer: No, they provide the potential difference or voltage, induced by an electric generator (Lesson 19.2). The power company's generator usually produces thousands of volts, so a step-down transformer is used to reduce the voltage to 120V –the standard voltage of a US electrical outlet*].

Prompt D: When you pay your power bill, what are you actually paying for? [*Sample answer: You are paying for how much energy is being transformed by the various resistors (refrigerator, TV, lights, etc) in your home circuit over time (in kilowatt-hours).*]

Prompt E: Power companies usually rely on a meter to measure how much electrical potential energy you consume over time, in kilowatt-hours, and charge you for this amount. If your local power company charges you about 13 cents per kilowatt-hour ($0.13/kWhr), how much does it cost to keep a 60W light bulb on for 2 hours? [*Sample Answer: about 2 cents*]

$(\frac{\$0.13}{1\ kWHr} \times (0.06\ kW) \times (2\ hrs) = \$0.02$

Power Scavenger Hunt [C head] Prompt students to find and record the power of two resistors that they normally use in their everyday lives, such as a kitchen appliance, hair dryer, computer, game system, or type of light bulb.

Optional: Students can use their phones or tablets to take a picture of the power wattage of a home appliance and bring the image into class.

Whiteboarding: Power Scavenger Hunt Results

Divide students into groups of 3-4 and provide each group with a whiteboard and dry erase markers. Prompt each group to use the information they gathered in their home scavenger hunt (the inquiry activity described above) to complete the chart below. They should use Ohm's law (V=IR) and the equation for Power ($P=IV$; $P=I^2R$) to solve for any unknown variables.

TABLE 19.2: This is where to put a caption, if any

Type of Electrical Appliance	Power (P, Watts)	Voltage (V, Volts)	Current (I, Amps)	Resistance (R, Ohms)

Display completed whiteboards at the front of the classroom, highlighting good examples and common themes.

Peer Teaching

Provide students with practice problems regarding step up and step down transformers. Pair each student up and have them alternate between tutor and tutee.

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

19.4 The Electromagnetic Spectrum

Key Concept

A vibrating charge produces an electromagnetic wave. The electromagnetic spectrum is a list of all the various types of electromagnetic waves produced by different frequencies of vibrating charges, from gamma rays to radio waves. Light is one type of electromagnetic wave that travels at 3.0×10^8 m/s in a vacuum. The speed of light in a vacuum is currently the universal speed limit and plays an important role in the study of physics.

Lesson Objectives

The student will:

- Understand what the electromagnetic spectrum is.

Lesson Vocabulary

electromagnetic spectrum
    The entire range of electromagnetic waves.
gamma rays

infrared waves

microwaves

radio waves

ultraviolet light

visible light

x-rays

Brainstorm

Divide students into groups of 3-4 and provide each group with a whiteboard and dry erase markers. Ask students the question in the prompt below and provide students with time to brainstorm an answer to the question using words, images, and examples.

Prompt: What is light?

Display completed whiteboards at the front of the classroom, highlighting good examples and common themes.

Be sure to highlight the following:

- *Moving charges generate waves in the electromagnetic field (EM waves) –this is often referred to as radiation.*
- *Visible light is the small range of EM waves (radiation) visible to the human eye.*
- *Light is considered to include all forms of EM waves (radiation) –from gamma rays to radio waves, as listed on the electromagnetic spectrum.*
- *Radio waves are EM waves, not sound waves.*

If time allows, show students the Veritasium video (7:39) at the link below that addresses the question, "What is light?":

https://www.youtube.com/watch?v=Iuv6hY6zsd0

Measuring the Speed of Light

Provide students with the opportunity to measure the speed of light using chocolate and a microwave by following the instructions found at the link below.

http://www.planet-science.com/categories/over-11s/physics-is-fun!/2012/01/measure-the-speed-of-light-using-chocolate.aspx

Here are some useful links regarding how microwaves work, which can be discussed before or after the inquiry activity above:

http://phet.colorado.edu/en/simulation/microwaves

http://home.howstuffworks.com/microwave1.htm

Be sure to highlight the following:

- The wave equation $V = f\lambda$ still applies to electromagnetic waves
- The velocity of the speed of light in a vacuum is $c = 3.0 * 10^8$ m/s. As a result, the wave equation for light in a vacuum is $c = f\lambda$.
- The EM waves are arranged according to their wavelength and frequency in the electromagnetic spectrum.
- The lower the energy of the EM wave, the lower the frequency, and the longer the wavelength.

Solar Panels

Challenge students to do some research regarding the prompt below and answer the question in their own words. Their answer should include 1-2 sentences, focusing on the big ideas. Then, discuss as a class.

Prompt: How do solar panels work?

The following links are good resources:

- *How Do Solar Cells Work?*: http://www.physics.org/article-questions.asp?id=51
- *The Photoelectric Effect*: http://www.colorado.edu/physics/2000/quantumzone/photoelectric.html
- *PhET: The Photoelectric Effect*: http://phet.colorado.edu/en/simulation/photoelectric
- *Photovoltaics: How do they work?*: http://vimeo.com/17986294
- *Energy 101: Solar PV*: http://youtu.be/0elhIcPVtKE?list=PLACD8E92715335CB2

Solar Circuits

Allow students to witness how solar panels provide a voltage source in a circuit, helping to convert solar energy into electric potential energy, by following the activity instructions at the link below.

http://www.solar4rschools.org/sites/all/files/Activity%207%20-%20Solar%20Circuits.pdf

Quick Write Review

Pass back students' index cards from the Quick Write warm-up activity in lesson 19.1. Allow students some time to review their answers and prompt them to correct any mistakes. If time allows, answer any unresolved student questions as a class.

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

Chapter Test

Copy and distribute the Chapter 18 Test using the *CK-12 Physics Intermediate Quizzes and Tests* link.

CHAPTER **20**   **Geometric Optics**

Chapter Outline

Chapter Overview
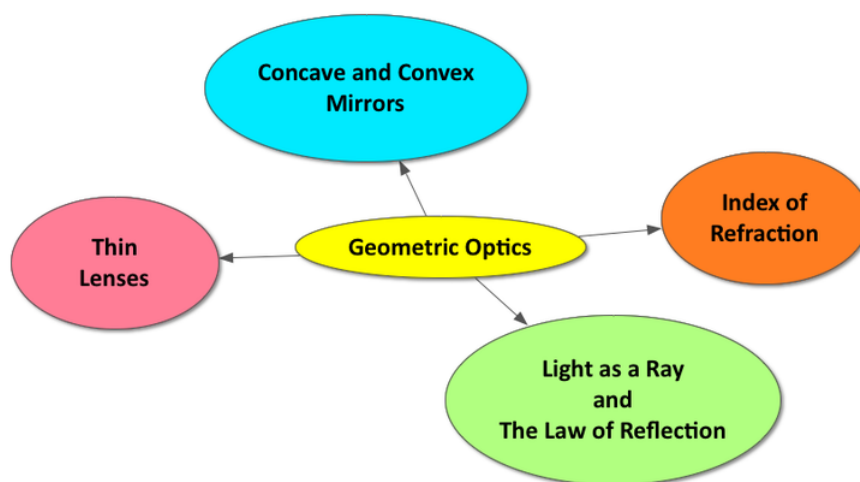
Geometric optics is the study of light traveling as a ray. These light rays behave in a predictable way. The law of reflection can be used to predict how light will behave when it reflects off a mirror. Snell's law can be used to predict how much light will bend as it travels from one medium to another, based on each medium's index of refraction. Ray diagrams can be used to predict the formation of an image in a mirror or behind a lens. Thin lenses are often utilized to magnify images, such as in a microscope or telescope.

Online Resources

Physics Classroom

This website provides a student friendly description of a variety of physical concepts, including reflection, refraction, and the ray model of light.

- Reflection and the Ray Model of Light:
  http://www.physicsclassroom.com/class/refln
- Refraction and the Ray Model of Light:
  http://www.physicsclassroom.com/class/refrn

Wolfram Demonstrations Project

The following links provide additional interactive simulations regarding geometric optics.

- Electromagnetic Wave:
  http://demonstrations.wolfram.com/ElectromagneticWave/
- Law of Reflection:
  http://demonstrations.wolfram.com/OpticsLawOfReflection/
- Reflections in a Mirrored Corner:
  http://demonstrations.wolfram.com/ReflectionsInAMirroredCorner/
- Ray Diagrams for Spherical Mirrors:
  http://demonstrations.wolfram.com/RayDiagramsForSphericalMirrors/
- Light Passing Through a Transparent Plate:
  http://demonstrations.wolfram.com/LightRayPassingThroughATransparentPlate/
- Ray Tracing with Lenses:
  http://demonstrations.wolfram.com/RayTracingWithLenses/
- Nearsightedness and Farsightedness
  http://demonstrations.wolfram.com/NearsightednessAndFarsightedness/

CK-12 Simulations

The simulations below provide additional opportunities for students to explore geometric optics.

