Core Knowledge
Physics Syllabus

Overview

This course is designed to provide teachers with the background and understanding necessary to teach the physics content of the Core Knowledge Foundation curriculum for grades K-8, although it would be of value to any teacher of K-8 science. It stresses the fundamental concepts and principles of physical science and illustrates how they are applied in our understanding of nature. The instructional approach reflected in this syllabus and the suggested text emphasizes conceptual understanding and concrete illustrations of the topics presented. Fundamental underlying principals such as conservation laws are stressed. The design of any one-semester physics course involves judgments concerning the topics to be included and those that will be omitted. As this course is intended to support the teaching of physics in elementary and middle school, the topics selected were chosen with this in mind. They include the motion of solid bodies (mechanics) and of fluids; energy, heat and energy transfer; sound; electrostatics and electrical currents; magnetism; properties of light and optics; and characteristics of waves and particles.

The course is intended to be taught in a thirteen-week semester, with two class periods and one correlated lab session per week, as indicated in the suggested schedule below. The laboratory exercises complement the lecture/discussion by emphasizing hands-on (and minds-on) experience in demonstrating the basic principles. An Instructor Guide is provided for each class period. The Guides identify four to six specific objectives that students should be able to accomplish at the completion of that session and contain suggestions for illustrations and demonstrations of the ideas presented in each class. Many of the labs and demonstrations use materials that should be available to K-8 teachers. This should be pointed out to the students to encourage them to use similar demonstrations in their classrooms

Each Guide also contains a suggested homework assignment to illustrate the level of student performance expected. Most of the questions and exercises in these assignments require written responses in the form of explanations or predictions about outcomes rather than numeric calculation. In our experience, students can often learn to manipulate formulas and get the “right” answer to physics problems without a clear understanding of the underlying principles. For this reason, homework assignments requiring written responses and explanations are recommended. Some of the questions in the text could elicit only one or two word responses. If you choose to use these questions, insist that your students not only answer the questions, but also explain their answers in complete sentences. Students who intend to be teachers need to be able to express scientific concepts and principles clearly.

The syllabus includes thirteen laboratory exercises to accompany the Instructor Guides. These correlated labs are intended to give students hands-on concrete experience with physical phenomena. They differ from the "cookbook" experiments found in the lab manuals that accompany some texts in that they emphasize observation as opposed to data collection and calculation. The instruction sheets are designed to be copied and distributed to the students so that they can record their observations right on the sheets. Students should be able to carry out the exercises and complete the sheets in a three-hour lab period. This allows lab instructors to work with students during the lab period to correct any misconceptions they have concerning their observations, an approach that we recommend.

This syllabus was created by Robert Alt, Professor of Physics Emeritus at California State University Dominguez Hills, and Sam Wiley, Professor of Physics at California State University Dominguez Hills, as part of What Elementary Teachers Need to Know, a teacher education initiative developed by the Core Knowledge Foundation. Although the syllabus is copyrighted by the foundation, and may not be marketed by third parties, anyone who wishes to use, reproduce, or adapt it for educational purposes is welcome to do so. However, we do ask individuals using this syllabus to notify us so we can assess the distribution and spread of the syllabi and serve as a repository of information about how they may be improved and more effectively used. Please contact us at http://coreknowledge.org/CK/contact.htm.

Class Schedule

Week	Session	Topic / Activities	Chapter: Section(s)	Lab Activities
1	1	Speed and Velocity	1: 1 - 2	Distance and Speed
	2	Acceleration, Free Fall	1: 3 - 4	
2	3	Three Laws of Motion	2: 1 - 3	Acceleration
	4	Momentum Conservation	3: 1 - 3	
3	5	Energy Conservation	3: 5 - 9	Energy and Momentum
	6	Gravity and Tides	4: 1 - 3	
4	7	First Examination (Structure)		Archimedes' Principle
	8	Fluids, Buoyancy	5: 1 - 5	
5	9	Temperature, Thermal Energy	6: 1 - 7	Temperature and Thermal Expansion
	10	Phase Change	6: 8 - 9	
6	11	Heat Transfer	7: 1 - 3	Thermal Equilibrium
	12	Convection and the Coriolis Effect	26: 3, 5 - 6	
7	13	Second Examination (Sample)		Static Electricity
	14	Static Electricity	8: 1 - 4	
8	15	Current Electricity	8: 5 - 8	Electrical Circuits
	16	Natural and Artificial Magnets	9: 1 - 4	
9	17	Magnets and Moving Charge	9: 5 - 9	Electric Motors
	18	Sound Waves	10: 1 - 6	
10	19	Interference, Moving Sources	10: 7 - 13	Standing Waves
	20	Third Examination		
11	21	Light Waves	11: 1 - 2	Color
	22	Color	11: 3	
12	23	Interference and Polarization	11: 4 - 6	Reflection
	24	Reflection, Refraction	12: 1 - 5	
13	25	Waves and Particles	12: 6, 13: 5 - 6	Lenses and Mirrors
	26	Fourth Examination		

The chapter and section references are from Conceptual Physical Science by Paul G. Hewitt, John Suchocki, and Leslie A. Hewitt, but there are a number of physical science texts that could be substituted. For example, Physical Science, by Bill W. Tillery, 4th Edition (McGraw-Hill), is simply written with clear illustrations and it comes in economical paperback form. For a somewhat more traditional approach than Hewitt, with more algebra, you might consider The Physical Universe by Krausekopf and Beiser (McGraw-Hill), now in its eighth edition.

If you wish a text that covers only physics and provides a bit more exposition of the topics, Conceptual Physics by Hewitt is an extremely popular book. It is similar in approach and level of presentation to Conceptual Physical Science, and also has a large number of review questions and problems at the end of each chapter. Other possibilities are Physics, a World View, by Kirkpatrick and Wheeler (Harcourt) and Inquiry Into Physics by Osdick and Bord (West Publishing). Any of these texts would need to be augmented with other material to cover Session 12 on atmospheric and ocean current circulation. The topics and the order of presentation suggested in the schedule are common to many physics texts, so instructors should encounter little difficulty in adapting this syllabus to their choice of textbooks.

The World Wide Web has a rich variety of supporting materials. Two major resources are:

http://www-hpcc.astro.washington.edu/scied/physics.html, with listings in math, chemistry, biology, etc.

http://cse.ssl.berkeley.edu, a science education gateway

The students may also enjoy http://HowStuffWorks.com

Instructor Guide Session 1 Speed and Velocity

Objectives:

- Given one or more definitions, supply the vocabulary word(s) from the list [Instantaneous speed, average speed, velocity] that best matches each definition.
- Perform simple calculations of speed and distance (including the units) applying these definitions.
- Draw a graphic representation of a velocity vector.
- Represent the addition of two different velocities graphically. Indicate the resultant velocity by means of a parallelogram.

Reading Assignment: Conceptual Physical Science, 2nd Edition, Paul G. Hewitt, John Suchocki, Leslie A. Hewitt. Chapter 1, Sections 1 - 2.
Suggested Homework Assignment: Conceptual Physical Science, Chapter 1, Review Questions: 1, 2, 3; Exercise 1 and Problem 2.

A number of studies have shown that students come to their first physics class with only partially formed ideas about the basic properties of motion -- speed, velocity and acceleration -- so it is best to move slowly through the discussion of these topics. This first session is limited to motion with constant speed, constant velocity, or situations involving average speed and velocity. Accelerated motion is reserved for the following session.

While the main focus of this unit is on the concept of speed and velocity, and on making clear the distinction between the two, there is also an important related sub-text: the distinction between scalar and vector quantities. Begin by pointing out that some quantities can be described using only magnitude (scalars) but other quantities also require directional information (vectors). Give the students illustrations of each: temperature, for example, as a scalar quantity and wind velocity as a vector. Have the students generate examples of each category. Point out the significance of the directional properties of vectors. If someone gives you instructions on how to get somewhere, you don't just want to know how far it is, but in addition you need to know the direction you must travel as well.

Give the definitions of speed and velocity and illustrate the distinction between the scalar properties of the former and the vector properties of the latter. A round-trip automobile journey at a constant speed is a good example. Contrast the average *speed*, given by the total distance traveled (the trip out plus the trip back) divided by the time, with the zero average *velocity* for the trip (since the vector displacement traveled on return subtracts from the displacement on the outbound trip).

When you feel the students have the definitions of speed and velocity well in hand, move on to a discussion of average speed and the distance traveled in situations where the speed is not constant. In general, the distance an object moves is equal to the product of the average speed times the time it moves. Illustrate this with a car driven at constant speed for an hour, plus a stop of 15 minutes, followed by another hour's drive at a different constant speed.

Duplicate the text's illustration of the airplane moving with a tail wind and also with a head wind for the class to re-introduce the directional properties of velocity and the addition of vectors. Then change to a 90-degree crosswind. Stress that the location of the velocity vector does not matter - all arrows with the same length and orientation are equivalent! When adding two vectors, they can be moved around as long as their magnitudes and directions are not changed. Start by drawing the velocity vectors of the airplane and the crosswind so that the tails of the vectors do not touch. Redraw the vectors so that the tails coincide and complete the construction. At this point it's probably best to avoid examples where the vectors to be added are not either parallel or perpendicular.

Demonstrations

March by the blackboard at a uniform pace marking the board every second and counting out aloud, "one-thousand-and-one, one-thousand-and-two, etc." as you go. Measure the distance between the marks and calculate your speed. Then add the direction to convert this to a velocity. Point out that walking along a straight line is a one-dimensional system. Direction can be indicated with a plus or minus sign. Both the direction and orientation of this coordinate system can be freely chosen.

Switch to a less complicated body . . . a simple ball such as a handball. It can be rolled along a tabletop but it is easier to control by having it ride in a groove. A piece of u-track, or shelving standard, works well, or place two meter sticks (or better yet, two 8 inch wide shelves that are as long as possible) together with a small space in between them. This forms a natural groove for the ball. Repeat the time and distance measurements for several different initial "pushes." If you like, you could point out the connection with the work done by Galileo, since this would provide a natural lead-in to the discussion of accelerated motion in the next session.

Objectives:

- Given one or more definitions, supply the vocabulary word(s) from the list [acceleration, free fall] that best matches each definition.
- Given a value of constant acceleration, construct a table of speed versus time.
- Sketch a graph of the speed versus time for constant acceleration; Determine the slope of a straight line speed versus time graph and find the acceleration from the slope.
- Find the distance traveled in the case of constant acceleration by using the fact that this distance = <u>Average</u> Speed x Time Interval = ½ at^2 when starting from rest.

Reading Assignment: Conceptual Physical Science, 2nd Edition, Paul G. Hewitt, John Suchocki, Leslie A. Hewitt. Chapter 1, Sections 3 – 4.
Suggested Homework Assignment: Conceptual Physical Science, Chapter 1, Review Questions: 7, 11, 12, and Exercise 12.

Acceleration is one of those concepts that can cause confusion when students first encounter it in a formal, quantitative context. The confusion sometimes arises from the fact that two things are changing when an object is accelerating: *position* and *velocity*. Emphasize that acceleration is the change in the *velocity* per unit time.

Everyone has experience with acceleration, and the use of illustrations that draw on that experience, for example, acceleration when driving an automobile, can help clarify their understanding. Illustrate acceleration by noting that driving in town involves starting from rest and slowing down at stoplights. As you start from rest and increase your velocity, you are accelerating. As you slow down, your velocity also changes. This decrease in velocity is referred to as a *negative acceleration* or *deceleration.* However, as you drive between stoplights or along a freeway at a constant velocity, your acceleration is zero. (Be careful to always refer to velocity, not speed, as you discuss acceleration in this unit. While this discussion focuses on motion in one dimension, later units will cover motion in two dimensions, and it is important that students remember the vector properties of motion and understand that acceleration can result from either the change in the magnitude of the velocity, or its direction, or both.)

Following Hewitt's example, initially write the units of acceleration as meters per second for each and every second or m/s per second rather than the more compact m/s^2. This highlights uniform acceleration as a regular change in velocity. Velocity is the change in position per unit time (with units of distance/time) and acceleration is the *change in this quantity per unit time.* Allow a steady transition to the compact representation. In fact, you may want to begin by mixing the units of time and talk about acceleration as the change for each and every second of a velocity measured in meters/hour or kilometers/hour since that may be more familiar from the students' automotive experience.

For example, do a calculation of average acceleration for an automobile that can go from zero to 100 km/hour (about 62 miles/hour) in ten seconds. Have the students find its acceleration in km/hr per second. Then, assuming the acceleration is constant, have them calculate how fast it is going at the end of one second, two seconds, three seconds, etc. in km/hr. Set up a table of velocity versus time. Then convert the velocities to meters per second. By noting the change in velocity is the same in each one-second interval, have them find the acceleration in m/s per second.

Once your students are comfortable working through calculations like the above (given the change in velocity over a period of time, what is the acceleration, or, given the acceleration, find the velocity at the end of a given time interval), they should be ready to consider the motion of falling objects. Begin by stating that falling objects undergo a constant acceleration of 9.8 m/s per second near the earth's surface, but to simplify the calculations in the class examples, you are going to round this to 10 m/s^2. Then ask them the velocity of a falling body at the end of one, two, three, etc. seconds and create a table as before.

This is a good place to introduce the graphical representation of motion as a function of time. Some texts (Hewitt included) don't do much with this approach. It does take additional time, but if done carefully it can be well worth the effort. Graphs of velocity and position versus time can be a real help to students who tend to think visually and they can also provide an easy way of deriving the expression for position as a function of time for constant acceleration. Carefully plot the velocity versus the time for each of the points that you've calculated in the table above (or have your students do this). Point out that the graph is a straight line and show that the slope of the line is the constant acceleration of the body. You can reinforce this concept by having them calculate and plot a similar set of points for a different acceleration, say 5 m/s^2, and compare the slopes of the two lines. Then ask what the line would look like if the acceleration were 20 m/s^2. When the majority of the class recognizes that the "steepness" of the slope is proportional to the acceleration, point out that the idea of slope (or tangent) can be applied to velocity and position graphs that are not straight lines. The tangent to the velocity curve at any specific time is the instantaneous acceleration and the tangent to the position curve is the instantaneous velocity.

The straight-line velocity graphs for constant acceleration can be used to show visually how to calculate the position of a falling body or any object undergoing constant acceleration at any given instant. Take one of the velocity versus time graphs that you've drawn and draw a horizontal line parallel to the time axis through the point midway between the initial velocity value and the final velocity. The students should be able to see easily that for every point on the velocity-time graph above the horizontal line there is a corresponding point an equal distance below the line. Then, by adding these points in pairs over the entire time interval, it's clear that the average velocity is just the value of the velocity at the midpoint. In other words,

$$v_{\text{avg}} = \tfrac{1}{2}(v_{\text{initial}} + v_{\text{final}})$$

From the previous unit, distance traveled = average velocity x time, so

$$d = v_{avg} \text{ x time} = ½(v_{initial} + v_{final}) \text{ x time}$$

For an object starting from rest $v_{initial} = 0$ and

$$d = ½(v_{final})\ t = ½(at)\ t$$

$$d = ½(at^2)$$

If time permits you can now calculate the total distance traveled starting from rest for each point corresponding to a velocity value in one of your tables and plot distance versus time. This graphical representation is rich in illustrations of the properties of motion under constant acceleration. Sketch in the distance versus time curve and draw the tangents at a few of the points. Point out how the increasing slope of the tangent corresponds to the increasing value of the velocity at these points. Show how the distance traveled in one second keeps increasing with time, also demonstrating the increasing velocity.

Distance and Speed Lab

Purpose

To become familiar with common distance measurements in the British and the metric system.

Introduction

All science begins with systematic observation and measurement. You may be familiar with measuring distance in feet and inches, and weight in pounds (the British system), but elsewhere in the world the most common measurement units are based on the metric system. This is also the system of units used in scientific measurements. The chief advantage of the metric system over the British system is that it is decimal in structure. (Our monetary system has some of this structure: penny, dime, dollar, ten-dollar bill. Each of these coins or bills is ten times greater than the one preceding it). In the metric system the basic unit of distance is the meter. Prefixes are used to designate many of the more common multiples of ten -- *mega* for one million, *micro* for one one-millionth, *kilo* for one thousand, *milli* for one one-thousandth, *hecto* for one hundred, *centi* for one one-hundredth -- these are some examples. Hence, one thousand meters would be a kilometer.

Equipment/Materials

Meter stick, stopwatch.

Procedure

This activity will provide practice with using the metric system.

1. Please fill in the appropriate prefixes:

   1,000 meters = Kilo meter 1,000,000 meters = ____ meter

   (1/100) meter = ____ meter (1/1000) meters = ____ meter

   (1/1,000,000) meter = ____ meter

2. Notice that a number of the units require many zeros. A handy shorthand is known as exponential notation in which you keep track of the number of zeros and whether you are multiplying or dividing. For example 1,000 meters has three zeros. It may be represented by 10^{+3}. The plus sign in the exponent indicates multiplication and the 3 means that you multiply by 10 three times. If the sign had been minus, 10^{-3}, that would mean that you divide by ten three times. Complete the following table:

1,000 meters = $\underline{10^{+3}}$ meter 1,000,000 meters = ____ meter

(1/100) meter = ____ meter (1/1000) meters = ____ meter

(1/1,000,000) meter =____ meter

3. In the metric system, the central unit of distance measurement is the meter. One meter is equal to 39.37 inches or 3.281 feet. Using these conversion factors, carry out the distance conversions below.

   Elaine is five feet tall. This is the same as _____ inches or _____ meters.

   Jose is a basketball player. He is 2 meters tall. This is the same as

   ________ feet _______ inches.

4. Fill in some of the measurements of your own body. For some of the measurements you'll need to cut and tape together a thin strip of paper to act as a flexible ruler. The measurement can be marked on the strip and measured with the rigid meter stick afterward.

   Knuckle to knuckle of little finger _________ millimeters.

   Inter-ocular distance (eye to eye) _________ centimeters.

   Hand span (little finger to thumb) __________ cm,

   Wrist size ___________ cm.

   Tip of nose to outstretched fingertip __________ cm.

   Height ____________ cms.

5. Now, a few quick measurements that are larger than your own body:

   Doorway height _______________ meters.

   Classroom Width ___________ m, Depth ____________ m.

   Length of a building _______________ m.

   Walk as fast as you can for the length of the building you recorded above, recording the time it takes you in seconds.