- Light Wave:
  http://interactives.ck12.org/simulations/physics/light-wave/app/index.html?referrer=ck12Launcher&backUrl=http://interactives.ck12.org/simulations/

- Diamond Cut:
  http://interactives.ck12.org/simulations/physics/diamond-cut/app/index.html?referrer=ck12Launcher&backUrl=http://interactives.ck12.org/simulations/?backUrl=http://www.ck12.org/teacher/

- Cassegrain Telescope:
  http://interactives.ck12.org/simulations/physics/cassegrain-telescope/app/index.html?referrer=ck12Launcher&backUrl=http://interactives.ck12.org/simulations/?backUrl=http://www.ck12.org/teacher/

- Contact Lens:
  http://interactives.ck12.org/simulations/physics/contact-lens/app/index.html?referrer=ck12Launcher&backUrl=http://interactives.ck12.org/simulations/?backUrl=http://www.ck12.org/teacher/

- Magnifying Glass:
  http://interactives.ck12.org/simulations/physics/magnifying-glass/app/index.html?referrer=ck12Launcher&backUrl=http://interactives.ck12.org/simulations/?backUrl=http://www.ck12.org/teacher/

Apps

Exploriments: Light - Optics Ray Diagrams for Concave and Convex Mirrors and Lenses

This engaging app enables students to explore ray diagrams for a variety of curved mirrors and lenses.

https://itunes.apple.com/app/exploriments-light-optics/id557848311?mt=8

Color Uncovered

This is a wonderful App, by the San Francisco Exploratorium, with a variety of interactive modules enabling students to explore the concept of light and optics.

https://itunes.apple.com/us/app/color-uncovered/id470299591?mt=8

TABLE 20.1: Pacing The Lessons

Lesson	Class Periods (60 min)
Lesson 20.1 Light as a Ray and the Law of Reflection	4
Lesson 20.2 Concave and Convex Mirrors	3
Lesson 20.3 Index of Refraction	1
Lesson 20.4 Thin Lenses	3

20.1 Light as a Ray and the Law of Reflection

Key Concept
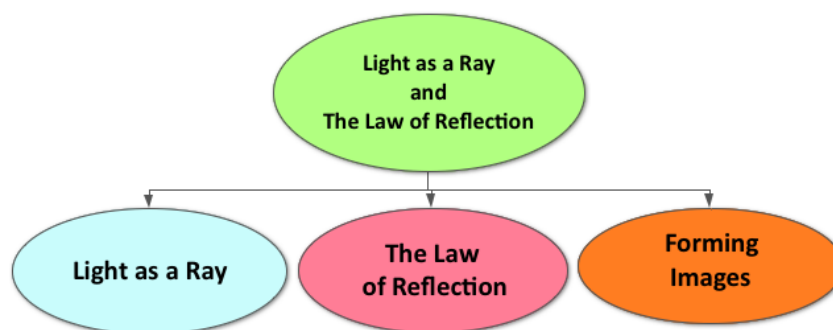
Our ability to see the world around us is dependent upon the reflection of light. Although light is actually an electromagnetic wave, our eyes see light as a ray that travels in a straight line. These rays of light behave in a predictable way. The law of reflection states that a ray of light will reflect off a mirror at an angle equal to the angle of incidence. Ray diagrams can be used to predict or explain the formation of an image in a flat mirror.

Lesson Objectives

The student will:

- Explain the ray model of light.
- Describe the Law of Reflection.
- Explain how images are formed from flat mirrors.

Lesson Vocabulary

angle of incidence
    The angle made by an incident ray with respect to the normal
angle of reflection
    The angle made by a reflected ray with respect to the normal
incident ray
    Makes an angle θ_i with the normal, N.
light ray
    Light traveling in straight lines.

normal

    The direction that is perpendicular to a surface

reflected ray

    Makes an angle θ_r with the normal, N.

virtual image

    An illusion created by the brain because light travels in straight lines.

Equations

- Law of Reflection: $\theta_i = \theta_r$

Think*Pair*Share: Light and Sight

If possible, prepare the classroom for this warm-up activity by taping black paper up over all classroom windows, closing curtains, etc (with the goal being that when you turn the classroom lights off, it is very dark and students are unable to see).

At the beginning of class, after all students are seated, turn the classroom lights off completely. Students should be unable to see objects and people around them.

Then, turn the lights back on and allow students time to think about the prompt below on their own, share their answer with the person next to them, and then discuss as a class.

Prompt: How are light and sight related?

***Be sure to introduce the following concepts in your class discussion regarding this warm-up activity:*

- *Sight is dependent on the reflection of light*"
- **Very few objects produce their own light (the sun, light bulbs, etc)**
- *The majority of objects reflect light (the moon, the objects in the classroom, etc)*
- *To our eyes, light acts as a ray traveling in a straight line (the Ray Model of Light)*

Physics Classroom: Reflection Lab

Engage students in the inquiry activity regarding light bouncing off a flat mirror and the law of reflection by following the instructions at the link below:

http://www.physicsclassroom.com/getattachment/lab/refln/rm1tg.pdf

The Images formed by Flat Mirrors [C head] Divide students into pairs and provide each pair with a flat mirror. Challenge students to use the flat mirror and objects found in the classroom to develop a list describing the image characteristics of objects reflected in a flat mirror. Then, engage in a class discussion compiling each group's list on the board.

'Sample List:'

- *The image is always upright*
- *The image is always located behind the mirror (**virtual image)*
- *There is a left-right reversal of the image*
- *The object's distance in front of the mirror is equal to the image's distance behind the mirror ($d_i=d_o$).*
- *The image size is always equal to the actual size of the object*

Ray Diagrams: Flat Mirrors

Connect the ray model of light, the law of reflection, and the image characteristics of an object reflected in a flat mirror by illustrating a ray diagram on the board for the class. If time allows, prompt students to draw their own ray diagrams.

Exit Slip

Pass out index cards to the students and ask them to write their response to the following prompt on the card. Collect the cards as students exit the classroom and assess.

Prompt: In your own words, describe what happens to light rays when they hit a flat mirror? [*Sample answer: They bounce off (are reflected) at an angle equal to the angle of incidence*].

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

20.2 Concave and Convex Mirrors

Key Concept
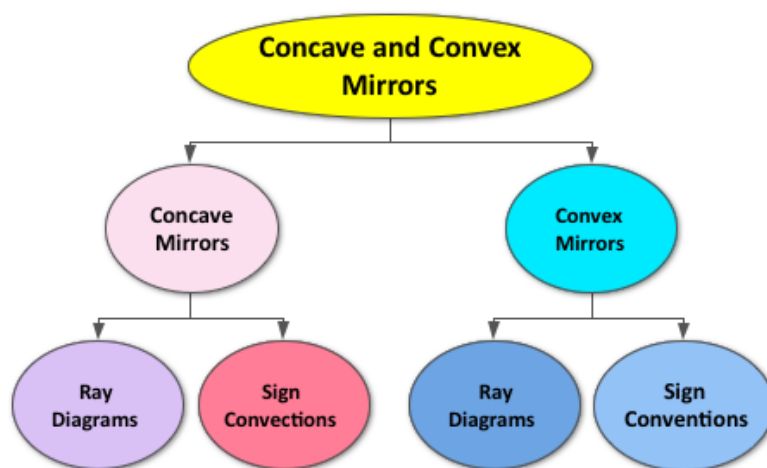
Although rays of light reflected off of a curved mirror still obey the law of reflection, the images formed differ from those in a flat mirror. The point in which all rays of light converge after being reflected off of a curved mirror is called the focal point. Based on the position of the mirror, the object, and the focal point, we can calculate how large the image will be. Ray diagrams can also be used to illustrate the formation of an image in a curved mirror. A mirror that curves inward is referred to as a concave mirror. An object placed closer to the concave mirror than the focal point always produces an upright, enlarged, and virtual image. An object placed beyond the focal point always produces an inverted, real image. A mirror that curves outward is referred to as a convex mirror. A convex mirror always produces an upright, reduced, and virtual image.

Lesson Objectives

The student will:

- Understand how to draw ray diagrams for concave mirrors.
- Understand how to solve problems involving concave mirrors.
- Understand how to draw ray diagrams for convex mirrors.
- Understand how to solve problems involving convex mirrors.

Lesson Vocabulary

concave mirror
A mirror that curves inwards, like the inside of a bowl.
convex mirror
A mirror that curves outwards, like the top of a dome.
focal point (or focus)
The point from a spherical mirror or thin lens where parallel rays of light converge.
real image
An image formed from rays of light converging, that can be projected onto a screen or paper.
spherical mirror
A curved mirror formed that matches the shape of a slice from a larger sphere.

Equations

- $f = \frac{r}{2}$
- $\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$
- $m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$

Spoon Images

Pass out a spoon to each student and prompt the class to observe the images that form on both sides of the spoon.

**∗∗*Be sure to use the spoon model to introduce the following terms:*

- ***concave mirror****: A mirror that curves inwards.*
- ***convex mirror****: A mirror that curves outwards.*

Physics Classroom: Exploring Curved Mirrors Lab

Engage students in the inquiry activity regarding light bouncing off curved mirrors (both concave and convex) by following the instructions at the link below:

http://www.physicsclassroom.com/getattachment/lab/refln/rm8tg.pdf

The Images formed by Curved Mirrors

Divide the class into the following two teams and prompt each team to complete the activity described below.

(1) The Convex Team:

Provide students on the convex team with convex mirrors (or the spoon from the "Inspire activity" above). Challenge students to use the convex mirrors and objects found in the classroom to develop a list describing the image characteristics of objects reflected in a convex mirror.

Sample List for a Convex Mirror:

- *The image is always upright.*
- *The image is always located behind the mirror (**a virtual image).*
- *The image size is always smaller than the actual size of the object.*

(2) The Concave Team:

Provide students on the concave team with concave mirrors (or the spoon from the "Inspire activity" above). Challenge students to use the concave mirrors and objects found in the classroom to develop a list describing the image characteristics of objects reflected in a concave mirror

Sample List for a Concave Mirror:

- *The image may be upright or inverted.*
- *The image may be located in front of the mirror (**a real image) or behind the mirror (**a virtual image).*
- *The image size may be smaller, larger, or the same size as the object.*
- *The characteristic of the image depends on where the object is placed in relation to the focal point.*
- *An object placed closer to the concave mirror than the focal point always produces an upright, enlarged, and virtual image.*
- *An object placed beyond the focal point always produces an inverted, real image.*

Then, engage in a class discussion compiling each team's list on the board.

Ray Diagrams: Curved Mirrors [C head] Connect the ray model of light, the law of reflection, and the image characteristics of an object reflected in curved mirrors by illustrating a ray diagram on the board for the class for both a concave and a convex mirror. If time allows, prompt students to draw their own ray diagrams.