Time to traverse the length of the building ______ seconds.

Average walking speed = Building length/ time = ______ m/s.

Using the conversion factor 1 m/s = 2.25 mile per hour, calculate your average speed:

________________ miles/hour. (A world-class racewalker can walk about 10 miles an hour).

Instructor Guide **Session 3** **Three Laws of Motion**

Objectives:

- Given one or more definitions, supply the vocabulary word(s) from the list: [Inertia, Mass, Weight, Force, Equilibrium, Friction] that best matches each definition.
- Describe the condition for equilibrium in terms of applied forces.
- State Newton's three laws of motion. Give an illustration of each law and apply them to find the forces acting on an object or its acceleration.
- For a given situation, identify both the action and the reaction forces.

Reading Assignment: Conceptual Physical Science, 2nd Edition, Paul G. Hewitt, John Suchocki, Leslie A. Hewitt, Chapter 2, Sections: 1 - 3.
Suggested Homework Assignment: Conceptual Physical Science, Chapter 2, Review Questions: 2, 15, 17, 25 and Exercise 6.

We all have an intuitive understanding of the connection between force and motion. However, that intuition is based on experience in situations where all the forces acting are not immediately apparent. For example, when an object is thrown or pushed and released, a casual observer may not perceive the frictional force acting on it. Or when we see a book resting on a table we may not think of the combination of forces from gravity and the supporting table that keeps it at rest. As a result, our experience of the relationship between force and motion is closer to that described by Aristotle than Newton. The genius of Galileo and Newton was to isolate and analyze the effect of forces like gravity in the absence of other external influences. The challenge in introducing students to the laws of motion is to do it in a way that draws on their experience but is not limited by it.

Newton’s first law describes "natural motion," which is motion in the absence of net external forces. When the net force on a body is zero, it is in equilibrium. The equilibrium may be static (no motion) or dynamic -- motion in a straight line with a constant speed forever. According to Newton’s First Law of Motion, perpetual motion is not impossible, but in fact mandatory once an object is set in motion, unless some force intervenes and stops the motion -- an entirely different vision of natural motion than Aristotle’s.

Newton’s Second Law is often written in the form "F = m a" (Force = mass times acceleration). This expression may be rearranged as $a = (F / m)$. This form stresses that the force is the <u>cause</u> and the acceleration is the <u>effect</u>. This is important in the context of the laboratory when students must distinguish between dependent and independent variables. Finally, written as $m = (F / a)$ the second law can be considered as the definition of *inertial* mass, that property of a body that resists acceleration. This property, resistance to change in motion, is known as inertia. It is introduced by the first law and quantified, here, in the second law.

Mass also is related to another important property, weight. The weight of an object is the gravitational force that the earth exerts on it and gravitational force is proportional to mass. Note that the inertial mass is a scalar while the weight of an object - the force of the earth on an object - is a vector. It includes both how much and in what direction. The text avoids the use of this terminology, but since you have already introduced the terms scalar and vector, you should point out this distinction.

The third law says that an isolated force acting on an object is not possible. Forces, like bookends, come in matched pairs. Although limiting, it could be called the law of transportation since some of the best illustrations come from simple examples of walking, the motion of cars and rockets, etc. Discuss why friction is needed to get a car moving. As an illustration, compare the acceleration of a car on dry pavement with the difficulty in accelerating it on ice. The same comparison can be applied to walking.

Bodies in equilibrium offer good illustrations of all three of Newton's Laws of Motion. A book resting on a table is at rest because the net force acting on it is zero (first law). It has zero acceleration because again, the net force is zero (second law). The weight of the book exerts an *action* force on the table. The table exerts an equal and opposite *reaction* force on the book (third law), keeping it at rest. Point out that the action and reaction forces never act on the same object.

Now consider a car moving with a constant velocity. Since its velocity is constant, the net force on it is zero (first law). In addition to the force of gravity (weight) acting on it and the equal reaction force of the road due to this weight, there are two other forces acting on the car: the air resistance (friction) opposing its motion and the frictional force between the road and the tires that pushes the car forward. The latter force may seem surprising to students at first, since we usually think of friction as opposing motion, but in this case friction exerts a reaction force on the car equal to the action force the tires are exerting on the road (third law). Since the car is moving with constant velocity, its acceleration is zero (second law). If it were not for friction, the road could not exert the force necessary to overcome air resistance and keep the car moving. Without friction, it would not be possible to exert the necessary force on the car to get it moving in the first place. Point out the difficulties of driving on a slippery surface.

Demonstrations

First law - Yank a tablecloth (or large sheet of butcher paper) from under a table setting. Pull both laterally and <u>downward</u> to avoid having the dishes hop into the air. If you don't want to risk the family china, you might want to just use some books, blocks of wood or other non-breakable objects. Just make sure that there's not too much friction between the objects and tablecloth or paper.

Falling bodies – Hewitt has suggested a nice sequence to show that objects all fall at the same rate in the absence of friction. Drop a book and a sheet of paper simultaneously. Naturally, the book falls more rapidly, due to the effect of air friction. Place the paper under the book and release them. It will be forced against the book as they both fall, so they fall at the same rate. Now place the paper on top of the book and drop them together. They again fall at the same rate! The book pushes the air aside as it falls, eliminating the air friction on the paper and demonstrating that, when the effect of friction is eliminated, the paper is accelerated at the same rate as the book. (If you try this demonstration, make sure that the paper is the same size or a little smaller than the book so that no air friction acts on its edges). You might want to add to this demonstration with a discussion of “drafting” in auto racing, explaining why a racer can travel faster when it is following closely behind another car.

Instructor Guide Session 4 Momentum Conservation

Objectives:

- Given one or more definitions, supply the vocabulary word(s) from the list [Momentum, Impulse, Conservation of Momentum, Elastic/Inelastic Collisions] that best matches each definition.
- Given the mass and velocity of an object, calculate its momentum.
- Given a constant force and the time it is applied, compute the impulse.
- Find the impulse related to a change in momentum and relate the force exerted to the time of the interaction.

Reading Assignment: Conceptual Physical Science, 2nd Edition, Paul G. Hewitt, John Suchocki, Leslie A. Hewitt. , Chapter 3, Sections: 1-3.
Suggested Homework Assignment: Conceptual Physical Science, Chapter 3, Review Questions: 1, 12, 13 and Exercise 13.

In this lesson students are introduced to the first of several conservation laws they will encounter in their study of physics, the law of *conservation of momentum*. Conservation laws are among the most important and fundamental relationships in physics. This is not only because they reflect basic, significant symmetries in nature, but also because quantities that are conserved during physical interactions can often be used to predict the outcome without having to know or understand the details of the interaction. For example, if a bullet is fired into a block of wood and remains lodged in it, conservation of momentum allows us to determine the resulting motion of the bullet and the block without having any detailed knowledge of the complex forces exerted by the bullet and block during their interaction. Be sure to stress the enormous simplifying power of conservation laws and illustrate this with examples like the one above.

The impulse-momentum relationship

$$F\ t = \Delta(m\ v)$$

and the law of conservation of momentum do not represent any new physics. They simply represent a very useful way of restating Newton's second and third laws of motion. Or, if you prefer, Newton's second and third laws are a different way of representing the impulse-momentum relationship and the conservation of momentum.

To illustrate this, consider an interaction between two bodies, say a rocket and the fuel that it burns. From the point of view of Newton's laws, the explosive burning fuel exerts a force on the rocket, accelerating it to some final velocity, v, when the fuel is used up. (You might want to check to see if there are still some students who think the force that drives the rocket comes from the exhaust "pushing against" the air, even though they've seen rockets operating in space where there is no air to push against). Newton's third law tells us that the rocket must supply an equal and opposite force to the exhaust that it ejects, so that at any moment the mass of the rocket (M_R) times the acceleration of the rocket (a_R) must be equal and opposite to the force ejecting the fuel from the rocket.

Analyzing the rocket-fuel system from the point of view of momentum conservation, there are no *external* forces acting on the combined rocket-fuel system (forces between the rocket and the exhaust fuel are internal to the system), so the total change in momentum must be zero from the conservation of momentum. Thus, the momentum that the rocket gives to the burnt fuel that it ejects must be accompanied by an equal but opposite momentum that the fuel imparts to the rocket, driving it forward. This is true in any two-body system in the absence of external forces. Whatever change in momentum one object experiences, the other must experience an equal but opposite change. There are many examples you can choose as illustrations: the "kick" of a rifle when it fires a bullet, the change in the velocity of billiard balls when one strikes another, and so on.

The relationship between impulse and force also offers an opportunity for an involving discussion with students. Illustrations can be drawn from automobiles (why is it preferable to hit your head on an airbag rather than a windshield or dashboard?), sports (why would you want to pull your hand back when catching a line drive, or why does a boxer pull his head back as a punch approaches?), and everyday experience (why would you prefer to fall on grass or a carpeted floor, rather than on concrete?). It's also interesting to point out that large changes in momentum can be produced by small forces if they are exerted over sufficiently long times. Perhaps the most exotic illustration of this concept is the suggestion that spacecraft could "sail" between planets powered by the radiation pressure of sunlight falling on large reflecting sails that they would unfurl once they were outside the earth's atmosphere.

Demonstrations

A pair of "carts," such as toy cars or trucks, with low friction wheels, or old-fashioned non-inline roller skates, is needed. Set the carts on a tabletop, place a spring between the carts, and compress it. Use a simple hook or latch (a bent paper clip will do) to keep the spring compressed. Release the carts by lifting the latch by means of a thin rod or pencil. With equal masses, the carts will move apart with equal velocities. Set up a balance by using a six-foot (shelving) board with a one-inch wide fulcrum. Place the carts on the balance so that the center of the compressed spring is right over the fulcrum. Repeat the original demo. If you have adjusted the balance and the placement of the carts carefully, the system will remain in balance until the carts near the end of the board. Next, go back to the tabletop and add weight (say one or two textbooks or another cart) to one of the carts. Now, the lighter cart will speed away much faster. How much faster? Mount the weighted carts on the balance (not easy!) and rerun the interaction. The carts will move unequally but in such a manner that the balance will not change. Point out that in principle you could run the demo backwards so that the carts approach each other. If the spring were present it would recompress and give you the original starting point. The carts would then move apart as before, due to the compression of the spring. This is an example of a perfectly elastic collision. If no spring is present the carts might collide and come to a dead stop. This is an example of a perfectly inelastic collision. In either case momentum is still conserved.

The multiple-pendulum, swinging balls apparatus (the device Hewitt calls “the swinging wonder”) that you can often find in science toy or museum stores is also an interesting demonstration. Typically it consists of five or six small metal balls suspended from a frame so that they are just touching. If one of the balls is pulled back and released, one ball will emerge after contact. If two or three or pulled back and released, two or three will emerge on contact, etc. This is a very visual demonstration of momentum conservation in elastic collisions. However, other possibilities that would conserve momentum never occur (one ball released with two emerging at half the velocity, for example). This is because they would violate energy conservation, our next topic. Because of this, you might wish to delay this demonstration until then or, alternatively, use it as an intriguing lead-in to the next class.

Acceleration Lab

Purpose

To illustrate motion characterized by a non-constant velocity, that is, to demonstrate accelerated motion.

Introduction

Recall that when you measured your average speed in the last part of the Distance and Speed lab, you attempted to move at constant speed, covering equal distances in equal time intervals. However, most of the motion we experience, whether it's walking, bicycling, skating or driving a car, involves starting, stopping and frequent changes in speed. When the speed of an object changes, it is said to be undergoing accelerated motion. In Part A of this exercise you will change your speed in a regular manner. Your speed will change by the same amount in each interval of time. Your motion will be accelerated. In Part B you will observe the motion of a body undergoing constant acceleration due to the influence of gravity.

Part A

Equipment/Materials

Colored paper, tape, and stopwatch.

Procedure

1. Find a walkway, building, or track that is at least 100 meters long. As a class, place a colored strip of paper at the starting line, marking it 0 meters. Then place other marked strips at the following distances (in meters) from the starting line: 1, 4, 9, 16, 25, 36, 49, 64, 81, 100. Describe the nature of this numerical pattern:

   ____

   Predict the next number in the sequence ___________ meters.

2. Beginning at the starting line and moving in groups of 2 to 4, have the person with the stopwatch call out four-second intervals (one, two, three, four). During each set of four seconds, move smoothly to the next maker. At first you are barely moving. You traverse 1 meter in four seconds for an average speed of 0.25 m/s. In the next interval of four seconds you will move 3 meters (4m - 1m) for an average speed of 0.75 m/s. In the last interval you will have an average speed of almost 5 m/s.

If time (and energy) permit, repeat the motion in the opposite direction, moving from the 100 meter mark to the 81 meter mark in the first four seconds, from 81 meters to 64 meters in the next four seconds, and so on. Your motion is now <u>decelerated</u>.

3. Complete the table below, listing the average speed in m/s for each interval. What is the change in average speed from one four-second interval to the next four-second interval?

_____________ m/s.

Time (sec)	Distance (m)	Avg. Speed (m/s)	Change in Speed (m/s)
0	0	0	0
4	1		
8	4		
12	9		
16	16		
20	25		
24	36		
28	49		
32	64		
36	81		
40	100		

Part B

Equipment/Materials

One or two boards, which are two to two-and-one-half meters long, a shim of 10 cm thickness, and either a handball (about 6 cm diameter) or a low friction toy car, chalk, stopwatch.

Procedure

The motion of falling objects at the earth's surface can be difficult to study because they rapidly accelerate to high speeds. Galileo Galilei argued that a body moving on a tilted surface would have the same quality of motion, but because of the incline the body would be "partially" supported and would therefore move more slowly. This is the approach we will use to study gravitational acceleration.

1. Set up a single board incline for use with a low friction toy car, or a double board incline for use with a ball, with the boards placed parallel to each other and a 2 or 3 cm space between them. Use the shim to elevate one end of the board or boards.

   Mark a starting position on the board(s) with the chalk. Have one person in the group use the stopwatch to call out one-second intervals. At each second mark with chalk the position of the car or ball. Measure the distance from the starting point for each elapsed time. Draw an initial graph of distance versus time. If the motion represents uniform acceleration then the distances should be proportional to the square of the elapsed times (parabolic shape). Draw a second graph plotting the square root of the distance versus time. For uniform acceleration this graph should be linear with a slope equal to the square root of one-half the acceleration, and an intercept of zero.

2. An alternate method of gathering the data is to mark the incline with distances in the proportion of 1, 4, 9, 16 etc. (For example, if your boards are two meters long, you could put marks at 2 cm, 8 cm, 18 cm, 32 cm, etc. from the starting point. This would give you 10 marks along the board). Release the ball or cart from the zero point and time how long it takes to travel to the first mark. Then release it from zero again and measure the time to the second mark. Repeat this for all the distances you've marked on the board and complete the table below.

Distance (m))	Time (sec)	Avg. Speed (m/s)	Change in Speed (m/s)
0	0	0	0

What do you notice about the time intervals?

What can you say about the change in the average speed between intervals?
How does this compare with what you found in Part A?

Question

This second approach interchanges the role of dependent and independent variables. Graph time versus the square root of the distances. What does this graph look like?

____

Objectives:

- Given one or more definitions, supply the vocabulary word(s) from the list [Energy, Potential Energy, Kinetic Energy, Joule, Power, Watt] that best matches each definition.
- Find the work done by a given force.
- Apply the expressions for gravitational potential energy and for kinetic energy to relate the energy of a body to its height and/or velocity.
- Apply the work-energy theorem to find the work necessary to change the energy of a body by a given amount.
- Describe the connection between energy and power.

Reading Assignment: Conceptual Physical Science, 2nd Edition, Paul G. Hewitt, John Suchocki, Leslie A. Hewitt. Chapter 3, Sections 5 - 9.
Suggested Homework Assignment: Conceptual Physical Science, Chapter 3, Review Questions 18, 20, 23 and Problem 3.

The second great conservation law in mechanics, in addition to conservation of momentum, is the *conservation of energy*. Simply put, energy cannot be created or destroyed; it can only be transformed from one form to another. This is a very powerful statement, one worth expanding in more detail. In any physical interaction, the total energy after the interaction must always equal the total energy present before the interaction, *once all the energy transformations occurring during the interaction have been taken into account.* The law of conservation of energy is always true, without exception. This is a point that cannot be emphasized too strongly, because we are accustomed to speaking (incorrectly) of energy *sources*. Those things that we normally speak of as energy sources, whether they are nuclear reactors, hydroelectric dams or windmills, are really energy transformers, converting one form of energy to another. You will sometimes come across inaccurate statements such as the description of an inelastic collision as one in which energy is not conserved, as opposed to an elastic collision for which it is conserved. What is meant, of course, is that *total kinetic energy* is conserved in a perfectly elastic collision, while in an inelastic collision some of the original kinetic energy of the colliding bodies is converted to other forms (heat, sound waves, etc.). Once all the forms of energy and all the energy transformations are taken into account, the total energy is conserved in both forms of collisions.

While total energy always remains constant in any interaction, the energy of an individual body can be changed by exerting a force on it and doing work. Since energy is the capacity to do work, the source doing the work must give up energy in the process. The energy that the source gives up is equal to the work that it does, which is equal to the change in the energy of the body that it does work on (from the work-energy theorem), so the total energy is conserved.

Just as a force exerted over time on an object can produce a change in its momentum, a force exerted on an object *over a distance* can produce a change in its energy. Starting with the definition of work as force times distance, point out that both force and distance (displacement) are vectors and that the orientation between them matters. Students often don't understand that this technical definition of "work" is different from the non-technical meaning, simply "effort." If the object doesn't move, no work has been done, regardless of how much force has been applied. A less obvious point that you may wish to mention is that the force must be in the direction of the motion (parallel or anti-parallel) to do work. Thus, on a level highway, the reaction force that the highway exerts on a moving car in response to its weight does no work since it is perpendicular to the motion, while the force of air resistance, opposing the motion of the car, is doing negative work, causing the car to lose energy, energy that must be replaced by the motor to keep it moving.

In mechanics we are generally concerned with only two forms of energy: kinetic energy, the energy of motion, and potential energy, stored energy that bodies have due to their position. All influences that transform energy to other forms (friction for example) are treated as losses.

Gravitational energy, the potential energy that an object has by virtue of its position in the earth's gravitational field depends on weight as well as position. To lift an object against the earth's gravity, a force equal to the weight of the object must be exerted in an upward direction. In lifting the body its weight must be exceeded, initially, to cause the body to move. Once in motion the upward force can just match the weight, until the object approaches the desired elevation. The upward force must then be less than the weight so that the body slows to a stop. The potential energy change is the weight of the object times the vertical distance moved, even though the applied force may vary.

A similar analysis of strictly horizontal motion would lead to no change in gravitational potential energy even though the body must be accelerated at the beginning and decelerated at the end of the motion. It is also useful to discuss the zero net change in gravitational potential energy for an object such as a roller coaster, which starts and finally stops at the same elevation.

The expression for kinetic energy can be derived by using the definition of work and the work-energy theorem. Consider the acceleration caused by a constant force F and work done on a body of mass m initially at rest.
The force will cause an acceleration $a = F/m$

and result in a velocity $v = at = (F/m)\ t$.

The force acts through a distance $d = v_{avg}\ t = ½\ v\ t$

From the first equation above, $t = m\ v\ /F$ so $d = (½\ v)(m\ v/F)$

The work done by F is equal to the kinetic energy, KE, of the moving body from the work-energy theorem, so $KE = Fd = F\,(\frac{1}{2}\,v)(m\,v/F)$

$$KE = (\tfrac{1}{2}\,v)(m\,v) = \tfrac{1}{2}\,mv^2.$$

As a review of the relationships between potential energy, kinetic energy and the transformation of energy from one form to another, return to the roller coaster illustration and ask the class where the velocity would be the greatest, where the potential energy would be the greatest, what the ratio of the velocities would be if one point on the track was twice as high as another, and so on.

Demonstrations

Stand with the textbook held out and ask if you are doing "work." Talk through the process of lifting the body vertically, lowering the body vertically, and moving the body horizontally. Discuss the work done and the change in potential energy in each case.

You can use a topographic map to introduce the idea of potential energy as a function of position to the class. (Actually, you’re showing them a graphical representation of a potential function, but that’s a bit beyond the level of this presentation). Explain that the lines (contours) are of equal elevation and for a given mass they indicate essentially equal amounts of gravitational potential energy.

The Prof-and-the-Pendulum demonstration can leave a lasting impression on students if you have a classroom that can accommodate it. Hang a heavy weight from the ceiling on a long rope to form a pendulum -- the heavier the weight and the longer the rope, the better. Pull the weight back and hold it at the tip of your nose. Release the weight and let it swing across the classroom in a long arc and then return, gathering speed as it passes the bottom of its arc. Show your confidence in energy conservation by standing still without flinching as it heads toward your nose, stopping just inches short. This is a classic demonstration, but if you do it, be sure that you don’t give the pendulum a shove when you release it or you may be the one left with a lasting impression!

Session 6 Gravity and Tides

Objectives:

- Given one or more definitions, supply the vocabulary word(s) from the list [Law of Universal Gravitation, Inverse Square Law, Weightlessness, Apparent Weight] that best matches each definition.
- Work problems involving the inverse square law of gravitation.
- Describe and sketch how the moon creates tides.
- Describe how your apparent weight can change if you are in a moving elevator. Explain what happens to your apparent weight if the elevator is in free fall.

Reading Assignment: Conceptual Physical Science, 2nd Edition, Paul G. Hewitt, John Suchocki, Leslie A. Hewitt. Chapter 4, Sections 1 - 3.
Suggested Homework Assignment: Conceptual Physical Science, Chapter 4, Review Questions 2, 6, 12, 15 and Problem 1

Of all of Newton's achievements, none had more impact on human thought and our view of the universe than did the Law of Universal Gravitation. For the first time it became possible to understand the behavior of the planets, the stars and everything in the universe in terms of a simple expression that applied equally here on the earth. It is perhaps not an exaggeration to suggest that science, as we now think of it, began with the Law of Gravitation. It is worth spending some class time to contrast the world view it created with prior perspectives that saw celestial phenomena as unique and governed by different laws than those that applied to terrestrial objects.

The law of gravitation is just one of several inverse-square laws that students will encounter, so they should understand how they are related to the fact that we live in a universe that has three space dimensions. Hewitt has a good discussion of how gravity is "diluted" with distance that you can augment by contrasting this distance dependence with the behavior of surface waves. When a two-dimensional surface wave, such as a water wave or a surface earthquake wave spreads out, its intensity decreases inversely with the distance from the origin of the wave. However, when a three-dimensional wave such as sound or light spreads out spherically in all directions in space its intensity decreases as the inverse square of the distance. Make sure that students understand that the distance in the gravitational force equation is measured from the center of the earth, not its surface. Have students draw, to scale, the gravitational force versus the distance from the center of the earth. Using the radius of the earth as the natural scale unit, sketch variation in the force from the surface to the distance of at least three earth radii.

Because the gravitational field of a spherical mass points inward to the center of the mass, the effect of gravity on a distributed body is two-fold: The vector forces acting on the top of a body will not be as strong as those on the bottom because of the inverse square law. This causes an elongation. Also, the gravitational forces acting on the right and left hand sides of a body point slightly inward, so that the horizontal components point in opposite directions. This results in a slight sideways compression. The two effects are very small for a person acted on by the earth, but they can be considerable for a body the size of the earth, when acted on by the gravitational force of another massive body, such as the sun or moon. The diagrams given in the text for the effect of the moon on the earth tides demonstrate both elongation and compression. The solid earth and the oceans experience the same tidal forces, but since the earth is much more rigid, the influence on the oceans is much greater. This difference creates the bulges that cause the ocean tides.

Have the students draw the effect of the moon on the earth and the oceans looking at the earth's spin axis from the side and redraw it as seen looking down on the spin axis. There is a possibly confusing statement in the text that you may want to discuss. The text states that, “Newton deduced that the difference in gravitational pulls between two bodies decreases as the *cube* of the distance between the centers of the bodies." If this is not read carefully, it appears to contradict the inverse-square law. Make sure that the students understand that it refers to the tidal force, that is, the difference between the inverse-square forces on the opposite sides of a body.

The use of the term “weightlessness” in the text also needs some attention. It is better to emphasize apparent weight and point out that it is zero in free-fall, while weight remains constant. If, in fact, an individual were “weightless," that person would not be falling since there would be no gravitational force acting on the person. While this assignment does not include satellite motion, the description of the apparent weightlessness of an astronaut in orbit would be a natural place to supplement the discussion with a treatment of the orbital motion of a satellite as a continuous process of falling around the earth.

Demonstrations

The description of inverse square laws and tidal forces is best done by chalkboard or overhead diagrams and sketches. However, you can show the effect of distance qualitatively as suggested below.

Use a compact bright light source (such as a tensor lamp) and a light detector (solar cell operated in the current mode) to show the reduction in strength with distance from the source.

Repeat the above process for a fixed frequency sound source with a microphone detector and a scope display.

Energy and Momentum Lab

Purpose

To illustrate conservation laws and their effect on motion.

Introduction

Newton's three laws describe motion. The second law, which describes the influence of forces on the acceleration of a body, results in the conservation of energy when the work done by the forces is taken into account. The second law can also be transformed into a form that expresses the change in linear momentum (mass times velocity) of a body. The third law is a statement that the forces between two bodies are always exerted in equal and opposite pairs. Taken together, the second and third laws require that in any interaction between two bodies the total linear momentum of two bodies does not change. The conservation of linear momentum is an exact law that always holds. The conservation of energy is also exact, but it is complicated by the fact that there are many kinds of energy. The energy of motion (kinetic energy) can be transformed into heat, sound, or other forms of energy. Interactions are classified as either *elastic* (kinetic energy is conserved), or *inelastic* (some kinetic energy is converted to other forms). In this exercise you will be observing collisions between two objects that are almost perfectly elastic.

Equipment / Materials

Two superballs, two one-meter lengths of string, a one meter vertical support, a large piece of butcher paper, a meter stick and a protractor.

Procedure

1. Hold the bottom of a superball one meter above the floor. Release it and when it rebounds, catch it at the top of its path and determine the elevation of the bottom of the ball.

   Initial height = 100 cm, rebound height = ______ cm.

   Superballs are highly elastic, which means that they tend to lose very little kinetic energy on impact. If energy were perfectly conserved, the ball would rebound to exactly the same height. In actuality, a small amount of the original energy is transformed into sound waves and thermal energy on impact. Next we shall look at a collision process that is almost perfectly elastic and see how conservation laws give rise to constraints on the way in which bodies move.

2. Make two one meter long pendulums using the superballs as bobs. Hang the pendulums from a common suspension and adjust it so that the bottoms of the superballs are almost touching the table or floor. Place butcher paper under the

superballs and mark the center of each one on the paper. Start by leaving one ball stationary at the center. Raise the other ball back by one half a meter and launch it so that it will miss the one at the center. Catch it after it passes through the center. Now release the ball again but don't catch it. What do you see happen? Until the strings get tangled one might invent the conservation law: <u>Once a Miss always a Miss</u> (In fact this is an illustration of another conservation law, the conservation of angular momentum).

Now release the ball so that it strikes the stationary ball. What do you observe? Invent a conservation law for this case:

<u>Once a Hit - - -</u>____

Practice releasing the ball so that it strikes the stationary ball head-on. Now mark the release point and catch the outgoing ball at the top of its swing.

Does the original ball come basically to a rest after the collision? _________ How does the distance moved by the outgoing ball compare to the distance moved by the incoming ball?

____

An idealized description would be that the original ball comes to rest and the outgoing ball moves the same distance as in incoming ball. Because the pendulums have the same length, the same distance moved means that the balls have the identical velocity, v.

For this simplified description, is linear momentum conserved? __________

Is kinetic energy = $(1/2)\ M\ (v)^2$ conserved? ________

Suppose that <u>after</u> the collision the incoming ball continued to move in the same direction with a reduced velocity (v/2) and the outgoing ball moved with a velocity (v/2).

Is linear momentum now conserved? __________

Is kinetic energy conserved? _________

3. Release the incoming ball so that it strikes the stationary ball off center. Note that after the impact both the balls spin (same or opposite direction?). Catch both of the balls at their maximum swing point. Draw a line from the collision point to the final position for each ball. Measure the angle between the two lines. Repeat for at least five different cases, striking the stationary ball both to the right and to the left of center.

Are the angles all quite different or is there uniformity? _________________

In the idealized situation that both momentum and energy are conserved, the angle between the two paths after collision is predicted to be 90 degrees. How do your observations compare to this prediction?

____

____

Session 7 - First Exam

Sample First Exam Questions

Fill in the correct answer in the items below. Give numeric results where appropriate.

1. The ____________________ of a moving body is defined as the distance the body travels divided by the time necessary to travel that distance.

2. According to Newton's first law, bodies tend to resist changes in their state of motion. This property is known as ___________________________.

3. A brick falls from the top of a 100-meter tall building. How fast is it traveling at the end of two seconds? _____________________.

4. How far will the brick in question 3 have fallen in that time? _______________.

5. A quantity that has both magnitude and direction is known as a ____________.

6. When a body is accelerated, its ___________________ must always change.

7. If the force acting on a body is doubled, its acceleration will be _____________ as great.

8, 9. If the velocity of a body is doubled, its kinetic energy will _______________ (increase/decrease) by a factor of ______________.

10,11. A 300 kg earth satellite is in orbit along with the 15,000 kg last stage of the rocket that carried it. An explosive charge is set off to separate the satellite from the rocket. This increases the satellite's velocity by 100 m/s. The velocity of the rocket will ____________________ (increase/decrease) by ______________________ m/s.

12, 13 An airplane flies due north at 600 km/hr for 20 minutes, due west at 600 km/hr for 40 minutes, then due south at 200 km/hr for one hour, and finally due east at 400 km/hr for one hour. It's average speed for the trip is ____________ km/hr. It's average velocity for the trip is _______________ km/hr.

14, 15 A. 3 kg mass is acted on by a 16 N force for 4 seconds. During this time the acceleration of the mass is ____________________m/s. The total work done by the force is ____________________________ Joules

MULTIPLE CHOICE / TRUE-FALSE

In answering the questions below, neglect the effect of friction.

_____16. Two bodies, one having a mass of 5 kg and the other having a mass of 10 kg, are dropped from a height of 20 meters. After falling 10 meters, they both have the same

A. kinetic energy
B. potential energy
C. momentum
D. none of the above.

_____17 The "kick" of a rifle when it is fired can be explained by Newton's

A. first law
B. second law
C. third law.
D. none of these apply

_____18. A planet has four times the mass of the earth and a radius that is twice the earth's. The acceleration due to gravity on the surface of his planet will be

A. greater than that on earth
B. less than that on earth
C. equal to that on earth.
D. insufficient information to determine.

_____19. A projectile fired straight up from the ground with an initial speed, v_0, will upon return strike the ground with the same speed.

A. True B. False.

_____20. A moving body <u>must</u> have momentum.

A. True B. False.

_____21. Ocean tides are created because the Moon and the Sun are on the same side of the earth at high tide and on opposite sides at low tide.

A. True B. False.

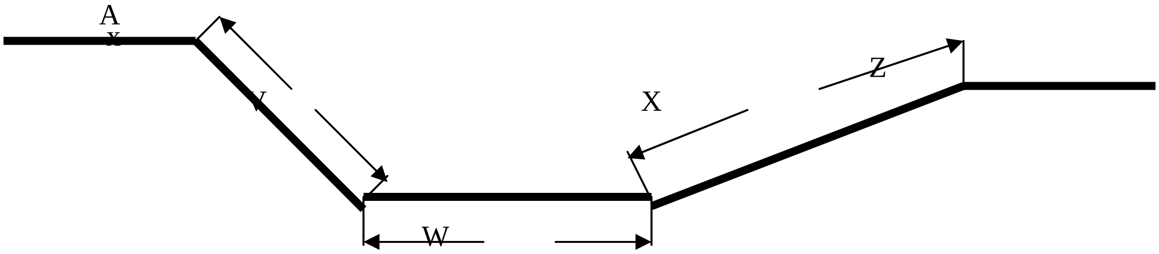
_____22. A ball is thrown directly upward from the surface of the earth. When it reaches its maximum height it will have zero acceleration.

A. True B. False

_____23. A man standing on the edge of a cliff throws a baseball downward with an initial speed, v_0. He throws a second baseball upward with the same initial speed. Comparing the energy of the two balls when they strike the ground below,

A. The ball thrown downward will have the greater energy.
B. The ball thrown upward will have the greater energy.
C. Both balls will have the same energy when they reach the ground.

For the following questions, refer to the diagram below. Read the description preceding each pair of choices. Select answer (A) if the quantity described in item A is greater than that in item B. Select answer (B) if the quantity in item B is greater than that in item A. If they are equal, enter the letter E for that question.



A segment of a roller-coaster track is represented diagrammatically above. A roller-coaster car is moved from rest in the region W up to the point A. From this point the car starts from rest and rolls without friction through the regions labeled V, W, X and Z. Assume the region W represents zero potential energy. The questions below refer to the energy and motion of the car as it moves from A to Z.

_____24. A. The work done in moving the car from rest in region W to point A.
B. The potential energy of the car at point A.

_____25. A. The work done in moving the car from rest in region W to point A.
B. The kinetic energy of the car when moving through region W.

_____26. A. The increase in the kinetic energy of the car in a given time interval when moving through region V.
B. The decrease in the potential energy of the car in the same time interval

_____27. A. The average speed of the car when moving through region V.
B. The average speed of the car when moving through region W.

_____28. A. The total energy of the car in region W.
B. The total energy of the car in region X.

_____29. A. The net force acting on the car in region W.
B. The net force acting on the car in region X.

_____30. A. The average speed of the car in region W.
B. The average speed of the car in region Z.

Objectives:

- Given one or more definitions, supply the vocabulary word(s) from the list [Area, Volume, Density, Force, Pressure, Buoyant Force, Archimedes' Principle] that best matches each definition.
- Calculate the density of an object given its mass (or weight) and volume.
- Describe the variation of pressure with depth in a fluid and explain how this results in a buoyant force.
- Compute the buoyant force on a body in any fluid of known density from the volume of the body immersed.
- Explain how a dense iron boat can float in water.

Reading Assignment: Conceptual Physical Science, 2nd Edition, Paul G. Hewitt, John Suchocki, Leslie A. Hewitt. Chapter 5, Sections 1 - 5.
Suggested Homework Assignment: Conceptual Physical Science, Chapter 5, Review Questions: 3, 5, 8, 10, 15 and Exercise 3.

There are similarities between the concepts of pressure (force per unit area) and density (mass per unit volume). Both are ratios that involve force or mass in the numerator and a dimension (area or volume) in the denominator. There are also similarities in the conceptual problems that they can create for students. Invariably, some students will associate a larger force with higher pressure and a heavier object with a greater density, ignoring the effect of area or volume, even when they can parrot the definitions or work problems correctly. Offer some counter-illustrations to combat these misconceptions. Ask who they would rather have step on their toe – a 250 pound basketball player in sneakers or a 100 pound woman wearing spike heels? Hewitt suggests passing around a small iron weight and a larger Styrofoam ball that weighs a little more. Ask which is the heavier. Most will choose the iron weight because of the sensation of pressure in their hands. Then weigh both and show that the Styrofoam ball is actually heavier, although less dense.

Do an in-class measurement of the density of water as described in the Demonstrations section below. In discussing density, be sure to include the definition of specific gravity as a dimensionless measurement of density. The specific gravity of water is 1 by definition. Many surface rocks have specific gravities in the approximate range of 2 to 3. (Granite is 2.67, shales are around 2 to 2.2, and limestone is 2.4). The average specific gravity of the earth is estimated to be about 5.5. Discuss how this disparity leads to the idea of a layered earth with a dense core.

Although most quantities are measured in metric units throughout this class, you may wish to discuss air pressure and water density in British units as well, because people are more familiar with things like tire pressure in pounds per square inch, and also to emphasize the magnitudes involved. It can create a lasting impression if you do a calculation of the total atmospheric force acting on a sheet of notebook paper (14.7 lbs/in^2 x 8.5 in x 11 in = 1374.5 lbs!), or show the class a rather small box approximately one foot on each side and tell them that if it were filled with water it would weigh 62.4 lbs. Have the students sketch a graph of the pressure of water as a function of depth. Have them find the depth at which water pressure, neglecting any air pressure, would have a magnitude of one atmosphere. You can then compare the atmospheric pressure that we experience to the much greater pressure that sea creatures encounter at depths of a few hundred feet.