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

20.3 Index of Refraction

Key Concept
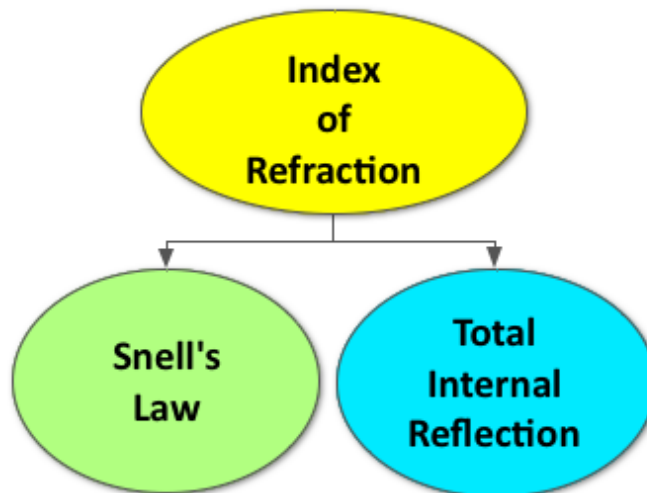
When light travels from one medium to another, it changes speed and bends as a result of obeying the principle of least time. The bending of light is referred to as refraction. Every material has an index of refraction that indicates how much light will change speed and bend. Snell's law can be used to predict the refraction of light as it travels from one medium to another. Total internal reflection occurs as a result of light traveling from a medium with a high index of refraction to a medium with a low index of refraction at an angle greater than the critical angle. As a result of total internal reflection, all of the incident light is reflected rather than refracted; this is the physical principle behind fiber optic cables.

Lesson Objectives

The student will:

- Understand how the index of refraction is defined.
- Solve problems involving the index of refraction.
- Understand Snell's Law.
- Solve problems involving Snell's Law.

Lesson Vocabulary

angle of incidence
> The angle made between a incident ray and the normal

angle of refraction
> The angle made between a refracted ray and the normal

incident ray
> A ray before traveling from one medium to another

index of refraction
> The ratio of the speed of light through vacuum (c) to the speed of the light through a particular medium (v).

refracted ray
> Light rays change direction when they pass through different material.

Snell's Law
> Expresses the relationship between the angle of incidence θ_1 and the angle of refraction θ_2 at the interface of two media.

Equations

- $n = \frac{c}{v}$
- $n_1 \sin\theta_1 = n_2 \sin\theta_2$

Disappearing Glass Rods

Get students excited to learn more about the index of refraction and Snell's law by beginning this lesson with a demonstration regarding invisibility found at the link below:

http://www.exploratorium.edu/snacks/disappearing_glass_rods/ *Italic text*

Physics Classroom: Least Time Principle Lab

Engage students in an inquiry activity regarding the speed of light as it travels from one medium to another by following the instructions at the link below:

http://www.physicsclassroom.com/shwave/leatimedirns

**Be sure to highlight the following:*

- *Light obeys the principle of least time (Fermat's Principle).*
- *When light travels from one medium to another, it changes speed and bends as a result of obeying the principle of least time. The bending of light is referred to as refraction.*
- *Every material has an index of refraction that indicates how much light will change speed and bend.*
- *Snell's law can be used to predict the refraction of light as it travels from one medium to another.*

Peer Teaching

Provide students with practice problems requiring them to use the Snell's law. Pair each student up and have them alternate between tutor and tutee.

Total Internal Reflection

Challenge students who finish the peer-teaching activity above to research total internal reflection and its connection to fiber optics.

http://computer.howstuffworks.com/fiber-optic6.htm

Lesson Worksheets

Copy and distribute the lesson worksheet in the CK-12 Physics Intermediate Workbook. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the CK-12 Physics Intermediate Quizzes and Tests link.

20.4 Thin Lenses

Key Concept
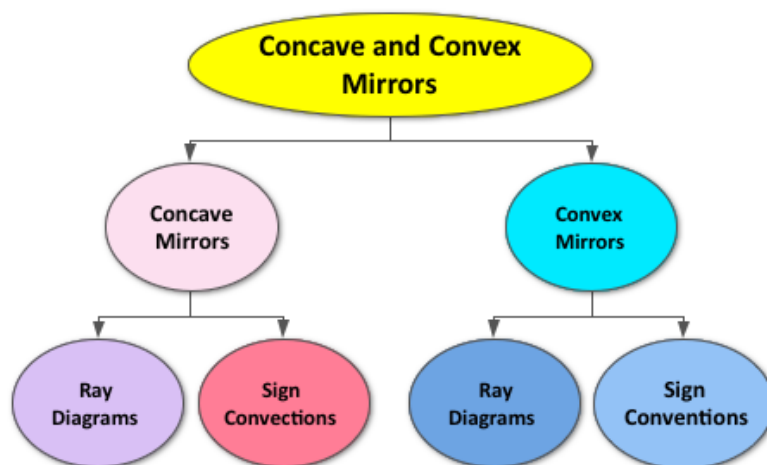
A thin lens is often utilized to refract light in a certain way. A convex (or converging) lens is thicker in the center than its edges. Convex lenses are often used as eye glasses or magnifying lenses. A concave (or diverging) lens is thinner at the center than its edges. Ray diagrams can be used to predict or explain the formation of an image behind a thin lens.

Lesson Objectives

The student will:

- Understand how to draw ray diagrams for convex lenses.
- Understand how to solve problems involving convex lenses.
- Understand how to draw ray diagrams for concave lenses.
- Understand how to solve problems involving concave lenses.

Lesson Vocabulary

concave lens
> A lens that is thinner at the center than its edges. Diverging lenses make rays parallel to the principal axis (P) diverge as shown below.

convex lens
> A lens that is thicker in the center than its edges. Converging lenses make rays parallel to the principal axis (P) converge at the focal point as shown below.

focus/foci
> The point(s) at which rays parallel to an axis converge.

optical center
> The center of the lens.

principal axis
> A straight line passing through the center of the lens and perpendicular to its surfaces.

Equations

- $\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$
- $m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$

Physiology of the Eye

Inspire students to learn more about convex and concave lenses by showing them this short video (2:46) on the physiology of the eye.

https://www.youtube.com/watch?v=_5dEO-LRV-g

PhET: Geometric Optics

Allow students to investigate converging and diverging lenses with the link below. Prompt students to work in pairs and create a list of observations regarding the simulation. Then, discuss these observations as a class.

http://phet.colorado.edu/en/simulation/geometric-optics

Physics Photos

Task each student to take one original photo exemplifying the refraction of light through a lens. They should submit their photos to you and write a 1-2 paragraph explanation regarding the physics of the photo.

Sample photos can be found at the link below:

https://www.flickr.com/photos/physicsclassroom/galleries/72157625102649965/

Making Real-World Connections

Challenge students to research some real-world applications of the refraction of light by converging and diverging lenses.

See the links below for examples of ways we rely on the curved lenses in the real world:

- How Cameras Work:
    - http://www.howstuffworks.com/camera.htm
- How Corrective Lenses Work:
    - http://science.howstuffworks.com/innovation/everyday-innovations/lens.htm
- How Telescopes Work:
    - http://science.howstuffworks.com/telescope.htm

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook.* You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

Chapter Test

Copy and distribute the Chapter 20 Test using the *CK-12 Physics Intermediate Quizzes and Tests* link.

CHAPTER 21 Physical Optics

Chapter Outline

Chapter Overview
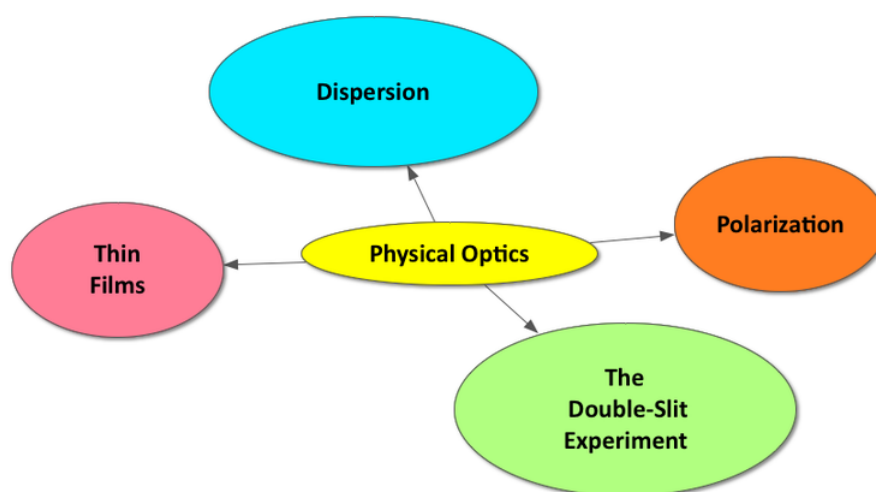
Physical optics is the study of light traveling as a wave. A rainbow is one product of light acting as a wave; white light from the sun disperses into all the colors of the visible spectrum as a result of the refraction and reflection of light waves in a raindrop. Thomas Young provided the necessary evidence for the acceptance of light as a wave in his Double Slit Experiment. In this experiment, monochromatic light passing through two slits resulted in a series of bright and dark bands due to the constructive and destructive interference of light waves. The interference of light waves also occurs in a thin film, such as in a soap bubble, and often results in colorful bands. Light produced by electrons vibrating in only one direction is polarized. Non-polarized light, such as sunlight, can become polarized through the process of transmission or reflection.

Online Resources

Physics Classroom

This website provides a student friendly description of a variety of physical concepts, including light waves and color.

- Light Waves and Color:
  http://www.physicsclassroom.com/class/light

Wolfram Demonstrations Project

The following links provide additional interactive simulations regarding physical optics.

- Light Ray in a Prism:
  http://demonstrations.wolfram.com/LightRayInAPrism/
- Dispersion of Light Through a Prism:
  http://demonstrations.wolfram.com/DispersionOfLightThroughAPrism/
- Waves Passing Through a Double Slit:
  http://demonstrations.wolfram.com/CylindricalWavesPassingThroughADoubleSlit/
- Interference of Waves from Young's Double Slit Experiment
  http://demonstrations.wolfram.com/InterferenceOfWavesFromDoubleSlitYoungsExperiment/
- Single Slit Diffraction:
  http://demonstrations.wolfram.com/SingleSlitDiffraction/
  http://demonstrations.wolfram.com/DiffractionGratingIntensities/
- Refraction Through Parallel Faces:
  http://demonstrations.wolfram.com/RefractionThroughParallelFaces/
- Light Beams Through Multiple Polarizers
  http://demonstrations.wolfram.com/LightBeamsThroughMultiplePolarizers

CK-12 Simulations

The simulations below provide additional opportunities for students to explore geometric optics.