To emphasize that buoyancy is caused by the increase of pressure with depth, have the students diagram all the forces acting on a volume of water that extends from the surface down to some depth d. Have them think of the volume of water as being in a thin plastic bag. The water is in static equilibrium. The weight of the water is exactly balanced by the upward buoyant force. Using the definition of pressure as force per unit area, derive an expression for the buoyant force. Ask what would happen if the volume of water in the thin plastic bag were replaced by, say, aluminum. The buoyant force, which is just the weight of the water displaced, would not change, but the greater weight of the aluminum would disrupt the equilibrium. Have the students change their diagram to show the same upward buoyant force as before acting on the aluminum, but with a greater force, the weight of the aluminum block, acting downward. The resulting force on the aluminum block is then its weight minus the buoyant force, which is just equal to the weight of the displaced water that was originally there. Contrast this result for a submerged object with the case of a floating object that only displaces an amount of water equal to its <u>own</u> weight.

Demonstrations

Use a graduated cylinder, say 100 cc. Weigh it and then fill it with water. Weigh it again and have the students use the definition of density to determine the approximate density of water.

Have students start handing you their textbooks and build a stack of books on a household scale. As you add books to the stack, have the students plot weight as a function of depth in the stack of books (measure the height of the stack downward with zero at the top). Then calculate the density of the books. It is interesting to note that the specific gravity of a textbook is about that of water.

Punch three small holes in a large coffee can or 1.75-liter plastic soft drink bottle -- one near the top, one near the bottom and one in the middle. Plug the holes and fill the can or bottle with water. Remove the plugs and display the variation of pressure with depth by the difference in the distance that the water spurts from the three holes. Also point out how this distance decreases as the water level drops due to the decreasing distance from the water surface to the holes.

There are a couple of classic demonstrations of the effect of atmospheric pressure that you may wish to use: (1) Put a small amount of water in a one or two gallon metal can with a screw-on cap. Heat it on a Bunsen burner until the water begins to boil. Then remove the can from the burner and cap it. As the air inside the can cools, the pressure is reduced and atmospheric pressure will crush the can. (2) To reinforce the calculation you did on the force exerted by the atmosphere on a sheet of paper, place a thin board on the edge of a table and strike it quickly with a hammer. The board, of course, will just flip off the table. Now put it back and cover the end resting on the table with a single (unfolded) sheet of newspaper. The weight of the air on the paper will hold the end of the board down this time. When you again strike the board, it will snap in two.

Do the calculation of the pressure exerted by automobile tires on the road as suggested in Home Project #5 in the text. Use an average weight for the car, maybe 2200 pounds, and confirm that a pressure of 30 lbs/in^2 is sufficient to support the car, assuming a reasonable area of contact for the tires. Challenge your students to check this information using data from their own cars (maybe some will have huge SUVs). They've probably never before thought of the fact that air is all that is holding up their automobiles!

Archimedes' Principle Lab

Purpose

To illustrate the concept of density and demonstrate Archimedes' Principle.

Introduction

The density of a fluid is easy to determine by measuring the mass of a known volume of the fluid. The density is then found by dividing the mass by the volume. This approach can be used for any object of regular dimensions whose volume can be easily calculated. Archimedes' Principle states that a body placed in a fluid is buoyed up by a force having the same magnitude as the weight of the fluid displaced by the body. This provides a means to determine the volume and calculate the density of a solid body that has an irregular shape.

Equipment / Materials

Graduated cylinder, beaker, pie pan, spring or balance-arm scale, small wooden blocks, rock samples.

Procedure

1. Measure out 100 cubic centimeters of water and pour it into a beaker. Determine the mass of the water by weighing the beaker empty and then after filling it. Calculate the density of the water from the definition that density equals the mass of the water divided by the volume.

   Density of water = ______________________ grams/cm^3

2. Measure the mass of a small rock. Suspend the rock by means of a thread. Set a beaker in a pie pan and fill the beaker to the brim with water. Slowly lower the rock into the water-filled beaker. Water should overflow into the pie pan. Measure the volume and weight of the overflow. Note that the volume of the overflow is the same as the volume of the rock. Compute the density of the rock.

   Density of the rock = ______________________ grams/cm^3

3. Attach the rock to the scale by means of a thread and record the scale reading when the rock is suspended in water. Recall that weight = mass times gravitational acceleration. If the mass is in kilograms and the acceleration is in m/s^2, then the force is in Newtons.

   Weight of rock in air = __________ Newtons.

   Apparent Weight of rock in water = _______ Newtons.

The difference between the weight of the rock and its apparent weight is caused by the buoyant force of the water. Check to see if the difference in weight is the equal to the weight of the water displaced.

Difference in weight = ___________________ Newtons.

Weight of the displaced water = _____________________ Newtons.

4. Measure the dimensions of a wooden block and calculate its volume. Weigh it to determine its weight and mass. Compute its density.

   Weight of the block = _____________________ Newtons.

   Density of the block = ________________________ grams/cm^3.

   Repeat the process of placing a beaker in a pie pan and filling it to the brim with water. Carefully place the wooden block in the beaker. Water will overflow again. Measure the volume and the weight of the water that overflows.

   Volume of the water = _______________________ cm^3.

   Weight of the water = _________________________ Newtons.

   How do these compare the volume and weight of the block?

   ____

Questions

Summarize your results by filling in the appropriate word (smaller, equal or greater) in the blanks below.

Compared to water, the density of the rock was ___________________________.

Compared to water, the density of the block was __________________________.

Compared to the volume of the rock, the volume of the water it displaced was __________________.

Compared to the weight of the rock, the weight of the water it displaced was __________________.

Compared to the volume of the block, the volume of the water it displaced was
_________________.

Compared to the weight of the block, the weight of the water it displaced was
_________________.

In both cases, for the rock and the block, compared to the weight of the water displaced, the buoyant force was ______________________.

Instructor Guide **Session 9** **Temperature, Thermal Energy**

Objectives:

:

- Given one or more definitions, supply the vocabulary word(s) from the list [Temperature, Fahrenheit, Celsius, Kelvin, Absolute Zero, Thermal (internal) Energy, Heat, Calorie, Joule, Specific Heat Capacity] that best matches each definition.
- Describe the differences between the Celsius, Fahrenheit and Kelvin temperature scales.
- Relate Temperature to average molecular kinetic energy and contrast it with Thermal Energy.
- Differentiate between Heat and Thermal Energy.
- Relate the Specific Heat Capacity of an object to the rate at which it heats or cools.
- Describe the principle of operation of a thermostat.

Reading Assignment: Conceptual Physical Science, 2nd Edition, Paul G. Hewitt, John Suchocki, Leslie A. Hewitt, Chapter 6, Sections 1-7.
Suggested Homework Assignment: Conceptual Physical Science, Chapter 6, Review Questions: 4, 8, 16, 19, 24.

In introducing temperature and heat flow, a useful analogy can be drawn between the material on fluids just completed and the new material on heat by comparing the pressure (or depth) in a fluid to the temperature of a system. If you connect two fluid systems of unequal depth, they will equilibrate their pressures and in doing so transfer fluid from the vessel at higher pressure to the one at lower pressure. Similarly, two systems at different temperatures, when placed in thermal contact, will equilibrate by a transfer of heat.

To illustrate this analogy, draw a sketch on the board of a tall, thin cylinder filled to the top with water. Then draw a second wider cylinder filled to a lower level. Make the second wide enough so that it's clear that it contains more water. (You might want to state this so that students don't miss this point.) Now draw a tube connecting the two containers at the bottom and ask the students what will happen. By now they should respond that water would flow from the thin cylinder to the wider one until the water levels are the same in both. Point out that the water flow went in the direction that equalized pressure, even though that container had more water. Now compare this to heat flow. State that heat will flow from an object that has a higher temperature to one at a lower temperature, even if the second has more thermal energy. The flow will continue until the temperatures, like the pressures, are equal. Use the text example of the hot thumbtack and the bowl of water. A large bowl of lukewarm water may have more thermal energy than a small piece of red-hot metal, but if you drop the metal into the bowl, heat will flow into the water until both are at the same temperature.

In discussing temperature and temperature scales, emphasize that a thermometer measures temperature, not thermal energy. Temperature represents the average kinetic energy per molecule in the object whose temperature is being measured. In contrast, the total thermal energy depends on the number of molecules, as well as the temperature. Point out that is why a large pot of water takes longer to boil than a small one. At the boiling temperature, they both have the same average kinetic energy per molecule, but the larger pot contains more energy because it has many more molecules. Conservation of energy (there's that principle again) requires that the fire had to give more energy to the larger pot, and therefore had to heat it longer to bring it to the same temperature.

The above discussion leads naturally to heat and heat units. The distinction between heat as energy *transferred* from one body to another and thermal energy as the energy *contained* by a body is not as significant as the fact that it is *energy* that is being described in both cases. Heat is just another form of energy and the heat units, calorie and Calorie, are just units of energy. So when the calorie content of food is given, as it is on all grocery items now, what you are really be told is the energy contained in that item. Likewise, when the amount of calories "burned" by an activity is given, you are being told how much energy the activity requires. As an aside, your students might be interested in a calculation of the energy equivalent of a standard 2000 Calorie diet. Do they realize that this is enough energy to bring 200 one-liter bottles of water from zero degrees to the boiling point? If they wish to balance that daily intake with energy consumption, then during the course of the day they must do that much work (work-energy theorem) or radiate that much heat, or some combination of the two, to dissipate that much energy. All dieting is controlled by the conservation of energy! Food generally captures everyone's interest, so you might wish to do some other comparative calculations, like the energy content of a Big Mac or a pizza.

Food is also a good way to lead into the concept of specific heat, since everyone has noticed that different foods cool at different rates. For example, your breakfast coffee stays warmer longer than your eggs or your toast. Explain that specific heat capacity is a measure of this property. Substances that cool more slowly are also substances that will warm more slowly, because they absorb or give off more heat energy per degree of temperature change. The greater a substance's specific heat capacity, the more slowly it heats or cools. Your coffee stays warm a long time since it is basically flavored water, and water has a high specific heat capacity. Go through the text discussion of the major climatic effects that are the result of the ability of water to absorb or emit large amounts heat with little change in temperature. Choose some more examples of locations at similar latitudes, but with greatly varying climates, and discuss them in class.

Thermal expansion is a topic that can be treated very briefly, if at all, in your class presentation. Just point out that it is the result of the increased motion of molecules as their temperature increases. The most familiar example of this property, of course, is common thermometer. You may wish to discuss (or demonstrate – see below) how differential expansion is applied in thermostats, or discuss the unusual expansion reversal of water below 4^o Centigrade and the importance of this variation for marine life in lakes and ponds.

Demonstrations

To show thermal equilibrium, prepare two equal size containers of water at two different initial temperatures beforehand. At the start of class, pour the two containers of water into a common container and observe the equilibrium temperature. Have the students predict the temperature of the final equilibrium. Repeat the process with one of the containers holding at least two to three times the amount of water.

To show the fluid analogy, prepare two pipettes that are connected at the bottom with a rubber hose and a screw clamp that is closed. Fill the two pipettes to different levels of water. Open the connecting clamp and note the equilibrium elevation. Again have the students predict the final equilibrium height.

There is a common commercially available apparatus that shows thermal expansion. It consists of a bi-metal strip with an insulated handle attached, so that it can be heated with a burner to demonstrate differential expansion and the operation of a thermostat.

Instructor Guide Session 10 Phase Change

Objectives:

- Given one or more definitions, supply the vocabulary word(s) from the list [Evaporation, Condensation, Boiling, Melting, Freezing, Heat of Fusion and Heat of Vaporization] that best matches each.
- Explain why evaporation is a cooling process and why it increases with temperature.
- Explain why condensation is a warming process.
- Distinguish between boiling and evaporation, and explain why the boiling temperature decreases with altitude.
- Describe the energy changes associated with freezing, melting and boiling.
- Sketch and label a graph showing the energy changes involved in phase transitions for water.

Reading Assignment: Conceptual Physical Science, 2nd Edition, Paul G. Hewitt, John Suchocki, Leslie A. Hewitt. Chapter 6, Sections 8 - 9.
Suggested Homework Assignment: Conceptual Physical Science, Chapter 6, Review Questions: 34, 39, 52 and Exercise 43.

To introduce evaporation and condensation, treat them in terms of molecular kinetic energy and energy conservation. This picture makes their cooling and heating properties clear. Point out that the molecules that escape from a liquid surface must be more energetic than the average. As a result, conservation of energy requires that the overall average molecular energy must decrease, thus cooling the liquid. Condensation is just the reverse process, raising the average kinetic energy of the molecules and increasing the temperature.

Apply these principles to the operation of refrigerators and air conditioners. Explain how they function by condensing a fluid in coils outside the region to be cooled and then allowing it to expand in the cool region, transferring heat out of the cold area and into a warmer area.

Extend the molecular analysis to boiling and freezing, using it to describe the boiling and freezing of water. Explain that steam consists of the more energetic water molecules. That is why you have to keep heating water to keep it boiling. The formation of ice, on the other hand, releases heat. Draw a temperature versus heat graph for water, illustrating the melting and vaporizing phase changes. Remind the students that both axes on the graph represent energy. The vertical axis, temperature, represents the <u>average</u> kinetic energy of the water molecules, while the horizontal axis is the <u>total</u> heat content of the water. Point out that there are certain regions (the melting and vaporizing regions) where the heat content of the water increases while the average kinetic energy of the molecules (temperature) remains unchanged. Ask the class where that additional thermal energy is going. Hopefully, they will recognize that if kinetic energy is unchanged, it must be the potential energy of the molecules that is increasing. The 80 calories per gram (heat of fusion) is needed to overcome the forces that hold water molecules in the crystalline ice structure and separate them into liquid water. Likewise, the 540 calories per gram (heat of vaporization) is needed to separate the liquid water molecules into the more widely spaced molecules in steam. These *latent heats* explain why steam burns are so much more severe than those from hot water and why ice is much more effective for cooling than water at zero degrees. (Note: Due to the relationship between heat and energy, these latent heats are often expressed in terms of SI energy units, joules. The conversion factor between calories and joules, 1 cal = 4.186 J, is known as the mechanical equivalent of heat. Using this conversion, in SI units the heat of fusion for water is 3.33×10^5 J/kg and the heat of vaporization is 2.26×10^6 J/kg.)

The topics of freezing, boiling, evaporation and condensation offer many examples from common experience. Be sure to take advantage of them in your class presentations. Ask your students why the boiling point would change with altitude; why a warm, dry, climate is more comfortable than one that is warm and humid; why they spread salt on icy roads in cold climates; why we can make snowballs with our hands but not sand balls; could we make sand balls? (The answer is yes, but not at temperatures and pressures our hands could withstand). Make sure that your students understand that phase changes are not just limited to the behavior of water.

Demonstrations

(Use this if you didn't do it in the session on Fluids and Buoyancy).
Place a small amount of water in a one-gallon metal container. Heat the water to boiling. Remove it from the heat and cap it off. Continue with the class. Most students will be surprised at the rapid collapse of the can. This allows you to discuss both phase change and pressure.

Boiling by Cooling: Heat water to boiling in a round bottom flask, remove it from heat and cork it, then let cool. The pressure in the flask will reduce by condensation. Further cooling, by pouring cool water over the flask, causes the water to begin to boil again.

Temperature and Thermal Expansion Lab

Purpose

To observe the effect of temperature on the volume of a gas.

Introduction

Most substances expand when they are heated. This can be understood by considering the relationship between temperature and molecular motion. As the temperature of a body is increased, the energy of its molecules is increased, causing the average distance between them to increase as well. This principal finds practical application in the measurement and control of temperature. Common thermometers use the expansion of a column of mercury or colored alcohol to measure temperature. Thermostats use the expansion of a bi-metallic strip to control the operation of heating devices.

Many gases display a linear relationship between their volume and temperature (measured on the Kelvin scale) over a wide range of temperatures. In this exercise you will observe the expansion of a gas as it is heated.

Equipment / Materials

Thin drinking straw, ink or food coloring, plumber's putty or silicon caulking compound, thermometer.

Procedure

1. Place the straw in a cup partially filled with ink or water tinted dark with food coloring, so that a droplet of liquid fills the end of the straw. Place your finger over the top end of the straw to close it and remove the straw from the liquid, inverting the straw. Carefully let some of the air out of the bottom of the straw, allowing the droplet to fall about halfway down. Close off the top of the straw with putty or calk. You now have a small column of air trapped between the droplet and the putty. This is the volume you will be heating.

2. Turn the straw right side up (with the sealed end at the bottom). If the droplet doesn't hold together, the straw is too wide. You need to use a thin "cocktail" type straw for best results*. With a marking pen, make a mark at the <u>bottom</u> of the droplet, indicating the location of the top of the air column.

   Record the room temperature (in C^o) ____________________________

   *The use of cocktail straws and ink droplets in this manner was suggested by our colleagues H. Keith Lee and James Imai in their lab manual (<u>Physical Science I Laboratory Manual</u>, Dominguez Press, 1995).

3. Heat some water to boiling and place it in a small beaker (or use very hot tap water). Place the straw in the water to heat the air and watch as the droplet rises. When it stops, mark the new position of the bottom of the droplet. The change in the length of the air column is proportional to the change in volume of the trapped air.

   Record the water temperature (in C^o) ______________________________

4. Remove the straw from the water. Measure the original length of the air column from the bottom of the straw your first mark. Then measure the length of the heated air column, to the second mark. Record the lengths.

   Original length ______________________________

   Heated length _______________________________

5. If the air has expanded linearly with the temperature, the ratio of the final length to the original length should be equal to the ratio of the final temperature to the original temperature (on the Kelvin scale). To test this, convert the Centigrade temperatures to Kelvin temperatures by adding 273 to each and take the ratio.

   Original Kelvin room temperature ________________

   Final Kelvin water temperature __________________

   Temperature ratio (Final / Original) _________________________

6. Now take the ratio of the final length divided by the original length and compare it to the ratio of the temperatures.

   Length ratio ________________________

   How do the two ratios compare? ___________________________________

Questions

1. What would happen if the outside air pressure increased after the straw had been sealed?

   ____

2. Suppose air were trapped in a fixed volume and could not expand. What would happen if its temperature increased?

   ____

Objectives:

- Given one or more definitions, supply the vocabulary word(s) from the list [Conduction, Convection, Radiation] that best matches each definition.
- Identify and distinguish between the methods of heat transfer in conduction, convection and radiation. Give examples of each.
- Sketch the atmospheric convection currents near the seashore.
- Explain why a clear cloudless evening is colder than it would be with cloud cover.