- Light Wave:
  http://interactives.ck12.org/simulations/physics/light-wave/app/index.html?referrer=ck12Launcher&backUrl=http://interactives.ck12.org/simulations/?backUrl=http://www.ck12.org/teacher/
- Wave Patterns:
  http://interactives.ck12.org/simulations/physics/the-marina/app/index.html?referrer=ck12Launcher&backUrl=http://interactives.ck12.org/simulations/?backUrl=http://www.ck12.org/teacher/

Apps

Color Uncovered

This is a wonderful App, by the San Francisco Exploratorium, with a variety of interactive modules enabling students to explore the concept of light and optics.

https://itunes.apple.com/us/app/color-uncovered/id470299591?mt=8

TABLE 21.1: Pacing The Lessons

Lesson	Class Periods (60 min)
Lesson 21.1 Dispersion	3
Lesson 21.2 The Double-Slit Experiment	3
Lesson 21.3 Thin Films	3

TABLE 21.1: (continued)

Lesson	Class Periods (60 min)
Lesson 21.4 Polarization	2

21.1 Dispersion

Key Concept
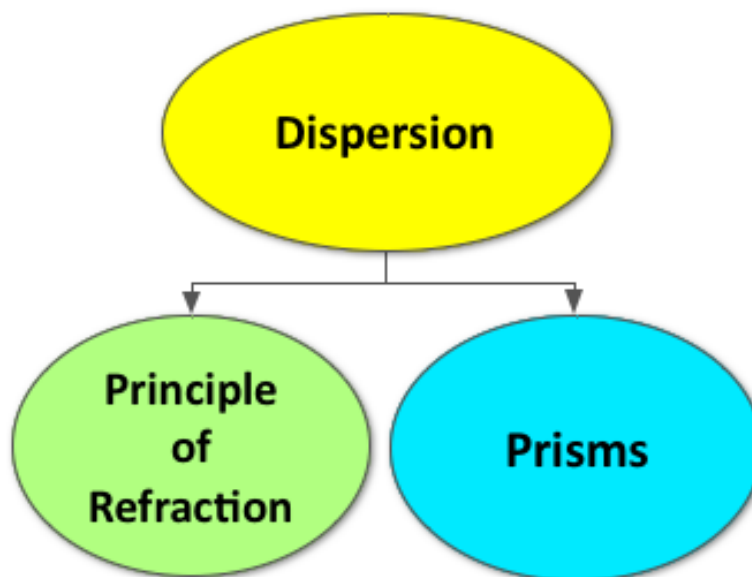
Dispersion is the process in which white light separates into all the colors of the rainbow as it exits a glass prism. The colors that make up the visible spectrum –red, orange, yellow, green, blue, indigo, and violet –each have a unique frequency and wavelength. Their index of refraction is dependent upon these varying frequencies and wavelengths. As a result, each color bends at a different angle as it travels through a glass prism.

Lesson Objectives

The student will:

- Understand the definition of dispersion and its causes.
- Understand the dispersion of light through a prism.
- Solve problems involving dispersion.

Lesson Vocabulary

dispersion
   The spreading of light through a prism.

Playing with Prisms

Divide the class into pairs and provide each pair with a prism. Allow the class to go outside to utilize sunlight to create rainbows with the prisms (or provide flashlights for the class to make rainbows inside). Prompt each group to consider the following questions as they explore what happens to light as it travels through their prism.

- *How did you make a rainbow using the prism?*
- *What are all the colors of the rainbow?*
- *Where do these colors originate?*
- *Why do you think the colors of the rainbow are always in the same order?*

PhET: Bending Light

Allow students to further investigate the dispersion of light using the Prism Break tab in the simulation below. Prompt students to work in pairs and create a list of observations regarding the Prism Break simulation. Then, discuss these observations as a class. http://phet.colorado.edu/en/simulation/bending-light

∗∗*Be sure to highlight the following:*

- *Each color in the visible spectrum has a different index of refraction.*
- *Red light has the lowest index of refraction (it bends the least), due to its long wavelength and low frequency.*
- *Violet light has the highest index of refraction (it bends the most), due to its short wavelength and high frequency.*
- *As a result of these differences in the index of refraction, white light disperses into all the colors of the rainbow as it travels through a prism.*

Whiteboarding: The Physics of Rainbows

Divide students into groups of 3-4 and provide each group with a whiteboard and dry erase markers. Prompt each group to create a model of how a rainbow forms as a result of the refraction, reflection, and dispersion of sunlight through a raindrop.

The following links provide a great explanation regarding the physics of rainbows:

http://www.photocentric.net/rainbow_physics.htm

http://www.physicsclassroom.com/Class/refrn/u14l4b.cfm

The Mathematics of Rainbows

Challenge advance students to make the necessary calculations using Snell's law and the law of reflection to determine the path of red light versus violet light through a raindrop (The index of refraction for red light in water is 1.33 and the index of refraction for violet light in water is 1.34).

The following link provides a great explanation regarding the mathematics of rainbows:

http://plus.maths.org/content/rainbows

3-2-1 Exit Slip

Pass out index cards to the students and ask them to write their response to the following prompt on the card. Collect the cards as students exit the classroom and assess.

Prompt: What are

- 3 things you learned?
- 2 facts you found interesting?
- 1 question you still have?

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook.* You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

21.2 The Double-Slit Experiment

Key Concept
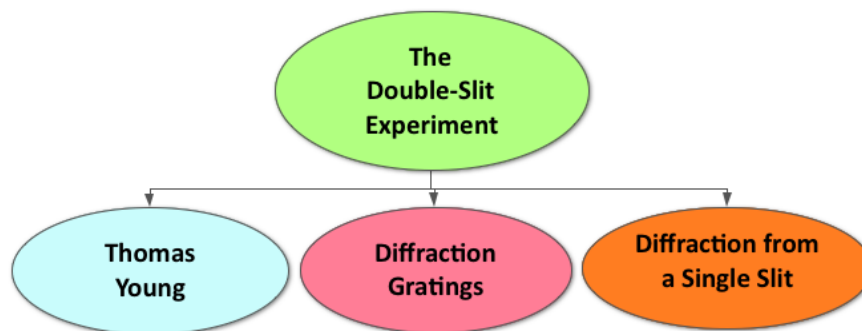
In his Double-Slit Experiment, Thomas Young demonstrated how light waves interfered just like water waves in a ripple tank. This provided the necessary evidence for the acceptance of light as a wave.

Lesson Objectives

The student will:

- Understand the Double-Slit Experiment.
- Solve problems involving the Double-slit Experiment.

Lesson Vocabulary

coherent
    A light source where all the light has the same phase and wavelength
monochromatic
    Describes a light source in which all the light has exactly the same single wavelength.
spectroscope
    Designed for the purpose of wavelength determination.
wave interference
    A situation in which two waves overlap each other.

Equation

- Constructive interference: $d \sin\theta = m\lambda$
- Destructive Interference: $d \sin\theta = (m + \frac{1}{2})\lambda$

Brainstorm: Wave Behavior

As a review exercise, challenge students to brainstorm all the characteristics describing the behavior of waves.

Sample list:

- Superposition
- Constructive Interference
- Destructive Interference
- Reflection
- Refraction
- Diffraction
- The Doppler Effect

NOVA: Parallel Worlds, Parallel Lives

The NOVA education lesson plan found at the link below enables students to explore Young's Double-Slit Experiment using the PhET simulation, "Quantum Wave Interference". It also touches on quantum theory and the wave-particle duality of light.

http://www.pbs.org/wgbh/nova/education/activities/3513_manyworlds.html

http://phet.colorado.edu/en/simulation/quantum-wave-interference

IOW

Challenge students to submit a written essay providing justification for the acceptance of light as a wave, with reference to Young's Double-Slit Experiment. All essays should be written in the students' own words and provide evidence of their achievement of the lesson objectives.

Instructional Videos

Prompt students to view the following videos as a way to summarize the meaning and importance of Young's Double Slit Experiment.

- Veritasium: The Original Double Slit Experiment (7:39)
  https://www.youtube.com/watch?v=Iuv6hY6zsd0

- MIT Videos: Thomas Young's Double Slit Experiment (7:13)
  http://video.mit.edu/watch/thomas-youngs-double-slit-experiment-8432/

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

21.3 Thin Films

Key Concept
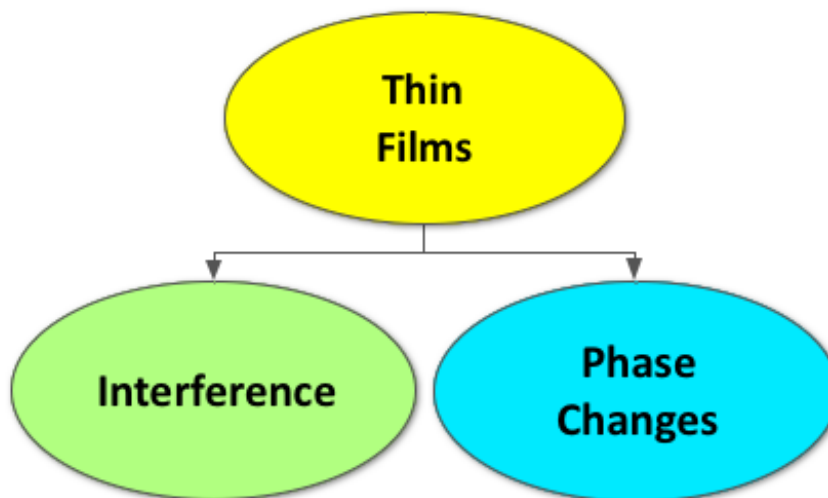
A thin film refers to a layer of material that reflects and refracts light in a particular way. As incident light reflects off the top and bottom of a thin film, certain wavelengths of light interfere and create patterns of colorful bands. When light reflects off a material with a higher index of refraction, it experiences a phase change. This is one of the necessary conditions for thin film interference.

Lesson Objectives

The student will:

- Understand how thin films recreate constructive and destructive interference.
- Solve problems involving thin films.

Lesson Vocabulary

phase change
    Occurs when a beam of light is reflected from a medium with a greater index of refraction than the medium in which it travels.

Equations

- Constructive interference: $2d = (m + \frac{1}{2})\lambda_n$
- Destructive interference: $2d = m\lambda_n$

Thin Film Interference: CDs and DVDs

Provide the class with a set of old/ used CDs or DVDs. Prompt students to make some observations regarding the light interference patterns created by the protective lacquer coating (acting as a thin film) on the discs.