Reading Assignment: Conceptual Physical Science, 2nd Edition, Paul G. Hewitt, John Suchocki, Leslie A. Hewitt. Chapter 7, Sections 1 – 3.
Suggested Homework Assignment: Conceptual Physical Science, Chapter 7, Review Questions: 4, 12, 19 and Exercise 13.

At the outset, students should be reminded of the definition of heat as thermal energy *in transit.* That is what this lesson is about: the transfer of energy from one place to another, in this instance, thermal energy. This means that the energy involved, ultimately, is the kinetic energy of molecules, although the mechanism for energy transfer may not always involve molecular motion.

Of the three mechanisms for heat transfer, conduction is easiest to understand. Use the molecular kinetic energy model of temperature and stress that conduction involves the direct transfer of kinetic energy through contact -- more energetic molecules giving up some of their energy to less energetic molecules. In solids thermal energy is transported by the movement of electrons. This means that materials that are good conductors of heat have relatively mobile electrons, and insulating materials are ones in which the electrons have difficulty moving and transferring energy. Ask the students to store this information away for reference when you discuss the electrical properties of materials. Give some common examples of conductors and insulators – how you can't touch a hot pan, but a one-quarter inch thickness of potholder will prevent the conduction of heat to your hand. Point out that air is a relatively poor conductor. You can put your hand into a 450^o oven for a few moments with little discomfort, but if you touch a pan in the oven, you'll be burnt. Since air is a poor conductor, many insulating materials, like double-pane windows, work because they contain trapped air.

The poor conducting properties of air can be used as a lead-in to a discussion of convection. As air is a poor conductor, another mechanism, convection, is responsible for heat transfer in the atmosphere. Convection is the dominant mechanism for heat transfer in fluids. It differs from conduction in that the molecular kinetic energy is transferred by the mixing of currents at different temperatures within the fluids. The mixing occurs because of density variations in the fluids that result from temperature variations. Warmer regions tend to be less dense and rise, causing a circulation of colder regions downward and warmer regions upward. These convection currents can be observed in boiling water. Convection is of considerable interest because of its connection with weather and plate tectonics. The daytime onshore winds and nighttime offshore winds near large bodies of water are good illustrations of this effect.

Radiation can be the most difficult of the three forms of heat transfer for students to visualize. It does not involve the direct transfer of molecular kinetic energy, but instead, the conversion of energy from one form to another. Thermal radiation may originate in molecular motions, but in transit the energy is in the form of electromagnetic waves. Since you will be discussing thermal radiation before the material on electricity and electromagnetic waves, you might choose to spend some time on the electromagnetic spectrum. A large classroom chart or an overhead projection of the complete spectrum would be useful at this point. Explain that the radiation involved in heat transfer is similar to light, x-rays and gamma radiation, differing only in wavelength. That is why these other forms of radiation can also generate heat.

Demonstrations

Use a prism to produce a spectrum from a white light. (Tell about Newton's original experiment in 1665-6). Use a photocell (light meter) to scan the different colors. Continue into the region beyond the red where nothing is visible. (This repeats William Herschel's observation in 1801. It was the experimental discovery of a non-visible portion of the electromagnetic spectrum). It is the infrared portion of the spectrum that produces the feeling of warmth when it strikes our bodies.

Use an unfrosted (clear) light bulb and a variac or some form of a dimmer control unit to lower the voltage applied to the bulb. Have the students look through a transmission grating at the colors emitted by the bulb. Slowly lower the voltage and observe that the colors do not all fade at the same rate. Violet and blue fade first. Red and yellow are the last to go. At the end the bulb is at much lower temperature. The amount of each color as well as the maximum output of a body is determined by the absolute temperature of the body. The peak frequency of the black body radiation curve is proportional to the absolute temperature. Reducing the temperature of the bulb moves the radiation toward the infrared.

Consider doing Home Project #1 from Chapter 7 of the text in the class. If you place ice in the bottom of a large test tube filled with cold water and block convection currents with a material like steel wool, you can demonstrate the poor conducting qualities of water by boiling the water in the upper part of the tube while the ice remains unmelted.

Convection and the Coriolis Effect

Objectives:

- Given one or more definitions, supply the vocabulary word(s) from the list [Solar Constant, Greenhouse Effect, Pressure-Gradient Force, Coriolis Effect, Gyre] that best matches each.
- Explain the effect that the tilt of the earth's axis has on the seasons and the creation of climate regions.
- Describe Greenhouse Effect and explain how it contributes to the surface temperature of the earth.
- Sketch and explain the role of convection in wind patterns and air circulation on the earth.
- Illustrate the cause of the Coriolis force on a rotating surface, and describe its effect on weather patterns, air circulation and ocean currents.

Reading Assignment: Conceptual Physical Science, 2nd Edition, Paul G. Hewitt, John Suchocki, Leslie A. Hewitt. Chapter 26, Sections 3, 5, 6.
Suggested Homework Assignment: Conceptual Physical Science, Chapter 26, Review Questions: 14, 19, 22, 26, 37. 39.

Although this session represents a deviation from the sequence of topics in the suggested text, this is a natural place to introduce a discussion of the factors that create the seasons, drive winds, and are responsible for the circulation of air and ocean currents on the earth. The heat transfer mechanisms of the preceding session, along with the Coriolis force, are the major influences that determine large-scale global weather patterns.

The starting point is solar radiation, energy from the sun that strikes the earth. Point out that with the exception of naturally occurring radioactivity, the sun is the ultimate source of all the energy on the earth. The fossil fuels and lumber that we burn represent solar energy that has been absorbed and stored by plants and animals in the past. Water and wind power are the result of cycles of evaporation, precipitation and air movement, all driven by solar energy. But the total energy provided by the sun is not the whole story. Equally important is how that energy is distributed over the earth's surface and how it is transmitted or absorbed by the atmosphere.

Describe the significance of the tilt of the earth's rotational axis and what the consequences would be if that were not the case. Not only would there be no seasons, but also the distribution of solar energy across the earth's surface would be significantly different, with much higher overall solar radiation in the equatorial regions and much lower intensities at the poles. (You might want to check how many of your students believe that summers are warmer because the earth is closer to the sun. Then surprise them by pointing out that those of us in the northern hemisphere are actually closer to the sun in the winter).

The atmospheric "window" for electromagnetic radiation is also significant. The earth's atmosphere is relatively transparent in the visible region of the spectrum but absorbs at frequencies above and below this range. As a result, potentially harmful levels of ultra-violet radiation are reduced, while light is passed through to the earth's surface where much of it is absorbed, heating the surface. But the earth, like any body at a temperature above zero Kelvin, also radiates energy. Since its temperature (fortunately) is much lower than that of the sun, it emits primarily in the infrared, a region where the atmosphere absorbs strongly. The atmosphere, in turn, also radiates energy due to its temperature. Part of this energy goes off into space and part is transferred to the earth's surface through the mechanisms of heat transfer we have previously discussed. The earth’s surface would be much colder if there were no atmosphere because, in effect, it receives energy from two sources, the sun and the atmosphere. If that were not the case, the temperature swings between day and night would be much larger and the average temperature on our planet would be below freezing.

The warming influence of the atmosphere is known as the greenhouse effect. Make sure you distinguish it from concerns about global warming, since the two are often confused in the media. Life on earth would not be possible without the greenhouse effect. This would be the place to inject a discussion of the role of atmospheric CO_2 in the greenhouse effect. Your students probably will be surprised to learn that water vapor is a bigger factor in absorbing heat in the atmosphere. However, make sure that they understand that it is the <u>increasing level of CO_2</u> and the related potential rise in the temperature of the atmosphere that are causing the concern about global warming. You can often find the greenhouse effect compared to the heat build-up in a closed car in the summertime or in a greenhouse (as the text does), but beware! While there is a similarity in that the absorption of higher frequency radiation and the emission of lower frequency radiation play a role, much of what happens in these two examples is the result of the absence of convection due to the closed windows in the car or the greenhouse, while convection is an important mechanism of heat transfer in the atmosphere (see below).

Now introduce the influence of convection. Point out that convection will occur due to the unequal heating of the earth's surface. Warm air (or any fluid) rises, expands and cools. Cool air sinks to replace the rising warm air. This process creates a circulation known as a convection current. Discuss the Coriolis effect and the influence it has on global weather patterns. If one is available, use a chalkboard version of a globe to show the class the effect. Draw a straight line (from the point of view of the class), starting from the North Pole to the South Pole, while the globe is rotated. Show them the pattern on the globe. Point out that the path appears curved from the point of view of an observer on the globe. The curvature is not caused by a force deflecting the chalk from its straight-line path, but rather by the rotation of the globe. Remind your students that this is just one illustration of the Coriolis effect. It is not limited to north-south motion. Similar deflections will take place for east-west motion or motion in any direction on the rotating globe.

Discuss the influence of the Coriolis effect on air circulation around high and low-pressure centers. Pressure differences between different air masses cause winds to blow. Once in motion, the air travels in a straight line (the law of inertia). The motion of the air with respect to the surface of the earth, however, is curved because of the rotation of the earth. The twisted cloud patterns one sees on the evening news weather report are a consequence of this effect. Similar flow patterns show up in the ocean currents, convection currents in the earth's mantle, and in the liquid inner core of the earth.

Spend some time going over the role of the Coriolis effect on global air circulation patterns and surface ocean currents. Show the students the north-south, south-north pattern of air circulation currents between the high and low-pressure regions. Then use the chalk lines you drew on the globe to demonstrate that the east-west, west-east deflection of the currents due to the Coriolis effect will always be to the right of the direction of motion in the Northern Hemisphere and to the left in the Southern Hemisphere.

Stress the interaction between these circulation patterns and the surface ocean currents. For example, the prevailing westerlies created by the influence of the Coriolis effect on the atmospheric circulation currents in the temperate regions drive the surface ocean currents in an easterly direction. The Coriolis effect deflects these currents southward in the Northern Hemisphere and Northward in the Southern Hemisphere. This deflection moves them toward the equator where they meet the westerly-flowing trade winds. As they change to a westerly direction under the influence of these winds, the Coriolis effect deflects the currents northward in the Northern Hemisphere and southward in the Southern Hemisphere. Diagram these motions on the board so that the students can see that the result is a clockwise circulation of surface currents in the Northern Hemisphere and a counter-clockwise circulation in the Southern Hemisphere.

Demonstrations

You can sometimes find good examples of wind patterns and weather circulation patterns by following several days of weather maps. The website *www.intellicast.com* has local, national and worldwide resources from radar imaging and satellite photos, as well as weather observations and forecasts.

Caution is in order, however. It is easy to fall into errors when dealing with relatively complex phenomena like the weather patterns and air movements. The Bad Meteorology website, *www.ems.psu/~fraser/BadMeteorology.html*, created by Alistair B. Fraser at Penn State University is an excellent source of examples of common errors made by teachers and texts. The *Bad Coriolis* and *Bad Greenhouse* pages are particularly relevant to this material. They correct a number of misconceptions about these two topics and are highly recommended as references.

The examples of the Coriolis effect in the text are illustrations of how students could become confused. The statement that the deflection produced is greatest at the poles and zero at the equator is true, as long as one considers only the deflection along the earth’s surface. The Coriolis effect, however, is actually independent of latitude. What changes is its direction. At the poles it is parallel to the earth’s surface and produces the greatest deflection. At the equator it is perpendicular and produces no deflection parallel to the surface. At intermediate latitudes, it has components both parallel and perpendicular to the surface and the amount of deflection depends on the size of the parallel component.

Thermal Equilibrium Lab

Purpose

To find the equilibrium temperature of a mixture of two fluids that are initially at different temperatures.

Introduction

In this exercise you will start with two masses of water at different temperatures. You will mix them and find the final equilibrium temperature. This is like finding the equilibrium balance point for a seesaw. The final equilibrium temperature, $T_{f,}$ is given by the thermal balance expression:

$$m_1 (T_1 - T_f) = m_2 (T_f - T_2)$$

Where m_1 and m_2 are the masses of the two water samples, T_1 the temperature of the warmer sample, T_2 the temperature of the cooler sample and T_f the final temperature of the mixture. In this equation, the differences between the initial temperatures and the final temperature are analogous to the lever arms in a seesaw.

Equipment / Materials

Three 8 oz Styrofoam cups and one 16 oz Styrofoam cup, thermometer, hot and cold running tap water, ice, and a scale or balance.

Procedure

1. Put hot tap water in a Styrofoam cup. Put cool tap water in a second Styrofoam cup. Put a 50-50 mixture of hot and cool tap water in a third cup. Place your left index finger into the hot tap water, and then move it into the 50-50 mixture. Note how warm or cool it feels. Remove your finger. Now, place your right index finger into the cool tap water, then move it into the 50-50 mixture again noting how warm or cool it feels. Do both your fingers tell you that the 50-50 mixture is at the same temperature? Describe what you feel:

   ____

2. Prepare equal amounts (masses) of water in two cups. Use hot tap water for one and cool tap water for the other. Record the temperature of the water in each cup.
   Temperature of: hot water = _____ cool water = ____ .

   Mix the two cups of water in a larger cup. Tell what you expect the equilibrium temperature to be from a symmetry argument:

____

Measure the equilibrium temperature of mixture: T_f = ________________.
How does this compare to your prediction?

3. Prepare unequal amounts of water in two cups, using twice as much cool tap water as hot tap water. Record the temperature of the water in each cup. Mix the two cups of water in a larger cup. Record the final equilibrium temperature. Temperature of:

hot water = _____ cool water = ________

equilibrium T_f = ________

Use the thermal balance equation to calculate T_f = __________

4. If an ice cube is added to one of the cups, the thermal balance equation must be adjusted to reflect the heat energy that is necessary to change the state of the ice into water. This change does not change the temperature of the water. About 80 calories/gram are required to melt ice. The adjusted thermal balance equation is:

$$m_1 (T_1 - T_f) = (m_2 + m_{ice})(T_f - 0) + (80 \text{ cal/gm})(m_{ice})$$

Prepare 100 grams of ice water at 0 ^{0}C in one cup. Weigh a small ice cube and add it to the cup. Prepare a second cup of 100 grams of hot tap water. Record the initial and equilibrium temperatures. Temperature of:

cool water = _____ hot water = ____

equilibrium T_f = _____

Use the thermal balance equation to predict the equilibrium T_f = ________

Question:

Explain how it would be possible, in the situation where there is a phase change, for the final equilibrium temperature to be zero.

____

Session 13 - Second Exam

Sample Second Exam Questions

Fill in the correct answer in the items below. Give numeric results where appropriate

1. According to molecular theory, the temperature of a gas is related to
____.

2, 3. A 50 g. weight is placed in a beaker filled with water. It displaces 20 ml of water.
The density of the weight is _________________________.
The buoyant force acting on the submerged weight is___________________.

4. The physical principle applied in answering questions 2 and 3 is
_______________________________________.

5. The transfer of thermal energy due to currents in a fluid is called
_______________________________________.

6. The deflection of moving objects due to the rotation of the earth is known as
_______________________________________.

7, 8. The two main influences on global wind circulation patterns are
_______________________ and __________________________.

9. On clear days, the temperature of the air in the desert drops sharply after sunset
due to what form of heat transfer? __________________________.

10. A Calorie is a unit of ______________________________.

11. The heat needed to raise the temperature of a unit mass one degree centigrade is
known as ____.

12. The heat needed to melt a unit mass of a substance is known as
____________________________.

13. The temperature scale with no negative values is the __________________ scale.

14,15. On sunny days, landmasses near the ocean will heat up (more/less)
___________________ rapidly than the water. This causes winds that will blow
(onshore/offshore)_______________________.

MULTIPLE CHOICE / TRUE-FALSE

_______ 16. A glass contains water and ice cubes. As the ice melts:
A. the water level in the glass will drop.
B. the water level in the glass will rise.
C. the water level in the glass will remain the same.

_______ 17. The atmospheric component most responsible for the heating of the earth's atmosphere through the greenhouse effect is:
A. carbon dioxide
B. water vapor
C. ozone
D. smog

_______ 18. The primary cause of surface ocean currents is:
A. rivers
B. temperature differences in the water
C. winds
D. differences in ocean depths

_______ 19. The force exerted by a liquid on a surface is equal to the pressure times the area of the surface.
A. True B. False.

_______ 20. At 100^o C, water can exist as both a liquid and a gas. Comparing the total energy of equal masses of the gas and the liquid, the gas has:
A. greater total energy.
B. less total energy.
C. the same total energy.

_______ 21. The climate near large bodies of water is moderated because of:
A. evaporation of the water.
B. reflection from the water.
C. specific heat of the water.
D. none of the above.

_______ 22. If equal masses of two different gases are at the same temperature, their molecules have exactly the same average velocity.
A. True B. False.

________ 23. The atmosphere is heated primarily by radiation from the warm earth, rather than directly by solar radiation.
A. True B. False

_______ 24. The pressure at the bottom of a column of water does not depend on which of the following?

A. the depth of the column.
B. the area of the water surface.
C. the density of water.
D. gravitational acceleration.

________ 25. Evaporation is a cooling process because of the velocity of the molecules that escape.
A. True B. False.

________ 26. Condensation is always accompanied by:
A. a drop in temperature.
B. heat absorption.
C. heat release.
D. none of the above.

________ 27. Winds in the atmosphere are influenced by convection currents.
A. True B. False.

________ 28. Winds in the atmosphere are influenced by the earth’s rotation.
A. True B. False.

________ 29. As a helium balloon rises in the atmosphere:
A. it becomes larger.
B. the buoyant force on it increases.
C. it becomes lighter.
D. all of the above.

________ 30. Heat always flows from the body with the greater thermal energy to the body with the lesser thermal energy.
A. True B. False.

Instructor Guide Session 14 Static Electricity

Objectives:

- Given one or more definitions, supply the vocabulary word(s) from the list [electron, ion, a Coulomb of (Positive or Negative) charge, Coulomb's (Inverse-Square) Law, electric polarization, Electric Field, Electrical Potential Energy, Electrical Potential, Joules, Coulomb, Volt] that best matches each definition.
- Describe the variation of force with distance for an inverse square law.
- Sketch a graph of an inverse square force.
- Sketch and describe electrical polarization.
- Sketch the electric field of a point charge; two point charges, and a pair of parallel plates.
- Correctly describe the analogy between water pressure and electrical potential.

Reading Assignment: Conceptual Physical Science, 2nd Edition, Paul G. Hewitt, John Suchocki, Leslie A. Hewitt. Chapter 8, Sections 1 - 4.
Suggested Homework Assignment: Conceptual Physical Science, Chapter 8, Review Questions 8, 11, 12, 16 and Exercise 1.

Similarities between Coulomb’s Law and the gravitational force can help students visualize electrical forces. Remind them of the material on gravity and the gravitational field (Session 6). Like the Law of Universal Gravitation, Coulomb's law is also an inverse-square force. The important difference from gravity, of course, is that there are <u>two</u> kinds of charge so that a repulsive force is possible. This also makes possible electrical polarization. Repeat the diagram of the negatively charged balloon polarizing the atoms at the surface of the wall so that the wall nearest the balloon becomes positive and the balloon sticks to the wall. Have the students redraw the balloon example assuming an initial positive charge.

It’s also important that students understand the enormous differences in strength between these two fundamental forces. The only reason that gravity is dominant in our everyday experience is that electrical charge is so perfectly balanced in most objects. Richard Feynman has pointed out that if two people stood at arm’s length and each had just one percent more electrons than protons, the force between them would be equal to the weight of the earth.

Continuing the analogy with gravity, the electrical field can be compared with the gravitational field. Just as the gravitational field of a mass is assumed to exist at any point in space whether or not there is another object there for it to exert a force on, the electrical field due to a charged object exists at a point, even in the absence of another charge.

The two other important ideas in this unit are electrical potential energy and the conservation of electrical charge. In every physical interaction, charge is never created or destroyed, only transferred from one body to another. This fundamental principal originates at the sub-atomic level, resulting in another conservation law on the same level of importance as the conservation of momentum and the conservation of energy.

The concepts of work and energy are important considerations in electrical fields. Since charged objects experience a force in an electrical field, they can have a potential energy, just as objects with mass have potential energy in a gravitational field. The presence of an electric field and the electrical force it exerts results in potential energy being associated with any charge placed in the field. This is usually described in terms of the energy per unit charge or "electric potential" of the field. The concepts of electrical potential energy and the work done by an electrical force can be developed in the same manner as were the similar concepts associated with mechanical forces. Emphasize the similarity between the gravitational potential energy (mgh) and the electrical potential energy. In the gravitational case one can define the gravitational potential by dividing the gravitational energy by the amount of mass m, so gravitational potential $V_g = gh$.

Demonstrations

Static electricity is an area that presents a number of opportunities for classroom demonstrations. You may wish to choose some or all of those listed below.

Hand out balloons to your students (you can find them inexpensively at party supply stores), have them blow them up and rub them on their hair or clothes, and duplicate the “stick to the wall” experiment described in the text. Or have them pick up small bits of paper with them.

Smooth two eight-inch-long strips of cellophane tape down on a table (Fold the ends over to make them easy to pull). Rip them off quickly, and then bring the strips toward each other. The repulsion is quite obvious. Argue from symmetry that the charges generated in the tape must be identical in sign. Therefore, charges of the same sign repel each other. Then break the symmetry by smoothing down one strip on a table, then smoothing the second strip on top of it. Remove the strips from the table then separate the two strips. The attraction is also very evident, indicating the presence of a second kind of charge and showing that charges of opposite sign attract.

When PVC pipe is stroked with a paper towel, it becomes charged. White PVC and Grey PVC produce opposite changes. By suspending a short section of pipe by a string, you can show that opposite charges attract and like charges repel. Further, you can also show polarization. Balance a wooden slat, which is 3" wide, ½” thick, and a yard in length on top of an inverted 5" diameter watch glass. Bring up a charged rod of either sign and the slat will swing toward it.

You can also demonstrate electrical charge by using the classic rubber-and-glass rod demonstration described in the text. When a hard rubber rod or comb is rubbed with fur or wool, it gains electrons from the cloth and becomes negatively charged. If it is then brought near a small ball of cork or Styrofoam that you’ve suspended from a thread, it will at first attract the ball (by inducing polarization) and then, after contact, repel it (because the ball will become negatively charged by picking up excess electrons on contact). A glass rod will transfer electrons to a silk cloth when rubbed, becoming positively charged. You can then show that it attracts the negatively charged ball repelled by the rubber rod, demonstrating the existence of two kinds of charge.

Static Electricity Lab

Purpose

To illustrate properties of electrical charge and observe the forces exerted between charged objects.

Introduction

The basic building block of matter, the atom, contains the two different types of electrical charge (positive and negative). The positive charge resides on the nucleus of the atom while the negative charge consists of electrons orbiting outside the nucleus. All atoms have equal amounts of positive and negative charges so that they are electrically neutral. However, it is possible to remove electrons from atoms through friction, leaving behind charged ions with an excess of positive charge. Everyone has experienced this at one time or another, perhaps when you walked across a carpet and experienced a shock when you touched a doorknob, or when you slid across a car seat and touched something metal in the interior. Electrostatic forces have many common applications, including photocopy machines and the "clinging" properties of household plastic wrap.

Equipment / Materials

Scotch tape, 6" piece of gray or white PVC plumbing pipe, 6" piece of clear Plexiglas, paper towels, glass rod & silk cloth, rubber rod & fur.

Procedure

1. Cut two strips of 8" long Scotch tape. Fold 1/2" over so that it creates a tab that you can hold. Smooth both strips down on a tabletop. Now, rip off both tapes quickly. Then move the tapes toward each other. Describe what happens.

   ____

   ____

   Since both tapes were charged by exactly the same process, a symmetry argument would suggest that the sign of the charge must be the same for both tapes. Complete the statement summarizing your observations. Like charges (attract? repel?)

   ____

2. Tack the two strips along the edge of your table. Rub the glass rod with the silk. Bring the rod toward the scotch tape strips. How do they react?

   ____

By convention, the glass rod is said to be positively charged. What is the charge on the strips?

____

Rub the rubber rod with the fur and bring it near the strips. How do the strips react? What is the charge on the rod?

____

Rub the Plexiglas with a paper towel and test its charge with the strips. What is the reaction of the strips? What is the charge on the Plexiglas?

____

Finally, rub the PVC with a paper towel and repeat the above process. What is the Reaction? What is the charge on the PVC?

____

3. Repeat charge generation with the two tapes but this time make the process nonsymmetric. Smooth the first tape on to the table then stick the second tape on top of the first tape. Rip off the combined tapes, then rip the second tape off the first tape. Keep track of which tape was the one on the table and which one was the tape that was on top. Move the tapes toward each other. Describe what the tapes do:

____

This time each tape is interacting with a different surface. This break in symmetry mean that the charges generated might be different. Tack the two strips along the edge of your table. Rub the glass rod with the silk. Bring the rod toward the scotch tape strips. How do they react?

____

Rub the rubber rod with the fur and bring it near the strips. How do the strips react?

____

Rub the Plexiglas with a paper towel and test the reaction of the strips.

Reaction of the strips? ____

Finally, rub the PVC with a paper towel and repeat the test.

Reaction? ____

Questions

1. When you rub a glass rod with silk material, the glass rod becomes positively charged. What happens to the silk?

2. When the two tape strips were placed on top of each other, what charge did the bottom tape acquire? What charge did the top tape acquire?

Instructor Guide Session 15 Current Electricity

Objectives:

- Given one or more definitions, supply the vocabulary word(s) from the list [Electrical Resistance, Ohm's Law, Series Circuit, Parallel Circuit, Direct Current, Alternating Current, Power] that best matches each definition.
- Draw a correct analogy between a hydraulic system and an electrical circuit.
- Apply Ohm’s law to find the current, resistance or potential drop in a circuit when two of the three quantities are known. .
- Draw examples of a series and a parallel circuit. Show the path of the current in both of these cases. Describe the relationship between the current flow in each element in the circuit and describe the potential drops across each element.
- Describe qualitatively the effect of series and parallel connections on the total resistance in a circuit.

Reading Assignment: Conceptual Physical Science, 2nd Edition, Paul G. Hewitt, John Suchocki, Leslie A. Hewitt, Chapter 8, Sections: 5 - 8.
Suggested Homework Assignment: Conceptual Physical Science, Chapter 8, Review Questions 29, 32, 36, 37 and Exercise 36.

Start by describing the model of the charge within a metal conductor as consisting of mobile electrons moving through positive charges that are relatively fixed. Although the metal is electrically neutral, the repulsive forces between the mobile electrons are enormous. Their thermal motion produces average speeds nearly 5% the speed of light, but the electrons are moving randomly in all directions, so there is no net movement of charge. Applying a potential difference across the wire does not change its electrical neutrality but it adds an overall component of velocity to the electrons in the direction of the positive end of the wire. However, this drift speed is only about one millimeter per second. Stress this since there is a tendency to think of the charge carriers as moving with very high speeds in the direction of the current flow.

Use the analogy with water pressure to relate voltage to the idea of electrical pressure. Using this comparison, students can see that current will only flow when there is a *difference* in voltage or electrical potential between two points. Use examples to illustrate this: birds can set on a high-voltage wire without being injured, but sometimes a squirrel will touch both sides of a power transformer and short out an entire neighborhood; or an individual can be safe inside an automobile that a high voltage wire has fallen on, but could be seriously injured if they were to step out onto the ground while still in contact with the car.

When electrons flow from a high electrical potential to a lower potential they lose energy. To keep a current flowing, energy has to be “pumped in” to the circuit (another useful water analogy). This is what batteries and other power sources do. Remind students, however, of energy conservation. These sources are merely converting energy from other forms into electrical energy. In batteries this is accomplished by a process that converts the energy of chemical bonds into electrical potential energy.

The greater the current flow between the high and low potential, the greater the energy per unit time that must be supplied to the circuit, and therefore the greater the power needed. Introduce Ohm's Law as the definition of electrical resistance, $R = V/I$, a purely empirical result. The greater the resistance in a circuit, the lower the current flow for a given potential difference and the lower the power delivered by the current.

Have the students find the current drawn by different household appliances like light bulbs, hair dryers, toasters, irons, etc. using the wattage ratings. Then have them find the resistances of the appliances from Ohm's Law. Make sure that they understand that household current is A.C., not D.C., but the basic relationships like Ohm's Law and power are the same. This is a good place to discuss the effect of insulating materials and why 120 volts may, at most, deliver only a mild shock to someone who is wearing rubber-soled shoes and standing on a dry surface, while it can be fatal to another person who is barefoot on a wet surface. Use the relationship between power and current flow to explain why the several thousand volts you can build up while scuffing your feet across a carpet doesn't produce a serious shock. Since the total charge build-up is small, the total current flow is low and little power is involved even though the voltage is high.

Series circuits may be familiar to students from the strings of inexpensive Christmas lights that all go off when one bulb burns out. It's easy to see why you wouldn't want the circuits in your house wired in series! Discuss how parallel circuits draw more and more current as more elements are added. Point out the need for fuses or circuit breakers to avoid dangerous overloading. Contrast this with series circuits where the power must be shared between the elements and each draws less power as the number of circuit elements is increased. An excellent demonstration (suggested by Paul Hewitt) illustrating this behavior is described below.

Demonstrations

A storage battery with two vertical rods extending from the terminals and several flashlight bulbs connected to leads that terminate in alligator clips can be used for a series of demonstrations. The rods can be compared to a household circuit or a power line. The light bulbs are the circuit elements drawing power from the circuit. Begin with just one bulb connected between the rods. Move it up and down the rods showing that the brightness doesn't change. The 12-volt potential difference due to the battery is the same everywhere along the rods. Students can see from this that the potential is the same at every wall outlet in the house or everywhere along the power line. Now attach a second lamp. Point out that they burn equally brightly – the current is the same through each. (Make sure that all the bulbs have the same wattage rating!) If the current is the same, each must have 12 volts applied across it. Now repeat this for a third bulb, observing that the brightness remains the same and it therefore draws the same current as the other two.

Now consider the current in the rods. Since each bulb draws the same amount, the total current must be three times what it was with only one bulb. Compare this to a household circuit and explain why fuses "blow" when too many appliances are connected to a circuit. You may want to extend this discussion one step further and consider the total resistance in the circuit. Since the current is three times as great, but the voltage applied to the circuit is still only 12 volts, Ohm's law tells us the resistance must have decreased by a factor of one-third. Connecting resistances in parallel reduces the total resistance in the circuit.

Disconnect the bulbs and use the alligator clips to connect two of them in series. Attach this series circuit between the rods. Students will easily see that the brightness is diminished. The current through the bulbs is less than for a single bulb. Now add a third bulb to the series circuit. The brightness is diminished further as the current is reduced and each bulb draws less power. Again, you can apply Ohm's law to show that the series connection results in an increase in the total resistance. If you have a lecture-size demonstration ammeter that you can connect in the circuit, you can demonstrate the quantitative relationship for series and parallel connections of resistances as well.

Instructor Guide Session 16 Magnets

Objectives:

- Given one or more definitions, supply the vocabulary word(s) from the list [Magnetic Poles, Magnetic Field, Magnetic Domains, Electromagnet] that best matches each definition.
- Sketch the magnetic field of a bar magnet and the field between the poles of two bar magnets in proximity to each other.
- Describe how two magnets interact – identify the forces of attraction or repulsion between two magnetic poles.
- Draw the magnetic field associated with a long straight wire, and a loop of wire.
- Explain the electrical origin of magnetism, and why some materials are magnetic and others are non-magnetic.

Reading Assignment: Conceptual Physical Science, 2nd Edition, Paul G. Hewitt, John Suchocki, Leslie A. Hewitt. Chapter 9, Sections: 1 - 4.
Suggested Homework Assignment: Conceptual Physical Science, Chapter 9, Review Questions 3, 5, 9 and Exercises 3, 13.

The main theme of this unit is the electrical origin of magnetism, in both naturally occurring magnets and electromagnets, but before delving into this topic it's best to first establish some of the properties of magnets. You may be surprised how many students have never seen these simple demonstrations!

Hold a bar magnet over some paper clips and lift them. This illustrates two things: the strength of the magnetic force (as Hewitt points out, the single bar magnet is overcoming the gravitational force of the entire earth), and induced magnetism – the fact that some materials can become magnetized in the presence of a magnetic field. Compare this to the induced electrical attraction created by polarization in the electrostatic case.

Place bar magnets and horseshoe magnets on an overhead projector and cover them with a thin sheet of plastic. Sprinkle iron filings over the plastic to demonstrate the magnetic field lines. You may need to tap the overhead to help the particles align. (Note: if you live near a beach, it may be possible to collect sand rich in natural magnetite grains, a free source of material.) Place two bar magnets under the plastic, first with their opposite poles in proximity, then with two north or two south poles near each other. Point out the concentration of the magnetic field lines corresponding to attraction between the two opposite poles and the apparent repulsion between the lines in the case of like poles. Have the students draw the electric field of a pair of equal and opposite electric charges (dipole). Demonstrate the field of a bar magnet and ask them to compare the form. Stress that single electrical poles (charges) are easy to generate but that single magnetic poles have not been observed. Note that among the elements, strong magnetism is very rare.

Discuss the magnetic field of the earth and the fact that the earth's spin axis and the magnetic poles are not in exact alignment. Point out that since the north pole of a magnet (more precisely the north-seeking pole) aligns in the direction of the earth's north magnetic pole, the earth's magnetic field behaves as if there were a south pole located there. Many students are not aware of the earth's magnetic pole reversals over time. In discussing this and the evidence for the earth's liquid core, use the sun as an illustration that an object does not have to be solid to be magnetic. The sun has a strong magnetic field that reverses itself on a cycle of about eleven years.

Electricity and magnetism were treated as separate phenomena until it was discovered that a current flowing in a metallic conductor disturbed a nearby compass. The current must have produced a magnetic field. Since all atoms contain electrical currents in the form of moving electrons, it is easy to see that magnetism originates from the motion of charged particles in atoms. In fact, the natural question is, since all atoms contain moving charges, why are not all elements magnetic? The answer rests in the way that the tiny magnets in the atom arrange themselves. In most atoms they are oriented so that the magnets point opposite to each other and cancel. Only in a few elements -- iron, cobalt and nickel -- is there a significant residual magnetism, with the result that substances containing these elements can be magnetized.

You may or may not wish to raise the relativistic origin of magnetism that Hewitt alludes to, but there is another important point that should be reinforced in your discussion. Students have seen demonstrations of the magnetic field and have been able to visualize it through its effect on iron filings. This is the third field that they have been introduced to in this class (we know, however, that both the electrostatic and the magnetic fields are just different aspects of the electromagnetic field). By now they should be beginning to understand that all of the fundamental forces in nature can be described in terms of fields, fields that can propagate through space, fields that transmit energy. Point this out. The concept of force fields and the existence of conservation laws are two of the most important ideas they should take away from this course.

Demonstrations

If you have a large enough classroom demonstration compass or a transparent one that can be placed on an overhead, show that a pivoted bar magnet (a compass) is easily deflected by other bar magnets. Alternatively, you can distribute small compasses and bar magnets to the class and have them experiment with the deflection. Ask why, in the absence of other bar magnets, the compass points north.

Also, if you have a demonstration compass, place it near a current-carrying wire and show that the current produces a deflection, just like the bar magnet.

Demonstrate magnetic induction by attracting a large iron nail to a magnet and showing that the nail itself is now magnetic and can pick up other objects like paper clips. Contrast this with the behavior of a non-magnetic metal like a brass screw.

Create an electromagnet by wrapping a few turns of insulated wire around a large iron nail and passing a current through the wire. Compare the induced magnetism in the nail due to the current to the magnetism induced when it was in contact with the permanent magnet.

It’s difficult to replicate in the classroom the text photographs that show the magnetic fields of current carrying-wires. However, there are excellent overhead transparencies available that illustrate the fields, and it is worthwhile to display a few in your lecture. The illustration of the field of the current-carrying loop is especially worthwhile as the current-carrying loop can be compared to the orbital motion of an electron, and the configuration of the field lines illustrates clearly why north and south poles are always created in pairs.

Electrical Circuits Lab

Purpose

To illustrate the properties of simple series and parallel electrical circuits.