Soap Film Interference

Allow students to witness the interference of light waves in a thin film of soap by following the instructions for an inquiry activity at the link below:

http://ap.smu.ca/demos/index.php?option=com_content&view=article&id=123&Itemid=85

Whiteboarding: Thin Film Interference

Divide students into groups of 3-4 and provide each group with a whiteboard and dry erase markers. Prompt each group to create a model of thin film interference, illustrating the light reflected and refracted from the upper and lower boundaries of a thin film.

The following links provide a great explanation regarding thin film interference:

http://www.physicsclassroom.com/class/light/Lesson-1/Thin-Film-Interference

http://www.exploratorium.edu/ronh/bubbles/bubble_colors.html

http://hyperphysics.phy-astr.gsu.edu/hbase/phyopt/thinfilm.html#c1

http://physics.bu.edu/py106/notes/Thinfilm.html

Iridescence and Interference

Prompt students to research the connection between the iridescence of plants or animals and thin film interference by reading the links below:

http://www.explainthatstuff.com/thin-film-interference.html

http://www.webexhibits.org/causesofcolor/15.html

http://www.theguardian.com/science/punctuated-equilibrium/2007/oct/16/birds-physics

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook.* You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

21.4 Polarization

Key Concept
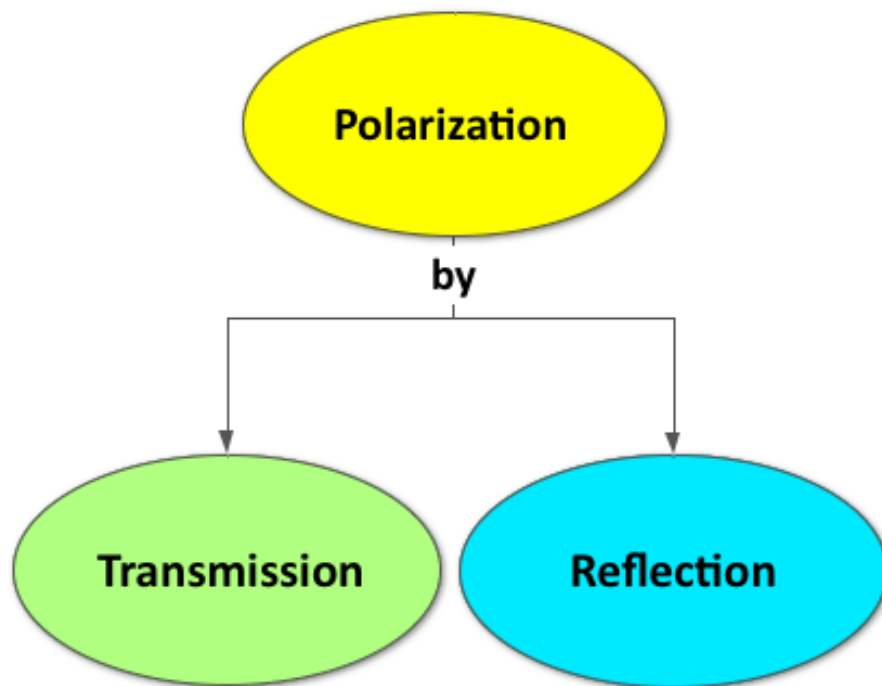
Light is a transverse electromagnetic wave created by vibrating electrons. When the electrons vibrate in only one direction, the light is polarized. Most light, such as sunlight, candlelight, or light from a light bulb, is non-polarized due to the random vibrations of the electrons. However, this non-polarized light can become polarized through transmission or reflection.

Lesson Objectives

The student will:

- Understand the meaning of polarization and its mechanism.
- Understand polarization by transmission and reflection.

Lesson Vocabulary

polarized light
> Light with electric field vibrations in only one direction, also known as linearly polarized light.

Polarization Demonstration using Sunglasses and a Computer Screen

If possible, complete the following demonstration in front of the class or show students this quick video (8 seconds) to get them excited to learn more about polarization.

https://www.youtube.com/watch?v=rIOVpYO7JPI

http://physicslens.com/polarization-using-sunglasses-and-a-computer-screen/

Exploratorium Snacks: Rotating Light

Allow students to further explore the polarization of light by engaging in the inquiry activity described at the link below:

http://www.exploratorium.edu/snacks/rotating_light/index.html

SEE-I

Divide the class into groups of 3-4 students and provide each group with a whiteboard and dry erase markers. Demonstrate how to use the SEE-I method to clarify terms and show understanding (see below for more information). Prompt students to use the SEE-I method to describe the following terms regarding physical optics:

- Polarization by Transmission
- Polarization by Reflection

Optional: Prompt students to take a picture of their whiteboards with their phones or tablets for future reference. Students keeping an electronic notebook should insert this image into their notes.

Learn more about the SEE-I method by visiting the link below:

http://en.wikipedia.org/wiki/SEE-I

Making Real-World Connections

Challenge students to research some real-world applications regarding the polarization of light.

Some examples include:

- Polarized sunglasses

- 3-D glasses
- LCD screens

See the link below for additional real-world examples:

http://en.wikipedia.org/wiki/Polarization_%28waves%29#Applications_and_examples

Exit Slip

Pass out index cards to the students and ask them to write their response to the following prompt on the card. Collect the cards as students exit the classroom and assess.

Prompt: How do we know light is a wave? [*Sample answer: Light reflects, refracts, interferes, and can be polarized as a result of being a transverse electromagnetic wave.*]

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

Chapter Test

Copy and distribute the Chapter 21 Test using the *CK-12 Physics Intermediate Quizzes and Tests* link.

CHAPTER **22**   # The Special Theory of Relativity

Chapter Outline

22.1 Atomic Physics
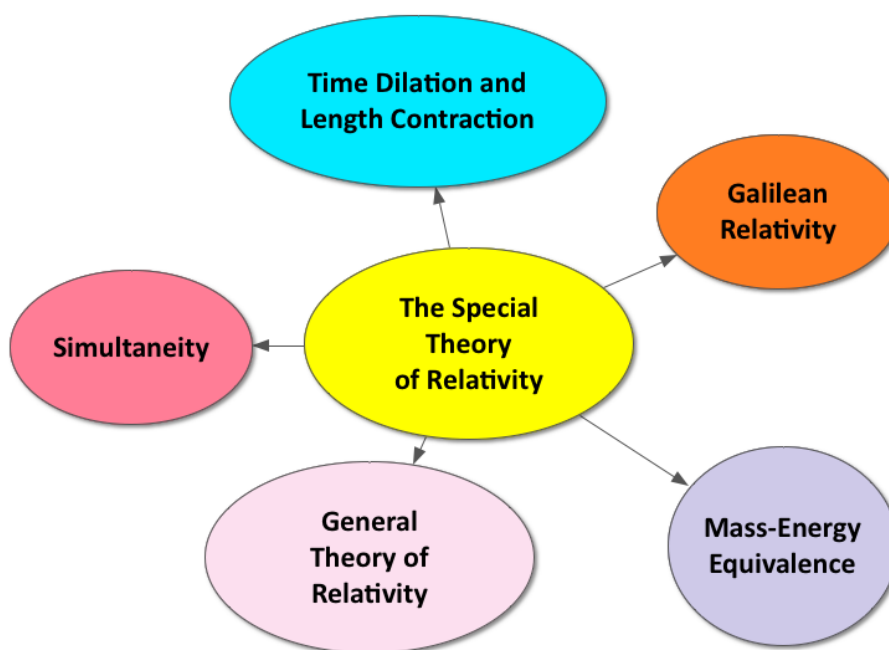
The principle of relativity states that the laws of physics should apply to all inertial frames of reference. However, when tested, Galilean relativity failed to apply to light. Einstein resolved this discrepancy by showing that the speed of light is not relative to motion, but a universal constant. In the special theory of relativity, Einstein established that space and time changed relative to the speed of light. The notion of absolute time and space was dismissed and replaced with the interdependence of space-time, time dilation (the slowing down of time) and subsequent length contraction (the shrinking of space). Einstein's theory of special relativity also led to the derivation of his famous equation, E=mc2, which established that mass and energy were equivalent. In his later general theory of relativity, Einstein addressed frames of reference that were accelerating. Einstein described the force of gravity as a result of a massive object producing an indentation in space-time, rather than a force acting at a distance. The general theory of relativity led to the principle of equivalence, which equates an accelerating frame of reference to the acceleration due to gravity.

22.2 **Online Resources**

HyperPhysics

This website, from Georgia State University, provides a student friendly conceptual framework of relativity.

http://hyperphysics.phy-astr.gsu.edu/hbase/relativ/relcon.html#c1

Special Relativity in a Nutshell

This article, written by the acclaimed physicist Brian Green, nicely summarizes Einstein's special theory of relativity.

http://www.pbs.org/wgbh/nova/physics/special-relativity-nutshell.html

CK-12 Relativity Study Guide

Students can download or print out this study guide for special relativity and general relativity. http://www.ck12.org/physics/Length-Contraction/studyguide/Relativity-Study-Guide/?referrer=concept_details

Wolfram Demonstrations Project

The following links provide additional interactive simulations regarding physical optics.

- Light Clocks and Time Dilation: http://demonstrations.wolfram.com/LightClocksAndTimeDilation/
- Lorentz Transformation for Twin Paradox: http://demonstrations.wolfram.com/LorentzTransformationForTwinParadox/
- Relativity of Simultaneity: http://demonstrations.wolfram.com/RelativityOfSimultaneity/
- Einstein's Formula for Adding Velocities: http://demonstrations.wolfram.com/EinsteinsFormulaForAddingVelocities/
- Bending of Light By a Star: http://demonstrations.wolfram.com/BendingOfLightByAStar/

22.3 Pacing the Lessons

Note to Teachers: The content contained in Chapter 22 of the Physics Intermediate Teacher's Edition has been consolidated to include one lesson plan for the entire chapter, as opposed to previous chapters that are composed of one lesson plan for each individual lesson in the chapter. The interactive activities and high-quality resources included are meant to provide an efficient introduction to the concept of special and general relativity for the high school level. The three-step instructional model outlined below - (1) Inspire and Inquire, (2) Explain and Elaborate, (3) Assess and Reassess –should take a total of five 60-minute class periods.