Introduction

There are two basic circuit elements in any DC (direct current) circuit: power sources and resistances. This exercise uses batteries as the power sources and bulbs as the resistances. Electrical components can be connected in series or in parallel configurations. If two bulbs or batteries are connected in series, the same current must flow through each and the total voltage across them is the sum of the voltages across each component. However, in the parallel case, the current is split between them so that the total current is the sum of the two individual currents. For parallel connections it is the voltage that is the same across each component

To help visualize electrical circuits, think of the current as a charged fluid and the battery as a pump that forces the fluid in one direction. For the series circuit, all the charged fluid flowing through the first bulb must then also flow through the second bulb. The current is common to both bulbs and each bulb has a pressure drop (voltage drop) across it. The total drop would be the sum of the drops across each of the individual bulbs. For the parallel circuit, the pressure drop (voltage drop) across each bulb is the same. The charged fluid (current), however, separates into two parts. Neither bulb passes the full current and the total fluid flow (current) would be the sum of the flows through each of the individual bulbs.

Equipment / Materials

Two D size batteries, several small flashlight bulbs, two or three 6" long wires, and a multimeter.

Procedure

1. The multimeter that you will use in this lab is a common and very versatile electrical instrument that can be use to measure current, voltage and resistance. Set the multimeter scale to DC volts and measure the voltage across each of the D batteries. Try switching the electrical leads and note the change in sign of the voltage.

   First battery = __(sign) _______ Volts

   Second Battery = __(sign) _______ volts

Describe the orientation of leads that will yield a positive (+) sign:

____

Place the two batteries with the tip of one touching the base of the other battery. This is the way you might place them in a flashlight. Then measure the potential between the two, from the base of one to the tip of the other.

Batteries facing in the same direction = ___ (sign) ___________ Volts

Is your measurement consistent with the <u>sum</u> of your individual measurements of the batteries above?

____

3. Reset the multimeter from DC voltage to resistance (Ohms). If you clip the leads together it should read zero ohms. Measure the resistance of one of the 6" long pieces of wire. It is also close to zero and will offer little resistance to the flow of electricity. Finally, place the leads across one of the bulbs. The bulb has enough resistance to limit the current produced by a battery.

   Place the tip of the bulb to the tip of the battery and then place one end of the wire on the base of the battery and the other end touching the outside metal cylinder of the bulb. Although you cannot see the electricity in motion, the current is large enough to heat up the bulb and make it glow. The larger the current the brighter the bulb will glow. Confirm that the bulb will also light when you "turn the battery around" in the following manner: place the tip of the bulb to the <u>base</u> of the battery and then one end of a wire to the tip of the battery and the other end to the outside metal cylinder of the bulb. The glowing bulb tells you that current is flowing but it does not reveal the direction of the current.

4. Now connect two bulbs to the battery in series. Place the tip of the first bulb to the tip of the battery. Then place one end of a wire to the outside metal cylinder of the first bulb and run the other end to the tip of the second bulb. Connect one end of a second wire to the outside metal cylinder of the second bulb and place the other end of the wire to the base of the battery. Both bulbs should glow.

   Compare the brightness of each bulb to the brightness of the single bulb case

   ____

What does this mean in terms of the current flowing through the bulbs?

____

5. Construct a parallel circuit by running two wires from the tip of the battery to each of the outside metal cylinders of the two bulbs, then run wires from the tip of each bulb back to the base of the battery. Both bulbs should glow. Compare the brightness of each bulb to the brightness of the single bulb case

____

What does this mean in terms of the current flowing through one of the bulbs?

____

Now disconnect one of the bulbs. Describe what happens and give an explanation.

____

____

Questions

1. The D size battery produces a potential of about 1.5 Volts. Other batteries at the store seem to be 3, 6, and 9 Volts. Explain why the numbers have these values.

____

2. Based on what you've observed today, do you think your household electrical outlets should be connected in series or parallel? Do you think a light switch should be in series or in parallel with the light it controls? Explain your answers.

____

____

Objectives:

- Given one or more definitions, supply the vocabulary word(s) from the list [Magnetic Force, Electric Motor, Electromagnetic Induction] that best matches each definition.
- Sketch the direction of the magnetic force on a moving beam of charges, and on a current in a wire.
- Explain the operation of ammeters, voltmeters, electric motors, transformers and generators.
- State Faraday's Law of Electromagnetic Induction. Describe how a voltage can be induced through motion or by a changing magnetic field.

Reading Assignment: Conceptual Physical Science, 2nd Edition, Paul G. Hewitt, John Suchocki, Leslie A. Hewitt. Chapter 9, Sections 5 - 9.
Suggested Homework Assignment: Conceptual Physical Science, Chapter 9, Review Questions 13, 21,26, 29 and 30.

Nature is replete with marvelous symmetries. The relationship between magnets and electrical currents illustrates one of them. Just as an electrical current flowing in a wire can exert a force on a magnet, a magnet can exert a force on a current-carrying wire. The interaction between the magnetic field and the current is a complicated three-dimensional phenomenon. The force depends on the angle between the current and the field, and its direction is always perpendicular to both the current and the field. Emphasize the two limiting cases: current in the direction of the field produces no effect; and current perpendicular to the field results in the maximum force.

As an application of the magnetic force law, describe the galvanometer and its application as an ammeter and voltmeter. This is even better if you have a large classroom demonstration galvanometer so that the students can see the coil and the magnet. Then describe the modification that leads to the simple D.C. electric motor. Point out the profound effect of the motor in the course of the industrial revolution.

The material in this unit has had a greater effect on modern life and technology than any other area of physics. Take full advantage of these connections. Challenge your students to come up with other examples of the application of the electromagnetic force in addition to motors and meters. See if they make the connection between this force and the deflection of electron beams in television sets and oscilloscopes. If they don’t, point it out to them.

In the previous unit, students learned that an electric current could produce a magnetic field. In search of another symmetry, people wondered if a magnetic field could cause an electric current. Faraday and Henry demonstrated that it could if there was time-dependence involved, that is, if the magnetic field was changing with time, or if there was relative motion between the field and the current-carrying wire. This affirmative answer further fueled the industrial revolution, for it made it possible to efficiently generate the electric current needed to power the motors. (What is produced, actually, is an induced voltage or electromotive force. The current will occur only if there is a closed conducting circuit present. When you point this out, you might want to go one step further and discuss the induced electric field produced by the changing magnetic field and the corresponding changing magnetic field induced by a changing electrical field).

Contrast the motor and the generator. Discuss the importance of the transformer and the advantages of alternating current in power transmission (high voltage, low current, low losses). Again, challenge your students to list applications of Faraday's law and electromagnetic induction.

Since so much of the discussion in this unit centers on electrical energy and power, electrical generators and motors, and power transmission, this is a good place to remind students of the significance of the conservation of energy as an overriding principle. Electrical generators do not produce energy or power. They merely transform it from a different form into electricity. Motors do not create energy or increase power. They merely take the electrical energy supplied to them and convert it into mechanical energy. Transformers can increase voltage in a power line, but only at the cost of a lower current output. The total power input (voltage x current) is always greater than the power output because these electrical devices are not 100% efficient.

Demonstrations:

Because of the enormous importance of the applications of the electromagnetic force and electromagnetic induction, students are intrigued by demonstrations of these effects and there are many possibilities for effective classroom demonstrations. In fact, your lecture for this unit might well consist of a series of demonstrations interspersed with questions directed to the students about what they've seen, with only brief explanations on your part.

Pass an insulated wire through the poles of a very strong magnet. Ask a volunteer to carefully hold the wire on extended fingertips and to tell the class if any slight movement can be felt as you pass a current through the wire. Use a 12-volt car battery or other high current supply and a tap key (to provide an intermittent contact) attached directly to the wire. The high field and high current will produce enough force to lift the wire right out of the student's hand.

A demonstration of the magnetic deflection of a visible beam of electrons such as that provided by an e/m demonstration apparatus is a must. Lacking an e/m demonstration, you can show the deflection of the beam on an oscilloscope screen (although the perpendicular relationship between the field, force and the electron beam won't be as obvious) or show the distortion of the picture on an old black-and-white television set. If you use a TV, be sure to caution students not to try this at home since it can cause permanent damage to the imaging qualities of a color television. A Crook’s tube containing a fluorescent screen can also be used with even a weak magnet.

Induction can be shown with a strong magnet, a many-turned coil of wire, and a center-positioned galvanometer. While talking about the effort it took to find a way to produce a current, you can thrust the magnet into the coil. The students notice the galvanometer jump but you can react slowly. When you finally look at the meter it is back to zero. Having milked this ploy, systematically go through the direction and the motion of the coil and magnet. Include the case where the coil and magnet move together at the same speed.

There are many commercial pieces of equipment that demonstrate applications of the principles in this unit. One is the “jumping ring," a coil of wire with an iron core that will repel a conducting ring placed around it when a current is passed thru the coil. It can also be used to light a flashlight bulb attached to another coil, through induction. You can compare this to the charging units found in electric toothbrushes where there is no conducting contact between the base and the unit being charged. There are also demonstration motors and generators to show the principles of operation of these devices.

Objectives:

- Given one or more definitions, supply the vocabulary word(s) from the list [Amplitude, Wavelength, Frequency (Hertz), Period, Wave Speed, Transverse Wave, Longitudinal Wave, Reflection, Refraction] that best matches each definition.
- Relate wave motion to the motion of the transmitting medium.
- Calculate the frequency of a wave given its period and vice versa.
- Compute any one of the quantities -- wavelength, frequency or wave speed -- given the other two.
- Distinguish between reflection and refraction in waves. Explain the cause of refraction.

Reading Assignment: Conceptual Physical Science, 2nd Edition, Paul G. Hewitt, John Suchocki, Leslie A. Hewitt. Chapter 10, Sections 1 - 6.
Suggested Homework Assignment: Conceptual Physical Science, Chapter 10, Review Questions: 5, 11, 15, 19, 22.

The purpose of this unit is to develop a vocabulary for describing wave motion and establish some basic properties that students can apply to sound waves, light and other forms of wave motion. Given this, it is best to begin with the simplest waves, mechanical waves propagating in one dimension, and then illustrate these properties in more complex waves like sound or water waves.

You can isolate the concepts of frequency and period by beginning with a simple vibrating system such as a pendulum or a small mass suspended from a vertical spring. Set it in motion and calculate the frequency by measuring the number of vibrations in a given time interval. Point out that this is not an example of wave motion since it has only time dependence and a wave varies with both time and distance. Next find the period by measuring the time to complete one vibration. Demonstrate that the period is the inverse of the frequency.

Go to the board and mimic the vibrations of the vibrating system by marking with a piece of chalk, up and down, in sync with the vibrations. Now trace out a wave by walking along the board at a steady pace while continuing to move the chalk up and down with the same frequency. Point out that the wave has the same frequency as the vibration producing it (your hand), but that it also varies with distance as it oscillates up and down across the board. This is the difference between vibrations and waves. Define the wavelength as the distance between two wave crests, or the distance between any two points where the wave begins to repeat itself. Define the amplitude of the wave and show how it is related to the source vibrations. If you wish, you could now trace a second wave by walking along the board at a different speed while moving the chalk with the same frequency as before. However, students should be able to visualize the relationship between wave speed and wavelength without this additional demonstration.

The above presentation gives a static picture of a wave, frozen at a given instant of time. A slinky toy can convert this into a dynamic picture and demonstrate the difference between longitudinal and transverse waves. It also illustrates another important point: As a wave travels down the slinky, the individual coils transmitting the wave do not travel with it. Instead, they execute vibrations with the same frequency as the wave. This is true of all wave motion. The medium propagating the wave does not experience any net displacement. It merely oscillates at the same frequency as the wave it is transmitting. The wave disturbs the medium and causes it to vibrate. It is the disturbance in the medium that transmits energy; it is this disturbance that is the wave.

With the basic vocabulary and the relationship between wave velocity, frequency and wavelength established, examples of different sorts of wave motion can be introduced. To reinforce the relationship between wavelength, velocity and frequency, have students calculate some wavelengths for known frequencies, say middle C (256 Hz) for a sound wave, using 340 m/s for the speed, and the wavelengths of one or two radio stations that they select.

Water waves are a good visual illustration of two-dimensional waves as the wave velocity can be easily seen as the ripples spread out from the source of the disturbance. Point out that ripples are a truer representation of wave motion than the image of crashing ocean breakers that most people have in their minds. By the time that true ocean waves (known as swells) have become breakers, their wave motion has been distorted by friction with the coastline ocean bottom. The long waves of the open sea can travel at surprising speeds, as much as 15 meters/second or more. As an aside, swells are a combination of transverse and longitudinal motion. This influences their velocity. Sound waves, which are pure compressional waves, travel much faster than this in water – about four times the speed of sound in air (around 340 meters/second at normal temperatures and air pressure). While the factors that affect wave speed are not covered in the text, you might wish to explain that waves travel at different speeds in different media because their speed depends on the elasticity (Bulk modulus) and the inertial properties (density) of the particular material. The greater the ratio of the elasticity to the inertial properties, the greater will be the wave speed in the medium.

Reflection and refraction are important wave properties, common to all waves. While there are abundant illustrations of applications (Sonar, ultrasound scans for medical imaging, acoustical design, bat navigation using echoes, ultrasonic imaging by dolphins, etc.), the effects are easier to visualize and demonstrate using light. You might choose to postpone a fuller discussion until then and simply emphasize that in reflection a sound wave is “bounced back” at an angle equal to the incoming angle, just like a rubber ball, while in refraction the wave is bent outward if its speed is increasing and bent in the opposite direction if its speed is decreasing.

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Demonstrations:

The key elements of wave propagation can be depicted by a row of students. Instruct each student to look only at the motion of the student to his or her immediate left. After a fixed time delay, for example one second, they should repeat the motion they see. The motion is the elastic response while the time delay is the inertial response. You can be the starting element and generate both transverse and longitudinal waves. Adjusting the delay time changes the wave speed.

Either a soft spring, like a slinky toy, or a torsional wave machine can be used for effective demonstrations of wave properties -- the slower the wave the better. As you send waves down the machine or the spring, emphasize that only the disturbance is traveling, not the medium. Compare this to the student “wave” above. They didn’t travel down the row, only the wave motion did.

Use a demonstration bell jar with a doorbell inside to demonstrate that sound is transmitted through vibrations of air molecules. Ring the bell as the jar is being evacuated and have the students listen as the sound disappears. Then open the stopcock and let the air back in – the bell rings again. So perhaps we don’t know the answer to whether or not a tree falling in a forest makes a sound when there is no one to hear it, but we definitely know that it doesn’t make a sound if there is no air to transmit it.

Strike a tuning fork and dip it into a dish of water to show by the splashing that it is vibrating, and that it is the vibrations that produce the sound. This works best if you have a large, flat, transparent dish and place it on an overhead so that students can see the ripples as well.

Demonstrate the properties of sound with an audio oscillator and loudspeaker as a source and an oscilloscope and microphone to display the sound waves. Show the relationship between wavelength (or frequency) and tone, and relate amplitude to loudness.

Electric Motor Lab

Purpose

To demonstrate the operating principles of electric motors.

Introduction

An electrical current passing thru a wire produces a magnetic field that can exert a force on a magnet or another current-carrying wire. This force, in turn, can cause the magnet or wire to move, converting the electrical energy in the current into kinetic energy. This is the basic principle that underlies the operation of all electric motors: the conversion of electrical energy into mechanical energy or work.

One example is the common doorbell. It uses a wire-wound coil with magnetic cylinder placed in center. Pushing the doorbell closes a switch and completes a circuit. When current passes through the coil, the magnetic field produced exerts a force on the cylinder, causing it to move. Electrical energy has been converted into (translational) motion. The resultant motion is used to strike a bell and make a tone or series of tones. A simple electric motor works on the same principle, except the moveable element is arranged so that it rotates, rather than translates. The current in the coils of a motor is used to produce rotary motion.

Mechanical energy can also be converted to electrical energy. When a magnet is rotated inside a coil of wires, it can induce a current in the wires. If the coil is connected to a closed circuit, current will flow, providing electrical energy to the circuit. A device that produces electrical energy in this manner is known as a *generator*. As you can see, this is just the reverse of the operating principle of the motor and, in fact, some motors can be driven as generators by mechanically rotating the shaft.

Equipment / Materials

Electro-Motor Kit, Industrial Arts Supply Co., 5724 W. 36th Street, Minneapolis, Minn. 55416, 6-volt battery and connecting wires.

Procedure

1. Detailed notes and labeled pictures for construction are provided with the kit. In your motor there are two current-carrying coils. The stationary coil provides the magnetic field that exerts the force on the rotating coil. Both coils are *electromagnets*: that is, they are magnetic only as long as a current is passing through them. The rotating coil is called the *armature* and the stationary coil the *pole pieces*. Both coils will have a North and a South magnetic pole when current passes through them. Like magnetic poles repel each other and unlike poles attract. How would you expect the poles of the armature to align themselves with the pole pieces when current is passed through them?

____

____

2. Current is provided to the armature by two metal contacts called *brushes* that allow it rotate freely while maintaining the electric current flow. The brushes make contact with a split conducting ring called the *commutator*. What is the function of the commutator and why is it split down the middle?

   ____

   ____

3. Connect the battery to your motor and start it rotating. Can you make it turn in either a clockwise or a counter-clockwise direction? How?

   ____

   Does it matter which contact is connected to the positive terminal of the battery and which is negative? Try reversing the contacts.

   ____

Questions

For each of the following statements, indicate whether it is true or false.

1. A compass needle is a permanent magnet. ___________

2. When the electricity from a battery passes through a coil of wire a magnetic field is sit up around the wire. ___________

3. When the North poles of two magnets are close together they will attract each other. __________

4. When the South poles of two magnets are close together they will repel each other. __________

5. The North Pole of a permanent magnet will not attract the South Pole of an electromagnet. ________

6. The conducting wire used for the motor windings had to have an insulating coating. __________

7. The armature is that part of the motor which has a rotating magnetic field. ________

8. The earth acts as a huge magnet. ________

9. Changing the direction of the current flow through a coil will change the polarity of this electromagnet. _________

10. The main purpose of the motor brushes is to keep the commutator segments clean. _______

11. A motor has two magnetic fields: the armature and the field. Both fields must change polarity for the motor to run. ___________

12. Like poles attract while unlike poles repel. ________

Objectives:

- Given one or more definitions, supply the vocabulary word(s) from the list [Interference (Constructive or Destructive), Beats, Standing Waves, Doppler effect, Bow or Shock Wave, Fundamental Frequency, Harmonic] that best matches each definition.
- Describe the conditions for constructive and destructive interference.
- Sketch a standing wave in a string. Explain how it results from interference and describe the relationship between wavelength and the spacing of the nodes and antinodes.
- Explain the connection between standing waves and musical tones, both in pitch and timbre.
- Describe the relationship between the fundamental and the overtones in the harmonic sequence.
- Diagram the Doppler effect and a shock wave. Explain how the pitch of a sound varies with the relative motion of the source and observer.