TABLE 22.1: Pacing The Lessons

Lesson	Class Periods (60 min)
Chapter 22	5

22.4 Inspire and Inquire

Quick Write

Prompt students to complete a 5-minute quick write to answer the theoretical physics prompt below:

Prompt: What do you think would happen if you were able to travel at the speed of light? How would the universe be perceived by your senses? What would you be able to see, hear, etc? Would the laws of physics you have observed in this classroom still apply?

If time allows, permit students to share their quick writes with a peer or with the rest of the class.

Then, show this short Veritasium video (4:12) that nicely summarizes Einstein's Special Theory of Relativity:

https://www.youtube.com/watch?v=vVKFBaaL4uM

Be sure to highlight the following:

- *Relativity indicates that the laws of physics should apply everywhere in the universe if you are traveling at a constant velocity (inertial reference frames).*
- *In the Special Theory of Relativity, Einstein established that the speed of light is actually constant and space and time are relative.*
- *According to Einstein, we will never know what it is like to travel at the speed of light because we will never be able to go that fast.*

Einstein's Innovative Thinking

The following link includes a wonderful two-day lesson plan, including multimedia resources and interactive activities, introducing students to Einstein's theory of special and general relativity.

http://www.pbslearningmedia.org/resource/phy03.sci.phys.fund.lp_einstein/einsteins-innovative-thinking/

22.5 Explain and Elaborate

SEE-I

Divide the class into groups of 3-4 students and provide each group with a whiteboard and dry erase markers. Demonstrate how to use the SEE-I method to clarify terms and show understanding (see below for more information). Prompt students to use the SEE-I method to describe the following concepts:

- Galilean Relativity
- Michelson-Morley Experiment
- Special Relativity
- Time Dilation
- Length Contraction
- Twin Paradox
- Mass-Energy Equivalence
- General Relativity
- Principle of Equivalence

Learn more about the SEE-I method by visiting the link below:

http://en.wikipedia.org/wiki/SEE-I

What?/Wow!

Prompt students to get out a pen and paper. Instruct students to fold the paper in half and write "WHAT?" on one column and "WOW!" on the other. As students watch the video, *The Elegant Universe, Part 1: "Einstein's Dream"* (described below), they should make a note of any questions they have in the "WHAT?" column and anything they feel is awe-inspiring in the "WOW!" column. When the video is over, discuss as a class.

The Elegant Universe, Part 1: "Einstein's Dream": This PBS NOVA mini-series, based on the book by Brian Greene, wonderfully illustrates the conflict between general relativity and quantum mechanics, as well as highlights Einstein's dream of developing one unified theory.

http://www.pbs.org/wgbh/nova/physics/elegant-universe.html

22.6 Assess and Reassess

Lesson Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Note to Teachers: The questions contained in Chapter 22 of the Physics Intermediate Workbook have been consolidated to include one worksheet for the entire chapter, as opposed to previous chapters that are composed of one worksheet per individual lesson. The Chapter 22 worksheet has a set of practice problems for every lesson in the chapter, rather than every objective. The conceptual questions included are meant to provide an efficient introduction to the theory of special and general relativity appropriate for the high school level.

Lesson Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

Note to Teachers: The questions contained in the Chapter 22 Quiz have been consolidated to include one quiz for the entire chapter, as opposed to previous chapters that are composed of one quiz per individual lesson. The Chapter 22 quiz has a set of problems for every lesson in the chapter, rather than every objective. The conceptual questions included are meant to provide an efficient assessment of student understanding regarding special and general relativity appropriate for the high school level.

Chapter Test

Copy and distribute the Chapter 18 Test using the *CK-12 Physics Intermediate Quizzes and Tests* link.
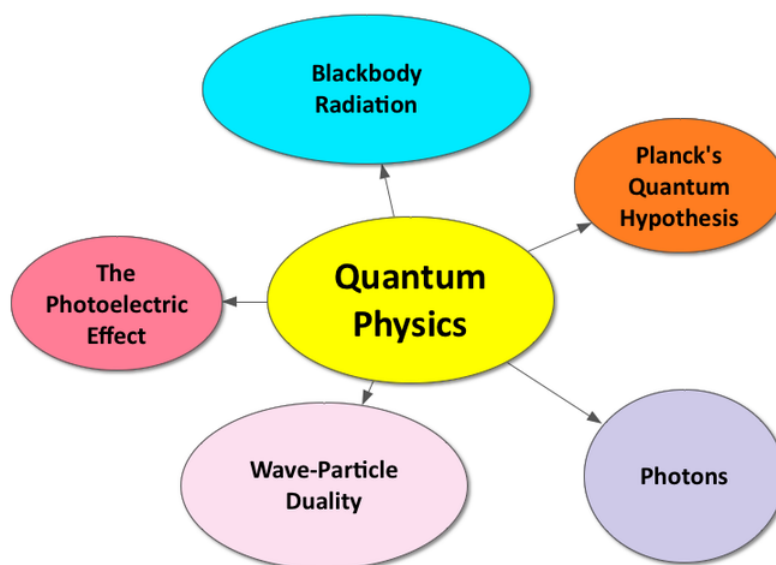
CHAPTER 23   Quantum Physics

Chapter Outline

    23.1   **ATOMIC PHYSICS**

Chapter Overview

Quantum physics is the study of physical quantities in the universe that only change in discrete amounts, or quanta. A blackbody is an idealized object that absorbs all wavelengths of light and re-emits a quantized electromagnetic frequency based on Planck's equation (E=nhf). Although this mathematical equation matched experimental results, Planck had no scientific explanation for the reason why the light emitted by a blackbody only radiated at specific frequencies. Another perplexing physical phenomenon at the time was the photoelectric effect, or the ability of light to transfer energy to electrons and eject them from a metallic surface. In his particle model of light, Albert Einstein deviated from describing light as a wave and, instead, suggested that light was made up of discrete particles called photons. This not only provided an explanation for Planck's blackbody equation, but also offered clarification regarding the photoelectric effect. Einstein proposed that photons of light were responsible for the observed ejection of electrons and won his only Nobel prize in physics for his paper on the photoelectric effect. Upon further examination of blackbody radiation and the photoelectric effect, the wave-particle duality of light became an accepted model in physics.

Online Resources

HyperPhysics

This website, from Georgia State University, provides a student friendly conceptual framework of Quantum Physics.

http://hyperphysics.phy-astr.gsu.edu/hbase/quacon.html

Yale National Initiative: Nanotechnology and Quantum Mechanics

This website provides teaching strategies and classroom activities to encourage teachers to introduce quantum physics at the high school level.

http://teachers.yale.edu/curriculum/viewer/initiative_10.05.04_u

Teaching Advanced Physics: Preparation for Quantum Physics

This website provides many resources for teachers preparing for quantum physics topics.

http://tap.iop.org/atoms/quantum/500/page_47000.html

Wolfram Demonstrations Project

The following links provide additional interactive simulations regarding physical optics.

- **Blackbody Radiation**
  http://demonstrations.wolfram.com/BlackbodyRadiation/

Pacing the Lessons

∗∗Note to Teacher's: The content contained in Chapter 23 of the Physics Intermediate Teacher's Edition has been consolidated to include one lesson plan for the entire chapter, as opposed to previous chapters that are composed of one lesson plan for each individual lesson in the chapter. The interactive activities and high-quality resources included are meant to provide an efficient introduction to quantum physics for the high school level. The three-step instructional model outlined below - (1) Inspire and Inquire, (2) Explain and Elaborate, (3) Assess and Reassess –should take a total of five 60-minute class periods.

TABLE 23.1: Pacing The Lessons

Lesson	Class Periods (60 min)
Chapter 23	5

23.1 Atomic Physics

Misconception Survey

The following statements highlight common misconceptions regarding the atom. Prompt students to take the following survey at the beginning of the chapter. Before the end of the chapter, students should review their initial answers and make any changes they feel necessary. At the end of the chapter, you should post the answer key and dispel any common misconceptions as a class.

Circle T/F to indicate of the following statements are true or false:

- (T / F)
  There has only been one model of the atom ever proposed and every scientific experiment conducted in history to test this model has supported its accuracy.
- (T / F)
  There is nothing smaller than an atom.
- (T / F)
  Electrons travel around the nucleus in an orderly and predictable way, similar to how the planets orbit the sun.
- (T / F)
  Scientists have been able to visualize the structure of an atom by looking through a very powerful microscope.
- (T / F)
  An element and an atom refer to the same thing.

(**All of the above statements are FALSE and should unveil common student misconceptions regarding the atom).

For more common misconceptions, see the link below that highlights student difficulties with the structure of the atom:

http://www.intel.com/content/dam/www/program/education/us/en/documents/project-design/atoms/small-misconceptions-about-the-structure-of-atoms.pdf

PhET: Models of the Hydrogen Atom

Prompt students to utilize this interactive simulation to engage in building a model of the atom and test historic models pertaining to atomic structure.

http://phet.colorado.edu/en/simulation/hydrogen-atom

∗∗Be sure to use this inquiry activity to highlight the following scientists and their contribution to the development of modern atomic physics (as discussed in the Physics Intermediate Ch. 24):

- *J.J. Thompson*
- *Ernest Rutherford*
- *Neils Bohr*
- *Louis DeBroglie*
- *Werner Heisenberg*

Just How Small is an Atom?

Pass out index cards to each student. Prompt students to answer the following questions while watching the short video clip (5:27) at the link below on their index card. When the video is over, collect cards. Look over them, reading common questions and answers aloud to ignite a class discussion regarding the atom.

- What is one thing you found surprising?
- What is one question you still have?

http://ed.ted.com/lessons/just-how-small-is-an-atom#watch

Divide students into groups of 3-4 students and provide each group with a whiteboard and dry erase markers. Challenge each group to complete the following chart by researching the size of each particle in meters and then developing an analogy that accurately illustrates the atomic scale.

TABLE 23.2: Size of atoms

Particle	Scale(meters)	Analogy
Electron		
Proton		
Nucleus		
Atom		

For an exemplary atomic scale chart click on the link below:

http://www.pbs.org/wgbh/nova/education/activities/3306_neutrino.html

Display completed whiteboards at the front of the classroom, highlighting good examples and common themes.

Quantum Tunneling and the Uncertainty Principle

Challenge advanced students to research quantum tunneling and its relationship to the uncertainty principle by at the links below:

http://www.physicsoftheuniverse.com/topics_quantum_uncertainty.html

http://abyss.uoregon.edu/~js/glossary/quantum_tunneling.html

https://www.youtube.com/watch?v=cTodS8hkSDg

http://en.wikipedia.org/wiki/Quantum_tunnelling

Misconception Survey

Students should review their initial answers to the survey given at the beginning of the chapter and make any changes they feel necessary. At the end of the chapter, you should post the answer key and dispel any common misconceptions as a class.

Chapter Worksheets

Copy and distribute the chapter worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

∗∗*Note to Teachers: The questions contained in Chapter 24 of the Physics Intermediate Workbook have been consolidated to include one worksheet for the entire chapter, as opposed to previous chapters that are composed of one worksheet per individual lesson. The Chapter 24 worksheet has a set of practice problems for every lesson in the chapter, rather than every objective. The conceptual questions included are meant to provide an efficient introduction to atomic physics appropriate for the high school level.*

Chapter Quiz

Copy and distribute the chapter quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

***Note to Teachers: The questions contained in the Chapter 24 Quiz have been consolidated to include one quiz for the entire chapter, as opposed to previous chapters that are composed of one quiz per individual lesson. The Chapter 24 quiz has a set of problems for every lesson in the chapter, rather than every objective. The conceptual questions included are meant to provide an efficient assessment of student understanding regarding atomic physics appropriate for the high school level.*

Chapter Test

Copy and distribute the Chapter 24 using the *CK-12 Physics Intermediate Quizzes and Tests* link.
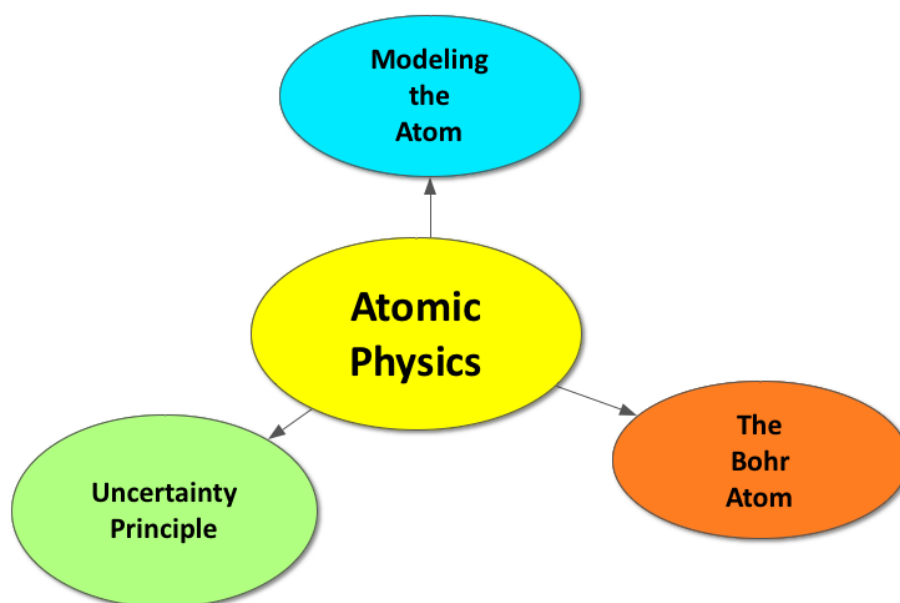
CHAPTER **24**

Atomic Physics

Chapter Outline

Chapter Overview

A scientific model must be used to illustrate the atom as a result of our inability to visualize particles of this size. These models are based on scientific observations and experimentation, and have continually changed overtime as a result of new discoveries. Thompson's model of the atom, often referred to as the plum pudding model, incorporated the electron as a subatomic particle surrounded by a pudding-like substance of positive charge. Rutherford's gold foil experiment led to the revision of the atomic model to include a densely packed positively charged nucleus at the center of the atom, often referred to as the nuclear model. Bohr later proposed that electrons orbited the nucleus in distinct quantum levels. According to Heisenberg's uncertainty principle, the precision of a subatomic particle's momentum and position cannot be known simultaneously. As a result of this uncertainty, subatomic particles were considered to exhibit more of a wavelike behavior. Quantum mechanics has further refined the model of the atom to what is accepted today as the electron cloud model.

Online Resources

Wolfram Demonstrations Project

The following links provide additional interactive simulations regarding physical optics.

- Rutherford Scattering
  http://demonstrations.wolfram.com/RutherfordScattering/
- Bohr's Orbits
  http://demonstrations.wolfram.com/BohrsOrbits/

Veritasium

The following videos dispel common misconceptions and highlight the main ideas behind many of the concepts introduced in this chapter.

- What are Atoms and Isotopes?
  https://www.youtube.com/watch?v=SeDaOigLBTU
- Thompson's Plum Pudding Model of the Atom
  https://www.youtube.com/watch?v=JUJPyQtoB5E
- Heisenberg's Uncertainty Principle Explained
  https://www.youtube.com/watch?v=a8FTr2qMutA#t=175
- Empty Space is NOT Empty
  https://www.youtube.com/watch?v=J3xLuZNKhlY

PHET: Build an Atom

This simulation would be a great resource for students who need more help with visualizing atomic structure.

http://phet.colorado.edu/en/simulation/build-an-atom

Backstage Science: Rutherford Gold Foil Experiment

Students can watch the short video (4:06) found at the link below to learn more about Rutherford's gold foil experiment.

https://www.youtube.com/watch?v=XBqHkraf8iE#t=135

NOVA: Picturing Atoms

Students can listen to the quick podcast, narrated by Neil DeGrasse Tyson, regarding Rutherford's surprising reaction to his discovery that the atom was mostly empty space.

http://www.pbs.org/wgbh/nova/physics/atoms-electrons.html

Pacing the Lessons

∗∗Note to Teachers: The content contained in Chapter 24 of the Physics Intermediate Teacher's Edition has been consolidated to include one lesson plan for the entire chapter, as opposed to previous chapters that are composed of one lesson plan for each individual lesson in the chapter. The interactive activities and high-quality resources included are meant to provide an efficient introduction to atomic physics for the high school level. The three-step instructional model outlined below - (1) Inspire and Inquire, (2) Explain and Elaborate, (3) Assess and Reassess –should take a total of five 60-minute class periods.

TABLE 24.1: Pacing The Lessons

Lesson	Class Periods (60 min)
Chapter 24	5

24.1 Atomic Physics

Misconception Survey

The following statements highlight common misconceptions regarding the atom. Prompt students to take the following survey at the beginning of the chapter. Before the end of the chapter, students should review their initial answers and make any changes they feel necessary. At the end of the chapter, you should post the answer key and dispel any common misconceptions as a class.

Circle T/F to indicate of the following statements are true or false:

- (T / F)
  There has only been one model of the atom ever proposed and every scientific experiment conducted in history to test this model has supported its accuracy.
- (T / F)
  There is nothing smaller than an atom.
- (T / F)
  Electrons travel around the nucleus in an orderly and predictable way, similar to how the planets orbit the sun.
- (T / F)
  Scientists have been able to visualize the structure of an atom by looking through a very powerful microscope.
- (T / F)
  An element and an atom refer to the same thing.

(**All of the above statements are FALSE and should unveil common student misconceptions regarding the atom).

For more common misconceptions, see the link below that highlights student difficulties with the structure of the atom:

http://www.intel.com/content/dam/www/program/education/us/en/documents/project-design/atoms/small-misconceptions-about-the-structure-of-atoms.pdf

PhET: Models of the Hydrogen Atom

Prompt students to utilize this interactive simulation to engage in building a model of the atom and test historic models pertaining to atomic structure.

http://phet.colorado.edu/en/simulation/hydrogen-atom

∗∗*Be sure to use this inquiry activity to highlight the following scientists and their contribution to the development of modern atomic physics (as discussed in the Physics Intermediate Ch. 24):*

- *J.J. Thompson*
- *Ernest Rutherford*
- *Neils Bohr*
- *Louis DeBroglie*
- *Werner Heisenberg*

Just How Small is an Atom?

Pass out index cards to each student. Prompt students to answer the following questions while watching the short video clip (5:27) at the link below on their index card. When the video is over, collect cards. Look over them, reading common questions and answers aloud to ignite a class discussion regarding the atom.

- What is one thing you found surprising?
- What is one question you still have?

http://ed.ted.com/lessons/just-how-small-is-an-atom#watch

Divide students into groups of 3-4 students and provide each group with a whiteboard and dry erase markers. Challenge each group to complete the following chart by researching the size of each particle in meters and then developing an analogy that accurately illustrates the atomic scale.

TABLE 24.2: Size of atoms

Particle	Scale(meters)	Analogy
Electron		
Proton		
Nucleus		
Atom		

For an exemplary atomic scale chart click on the link below:

http://www.pbs.org/wgbh/nova/education/activities/3306_neutrino.html

Display completed whiteboards at the front of the classroom, highlighting good examples and common themes.

Quantum Tunneling and the Uncertainty Principle

Challenge advanced students to research quantum tunneling and its relationship to the uncertainty principle by at the links below:

http://www.physicsoftheuniverse.com/topics_quantum_uncertainty.html

http://abyss.uoregon.edu/~js/glossary/quantum_tunneling.html

https://www.youtube.com/watch?v=cTodS8hkSDg

http://en.wikipedia.org/wiki/Quantum_tunnelling

Misconception Survey

Students should review their initial answers to the survey given at the beginning of the chapter and make any changes they feel necessary. At the end of the chapter, you should post the answer key and dispel any common misconceptions as a class.

Chapter Worksheets

Copy and distribute the chapter worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

∗∗*Note to Teachers: The questions contained in Chapter 24 of the Physics Intermediate Workbook have been consolidated to include one worksheet for the entire chapter, as opposed to previous chapters that are composed of one worksheet per individual lesson. The Chapter 24 worksheet has a set of practice problems for every lesson in the chapter, rather than every objective. The conceptual questions included are meant to provide an efficient introduction to atomic physics appropriate for the high school level.*

Chapter Quiz

Copy and distribute the chapter quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

***Note to Teachers: The questions contained in the Chapter 24 Quiz have been consolidated to include one quiz for the entire chapter, as opposed to previous chapters that are composed of one quiz per individual lesson. The Chapter 24 quiz has a set of problems for every lesson in the chapter, rather than every objective. The conceptual questions included are meant to provide an efficient assessment of student understanding regarding atomic physics appropriate for the high school level.*

Chapter Test

Copy and distribute the Chapter 24 using the *CK-12 Physics Intermediate Quizzes and Tests* link.
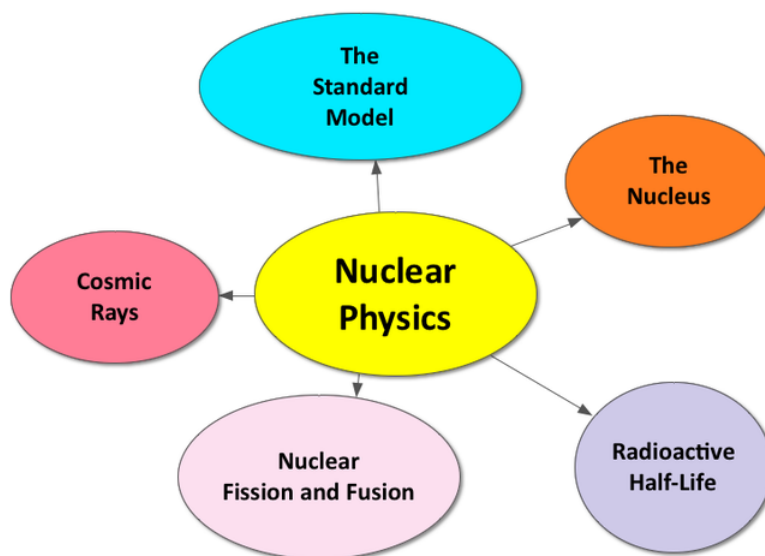
CHAPTER **25** **Nuclear Physics**

Chapter Outline

Nuclear physics is the study of nucleons, the subatomic particles contained in the nucleus of an atom. Nucleons that have an overall positive charge are called protons and nucleons that have an overall neutral charge are called neutrons. An atom's atomic number (Z) refers to how many protons are contained in its nucleus. An atom's atomic mass number (A) refers to the total number of nucleons contained in its nucleus. Atoms that contain the same number of protons but a different number of neutrons are called isotopes. An atom is always neutral, so the number of electrons orbiting the nucleus will be equal to the number of protons in the nucleus. Nucleons are bound together by a short-range, attractive force that exists only in the nucleus called the strong nuclear force (a fundamental force of nature, alongside the electromagnetic force, gravitational force, and the weak nuclear force). This strong nuclear force between the protons and neutrons counters the repulsive electrostatic force between the positively charged protons in the nucleus and helps to make the nucleus stable. As the number of protons in an atom's nucleus increases, the stability of the atom decreases. Unstable nuclei are described as radioactive and can spontaneously decay. There are three types of spontaneous radioactive decay: alpha decay (α) beta decay (β), and gamma decay (γ). Every isotope has a unique radioactive half-life that determines how quickly it will decay. The amount of energy needed to overcome the strong nuclear force in order to separate the nucleons from each other is referred to as the binding energy. The binding energy can be derived using the equation $E=\Delta mc^2$, in which Δm is the mass deficit. The more stable the atom, the greater the binding energy. Nuclear fusion describes the process in which the small nuclei of lighter elements combine to form a heavier element, resulting in the release of a large amount of energy. Nuclear fission involves the splitting of an atom with a large atomic mass into to smaller atoms, also resulting in the release of a large amount of energy. The weak nuclear force is now understood to be responsible for radioactive decay and nuclear fission. The Standard Model of Physics encompasses our current understanding of and ongoing inquiry regarding the fundamental structure of matter, governed by the four fundamental forces of nature.

25.1 Online Resources

Wolfram Demonstrations Project

The following links provide additional interactive simulations regarding nuclear physics.

- Exponential Decay: http://demonstrations.wolfram.com/ExponentialDecay/
- Carbon Dating: http://demonstrations.wolfram.com/CarbonDating/
- Isotope Decay: http://demonstrations.wolfram.com/IsotopeDecay/

PhETs

The links below provide alternative interactive simulations for students who are visual learners or need more practice with many of the concepts in this chapter.

- Alpha Decay: http://phet.colorado.edu/en/simulation/alpha-decay
- Beta Decay: http://phet.colorado.edu/en/simulation/beta-decay

CK-12 Nuclear Physics Study Guide

Students can download or print out this study guide for Newton's three laws of motion.

http://www.ck12.org/physics/Radiation/studyguide/Nuclear-Physics-Study-Guide/

Pacing the Chapter

Note to Teachers: The content contained in Chapter 25 of the Physics Intermediate Teacher's Edition has been consolidated to include one lesson plan for the entire chapter, as opposed to previous chapters that are composed of one lesson plan for each individual lesson in the chapter. The interactive activities and high-quality resources included are meant to provide an efficient introduction to nuclear physics for the high school level. The three-step instructional model outlined below - (1) Inspire and Inquire, (2) Explain and Elaborate, (3) Assess and Reassess –should take a total of five 60-minute class periods.

TABLE 25.1: Pacing The Lessons

Lesson	Class Periods (60 min)
Chapter 25	5

25.2 Inspire and Inquire

NOVA: The Ghost Particle Classroom Activity

Allow the class to experience what it is like to be a particle physicist and gather information about objects that they cannot physically see by challenging students to identify an object in a "mystery box", as described at the link below. http://www.pbs.org/wgbh/nova/education/activities/3306_neutrino.html

If time allows, connect this activity with the current research of fundamental particles being conducted at CERN: http://home.web.cern.ch/ .

Be sure to remind students of the mystery tube activity done in the first week of school (Chapter 1, Lesson 1), highlighting that science begins and ends with inquiry.

Teaching Advanced Physics: Radioactive Background and Detectors

First, prepare the class for an inquiry regarding radioactivity by ensuring that students have the prior knowledge described at the link below:

http://tap.iop.org/atoms/radioactivity/508/page_47066.html

Then, follow the teaching strategies outlined at the following link, http://tap.iop.org/atoms/radioactivity/509/page_47071.html , to help students address these big questions:

- What are sources of radiation?
- What is background radiation?
- Should we worry about everyday exposure to radiation?

Be sure to dispel these common misconceptions regarding radioactivity:

http://www.furryelephant.com/content/radioactivity/teaching-learning/radioactivity-misconceptions/

25.3 Explain and Elaborate

Nuclear Fission vs Nuclear Fusion: Whiteboard Model

Prompt students to learn more about *nuclear fission* and *nuclear fusion* at the corresponding links below:

- Nuclear Fission: http://phet.colorado.edu/en/simulation/nuclear-fission
- Nuclear Fusion: https://www.youtube.com/watch?v=Ux33-5k8cjg

Divide students into groups of 3-4 and provide each group with a whiteboard and dry erase markers. Challenge each group to create a whiteboard model that illustrates the similarities and differences between nuclear fission and nuclear fusion using words, images, and equations.

Display completed whiteboards at the front of the classroom, highlighting good examples and common themes.

Be sure to highlight the following main ideas:

Similarities:

- Fission fusion both produce large amounts of energy
- Mass is not conserved in either reaction –it is lost/turned into energy (E=mc2)

Differences:

- Fission: one atom splits into two, prompted by a neutron
- Fusion: two atoms combine into one, producing 3-4 times more energy than fission

If time allows, prompt students to use the third tab in the nuclear fission simulation to investigate nuclear reactors and the function of control rods. Then, prompt students to watch the following video highlighting what happened to the Fukushima nuclear power plant after the 2011 earthquake and tsunami.

https://www.youtube.com/watch?v=BdbitRlbLDc

25.4 The Standard Model=

Prompt advanced students to learn more about the Standard Model of Particle Physics and current research being conducted to investigate fundamental particles by visiting the following links:

- Lawrence Berkeley National Laboratory: The Particle Adventure: http://www.particleadventure.org/index.html
- Veritasium: What Now for the Higgs?: https://www.youtube.com/watch?v=649iUqrOKuE

25.5 Assess and Reassess

Final Class Exit Slip: The Most Astounding Fact

During your last class meeting, inform the students of the background information regarding the video below and show them the short video clip (3:33).

Background and video clip: In an interview with Time Magazine, famous astrophysicist Neil DeGrasse Tyson was asked, "What is the most astounding fact you can share with us about the universe?" and offered this response, narrated in the following short video: https://www.youtube.com/watch?v=9D05ej8u-gU .

Then, pass out index cards to the students and ask them to write their response to the following prompt on the card. Collect the cards as students exit the classroom and assess.

Prompt: What is the most astounding fact you have learned in this physics class?

Chapter Worksheets

Copy and distribute the lesson worksheet in the *CK-12 Physics Intermediate Workbook*. You can also upload the PDF or provide the worksheet link on your class website.

Note to Teachers: The questions contained in Chapter 25 of the Physics Intermediate Workbook have been consolidated to include one worksheet for the entire chapter, as opposed to previous chapters that are composed of one worksheet per individual lesson. The Chapter 25 worksheet has a set of practice problems for every lesson in the chapter, rather than every objective. The conceptual questions included are meant to provide an efficient introduction to nuclear physics appropriate for the high school level.

Chapter Quiz

Copy and distribute the lesson quiz using the *CK-12 Physics Intermediate Quizzes and Tests* link.

Note to Teachers: The questions contained in the Chapter 25 Quiz have been consolidated to include one quiz for the entire chapter, as opposed to previous chapters that are composed of one quiz per individual lesson. The Chapter 25 quiz has a set of problems for every lesson in the chapter, rather than every objective. The conceptual questions included are meant to provide an efficient assessment of student understanding regarding nuclear physics appropriate for the high school level.

Chapter Test

Copy and distribute the Chapter 18 Test using the *CK-12 Physics Intermediate Quizzes and Tests* link.