Reading Assignment: Conceptual Physical Science, 2nd Edition, Paul G. Hewitt, John Suchocki, Leslie A. Hewitt. Chapter 10, Sections 7 - 13.
Suggested Homework Assignment: Conceptual Physical Science, Chapter 10, Review Questions: 34, 37, 39, 40 and Exercise 13.

The preceding session introduced several examples of wave motion: mechanical waves in a spring, water waves, sound and light. In the first two examples, the wave characteristics can be easily observed. You can see the crests and troughs or the compressions and rarefactions, and observe the amplitude and velocity of the waves. But how about the latter two examples? You can't see the wave motion of sound waves or light. Is there a unique wave characteristic that can be used to demonstrate conclusively the wave nature of these phenomena? Is there a single property common to all waves, and only demonstrated by waves? The answer is yes, and that property is interference: the ability of waves to combine in ways that can produce either reinforcement or cancellation. It was the interference pattern produce by Thomas Young's double-slit experiment that established the wave properties of light; it was the interference pattern produced by a beam of electrons when reflected off the atoms in a crystal that demonstrated the wave properties associated with particles; and it is the interference patterns produced in vibrating strings and air columns that result in the music we hear. Interference is the key to establishing the presence of wave motion. Interference patterns are the subject of this lesson.

Begin by sketching a sine wave on the chalkboard, suggesting that it represents a wave in a string or rope. Then, using a different colored chalk, sketch another identical wave on the same axis, one that is one-half wavelength out of phase with the first. Show that at every point the displacement in the positive direction is exactly cancelled by an equal displacement in the opposite direction. The result is complete cancellation, or *destructive interference.* Now sketch two waves of equal amplitude and wavelength that are exactly in phase. Show that at every point the resultant displacement would be twice that of one of the individual waves. The result is reinforcement, or *constructive interference*, producing a wave of greater amplitude.

Switch to a pair of speakers driven by a single oscillator as an example of a two-dimensional interference. Have students block one ear and move their heads slowly from side-to-side. Even with the additional reflections from the walls, the maximums and nulls can be heard. (Set the frequency to 1-2 KHz range and experiment with the spacing of the speakers to make sure that the maximums and minimums are close enough together for students to be able to hear the variation as they move their heads.) Be aware that students may have difficulty making the connection between the waves you sketched on the board and the variations in sound intensity that they hear. Remind them of the relationship between loudness and amplitude in a sound wave. Point out that the locations where they hear minimums are locations where the sound waves reaching their ears from the two speakers are one-half wavelength out of phase, and the locations where the sound is loudest correspond to the points where the two waves are in phase. Overhead transparencies, a ripple tank or film loops illustrating interference in water waves can be helpful in bridging the gap between the one-dimensional waves sketched on the board and the sound interference pattern.

Standing waves are sometimes approached as a topic separate from interference patterns but, in fact, they can be viewed as another example of constructive and destructive interference. Just as was the case in the interference examples above, standing waves consist of locations where two waves combine to produce a minimum and other locations where the resulting combination of two waves has a maximum amplitude. The standing wave patterns produced in vibrating strings and air columns are the result of interference between incident waves and reflected waves, traveling in opposite directions. The order of presentation suggested in this guide emphasizes the connection between interference and standing waves by beginning with the concept of interference, then progressing to standing waves, and finally to resonance.

You can show an example of standing waves by holding a coiled spring or rope, fixed at both ends, and then moving one end up and down at the right frequency to produce a standing wave. Explain that the standing wave is the interference pattern produced by the wave you are creating and the reflected wave coming back from the other end of the spring or rope. Then point out that it is also an example of resonance, since a standing wave will only occur if there is exactly the right relationship between the incident and reflected waves so that they always cancel or reinforce each other at the same points. Demonstrate that there are other possible standing wave patterns by shaking the end up and down twice as fast, generating a pattern with a null point in the middle. The first pattern you produced is called the fundamental. It will have the lowest frequency and the longest wavelength possible. The other frequencies that can form standing waves are whole number multiples of the fundamental frequency. The higher frequencies are termed overtones. This very special set of frequencies is called the harmonic sequence. Stringed musical instruments produce this same sequence. Wind musical instruments also produce standing acoustical waves that are similar. This leads naturally to a discussion of the role of overtones in determining the quality of musical tones.

Students are familiar with the Doppler effect (although they may not know its name) from the commonly experienced shift in the pitch of a car horn or siren as it passes by. Sketch the change in wavelength that occurs as a source moves or, as an activity, have the students use a compass to draw the Doppler and the shock wave patterns as shown by the author. Quiz them on how the pitch changes as the source approaches them and recedes. Does it go up or down? Does that agree with the wavelength change in the sketch? Ask them what would happen if the source were stationary and they were moving. What if they were moving at the same speed as the source? Discuss how speed can be measured using the Doppler shift. Point out that this is how the radar guns used by the police work. They compare the wavelength (frequency) of the signal they send out with the wavelength reflected back by the vehicle that they are clocking. The difference is used to find the speed.

Demonstrations

As an alternative or supplement to the sound interference demonstration suggested above, try the out of phase speaker combination described in the text. Don't explain the set up at first; just show how the sound varies as you move the speakers. Make sure the sound source is monophonic, not stereo, or the cancellation won't be as dramatic. Then explain the phase relationship and why you always want to make sure that the speaker leads in your home music system are connected correctly.

Mechanical resonance can be demonstrated with a pendulum. Start by shaking the support point back and forth at high speed. The bob will hardly move, and its motion will be in the opposite direction of the shake (180 degree phase shift). Now move the support point very slowly. Again there will be little response, and this time the bob will move in the same direction as the shaking (zero degrees phase shift). Finally, move the support point at different frequencies until a large amplitude is achieved. Compare the frequency of this motion with the natural frequency of the pendulum when it is allowed to swing freely.

A pair of matched tuning forks (with resonance boxes fastened to the bottom) can create acoustical resonance. Explain that the boxes are themselves adjusted in length to resonate at the frequency of the tuning forks. The boxes are usually closed at one end and open at the other end. This produces a resonant wavelength equal to four times the length of the box.

Standing waves in a string can be demonstrated by attaching a string (about one meter in length works well) to a light weight and hanging the weight over a pulley. Drive the other end of the string with a vibrator connected to an audio oscillator. By experimenting with different weights and frequency ranges, you should be able to find a combination that will generate at least six different harmonics as you vary the frequency.

If you have a dramatic flair, you might want to try cracking the whip (literally) in your class. It takes a little practice, but when you have it down pat, use it to demonstrate a sonic boom. Explain that the "crack" is produced when the end of the whip is moving faster than the speed of sound, compressing the sound waves together. The only difference between the sound you make and that produced by the Space Shuttle or a jet aircraft is the amount of air being compressed.

Standing Waves Lab

Purpose

To illustrate the interference pattern generated by two identical sinusoidal waves traveling in opposite directions.

Introduction

Wave motion occurs in water, solids, sound and light. If a wave is reflected back and forth between two boundaries, for certain wavelengths a stable pattern forms. For the spring system in this exercise, the pattern consists of one or more "loops" in which the spring does not appear to move right or left but moves only up and down. The resultant pattern is called a "standing wave."

Equipment / Materials

A long coil spring or slinky, stopwatch, meter stick.

Procedure

1. Measure a length of about 1 to 1.5 meters of the long coil spring. Fasten one end of the spring or have a partner hold it stationary. Have the other partner snap a sharp pulse down the spring. It will reflect from the stationary end and return to the sender. After a little practice in getting a sharp pulse, measure the time it takes to make the round trip and calculate the speed of the pulse by dividing the distance traveled by the time of travel.

   Time of round trip flight = ________ seconds

   Speed = ________ meters/second

2. Now shake the free end up and down with a period (time per cycle) that corresponds to the time of flight. A large standing wave with a single loop will be established. Time ten complete cycles of this motion. Determine the average period and the reciprocal of the period (the frequency). This is the lowest frequency that generates a standing wave. It is termed the "fundamental" frequency.

   Period = _________ seconds/cycle Frequency = ________ cycles/second

   The wavelength of the wave for the fundamental is twice the distance between the two ends.
   Wavelength = ________________ meters/cycle.

The speed of the wave is the distance traveled divided by the time of travel. If you choose the wavelength as the distance traveled, then the time is the period of the wave.

Speed = (wavelength)/(period) or   Speed = (wavelength)(frequency)

Check to see that your measurements are consistent with this expression.

3. The wave you have generated lies in a plane. It is called a plane-polarized wave. You were instructed to make a vertically plane polarized wave. You can choose any plane you wish. (You can even place the spring on the floor and duplicate the plane wave motion - this gets rid of the sag of the spring because of gravity). This would produce a horizontally polarized wave. If you move your hand in a small circle with the same period, the wave will rotate exactly as a skip rope! This motion is a circularly polarized wave.

   By increasing the frequency you can generate shorter wavelengths. Determine and tabulate the wavelengths and frequencies for two, three, four, five or more standing wave loops. Prepare a graph with the measured frequencies along the vertical axis and the integer number of loops along the horizontal axis. Find the slope of the graph and compare it to the expected slope, which is the fundamental frequency. Another way of expressing this outcome is to say that the only allowed frequencies are the fundamental and integer multiples of the fundamental frequency. These frequencies form the "harmonic" sequence.

Question

Are the frequencies produced by a single string of a musical instrument harmonic? Explain.

Session 20 – Third Exam

Sample Third Exam Questions

For each definition below, enter the most appropriate word or words in the corresponding blank.

1.____________________The name for the effect describing the shift in the apparent frequency of a wave due to motion of the source and/or observer.

2. ___________________The generation of an electric field when a magnetic field changes with time.

3. ___________________The time it takes a vibration or wave to complete one cycle.

4.____________________An electrical circuit in which the same current flows through all of the circuit elements.

5.____________________The quantity equal to the product of the current times the voltage in an electrical circuit.

6.____________________A type of wave in which the transmitting medium moves at-right angles to the direction of wave motion.

7.____________________The distance traveled by a wave in one period.

8.____________________A distribution of charge on a neutral body such that the charges are aligned so that one side has a slight positive charge and the other has a slight negative charge.

9.____________________An atom with an excess or deficiency of electrons.

10.___________________The charge carriers responsible for current flow in most conductors.

11.___________________A magnet whose field is produced by an electric current.

12.___________________The change in wave direction when entering a medium where the wave speed changes.

13.___________________The type of wave formed in water when the source of the wave travels faster than the wave itself.

14.____________________The wave pattern generated by the interference of identical waves traveling in the opposite directions..)

15.____________________The wave property that is the inverse of frequency.

MULTIPLE CHOICE / TRUE-FALSE

For each item below, enter the letter corresponding to the correct answer in the blank provided

16.______A current-carrying wire experiences a force perpendicular to the wire when placed in a magnetic field.
A. True B. False.

17.______A current-carrying wire experiences a force perpendicular to the field when placed in a magnetic field.
A. True B. False.

18.______Ohm's Law applies to both alternating and direct current circuits.
A. True B. False.

19.______The pitch of a sound is depends on its
A. speed B. frequency C. amplitude D. all of these.

20.______An ambulance is approaching you, sounding its siren. Compared to the normal pitch of the siren, the pitch that you hear is:
A. higher B. lower C. the same
D. higher or lower, depending on the speed of the ambulance.

21.______All waves transport energy.
A. True B. False.

22.______Only light waves can exhibit interference.
A. True B. False.

23.______The current flowing through a 60 watt, 120-volt light bulb when it is lighted is:
A. 2 amps B. ½ amp C. 7200 amps D. 4 amps.

You are given two objects, A and B, and asked to determine whether or not they are charged. To determine this, you rub a rubber rod with fur, giving it a negative charge:

24.______Object A is attracted to the rod. This indicates that A may be:
A. positively charged B. negatively charged
C. neutral D. either positively charged or neutral

25.______Object B is repelled by the rod. This indicates that B may be:

A. positively charged   B. negatively charged
C. neutral   D. either positively charged or neutral

26.______If brought close together without touching, the action of object B on object A would be:
A. attraction   B. repulsion
C. no action   D. unpredictable

A string, 3 meters long and fixed at both ends, is illustrated below. It vibrates with a fundamental frequency of 200 Hz.

end X---X end

27. Sketch the standing wave for the second harmonic on the diagram above.

28. Find the wavelength of the fundamental _________________________'

The circle below represents the cross-section of a current-carrying wire. Assume the wire carries a current perpendicular to the paper, pointing toward you.

29. Sketch the magnetic field lines due to the current, indicating their direction.

30. Indicate with an arrow at the point X the direction the north pole of a compass needle would point if the compass were placed there.

X

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Instructor Guide Session 21 Light Waves

Objectives:

- Given one or more definitions, supply the vocabulary word(s) from the list [Electromagnetic Wave, Electromagnetic Spectrum, Frequency, Wavelength, Transparent, Opaque, Transverse Wave] that best matches each definition.
- Relate the production of electromagnetic waves to vibrating charges.
- Identify and order the regions of the electromagnetic spectrum in terms of frequency or wavelength
- Describe the transmission of light through matter and explain why some wavelengths are transmitted while others are not.
- Explain why light travels slower in a material than in a vacuum

Reading Assignment: Conceptual Physical Science, 2nd Edition, Paul G. Hewitt, John Suchocki, Leslie A. Hewitt. Chapter 11, Sections 1 - 3.
Suggested Homework Assignment: Conceptual Physical Science, Chapter 11, Review Questions: 3, 6, 9; Exercises: 4, 8.

This lesson focuses on the link between electricity, magnetism and light, providing a bridge to the next major topic, *optics,* the study of light and its properties. This link was first clearly established in 1865 when a twenty-four year old Scottish physicist, James Maxwell, published a theory that demonstrated the links between electricity and magnetism. In addition, it suggested the existence of electromagnetic waves that were capable of transmitting energy through space. Maxwell found that these waves would travel at a speed equal to the velocity of light, thus suggesting for the first time that light was electromagnetic in nature. Maxwell’s theory stands as one of the crowning achievements of nineteenth century physics. By demonstrating the existence of electromagnetic radiation that could carry energy, it put these invisible fields on an equal footing with matter in our picture of the universe.

Invisible waves in invisible fields are not easy to visualize, so you need to spend some time helping your students with this. Begin with Hewitt's illustration of "shaking" a charged rod back and forth. If you didn’t do the charged rubber rod demonstration in the electrostatics lesson, you might wish to do so now. Otherwise, remind the students of what they saw and draw a sketch on the board of the rod with field lines emanating from it. Then ask them to imagine the “kink” you could put in the lines if you quickly jerked the rod up and down. Draw the kink and compare it to the ripple you would create on a water surface if you dipped a stick into it. Have your students visualize the kink moving away from the rod in the same way that the ripple would move away from the stick. Draw the kink in several locations as it moves away. Then have them think of the ripple pattern produced if you continued dipping the stick in the water, producing a series of waves. Suggest that you could generate the same sort of pattern in the electric field by continuing to move the rod up and down – so an electric charge that oscillates back and forth produces waves in the field.

Point out that a moving charge represents an electrical current and, since an electrical current produces a magnetic field, an oscillating charge will also generate an oscillating magnetic field. As the electric and magnetic waves travel through space, the changing magnetic field induces a changing electric field, which in turn induces a changing magnetic field, and so on. Explain that these oscillating fields constitute what is known as electromagnetic radiation. All electromagnetic radiation originates from vibrating charges, and the frequency of oscillation of the radiation is equal to the vibrational frequency of the charges.

Move on to a discussion of the electromagnetic spectrum. A wall chart or overhead projection of the spectrum will be helpful as you describe the various regions. Remind the students of what an extremely small part of the spectrum light represents, and that we are "blind" to all of the other forms of electromagnetic radiation, even though they differ from light only in frequency. Discuss the vibrating charges that produce the different kinds of electromagnetic radiation: oscillating currents in antennas for radio and television waves, vibrating molecules for infrared radiation, electron vibrations in atoms for visible, ultraviolet and x-rays, etc. Point out the correlation between the size of the sources and the wavelength of the waves -- from large antennas for the long wavelength radio waves, to the sub-atomic level for the very short waves in the visible region and beyond. Again, emphasize that all of the electromagnetic spectrum originates in oscillating charges and that all of the regions are identical except for frequency (and wavelength).

Hewitt's discussion of light transmission as a process of absorption and re-emission is an excellent model for explaining why some materials transmit light and others absorb all or parts of it. Students are intrigued by the idea that the light they see when looking through a window is not the light striking the outer surface, but in fact is light emitted from the inner surface after many absorptions and re-emissions. State that light waves travel at one fixed speed, 3×10^8 m/s, but their average speed when passing through matter is slower because of the absorption and re-emission.

You can extend this idea further by pointing out that when they are outside light must travel through air to reach them, so even then the light they see coming from an object is not the light that left its surface. Both air and glass are transparent to light, but since air has are fewer atoms per meter to absorb and re-emit the light as it passes through, the speed of light in air differs very little from its speed in empty space.

Talk about the idea of a glass window (transparent for visible light) and a wall (opaque). Extend this to, for example, the radio range, where the wall becomes transparent. Discuss the major atmospheric window (high transmission at a wavelength of 10 microns) and its effect on the heat balance of the earth

Demonstrations

Shine light through a prism to produce a spectrum. Use a photometer or connect a solar cell to a current meter to detect the various colors. Demonstrate that the detector picks up radiation beyond the red (infrared). Cover the detector with a "window" of glass and show that visible light passes through the glass but that infrared does not pass so easily. Use this demonstration to illustrate Hewitt’s discussion of molecular vibrations and thermal energy. Point out the connection between the absorption of light by opaque materials and temperature increase.

Objectives:

- Given one or more definitions, supply the vocabulary word(s) from the list [Selective Reflection, Selective Transmission, Additive Primaries, Subtractive Primaries, Complementary colors] that best matches each definition.
- Relate the frequency (and wavelength) of light to color.
- Describe and explain the different results of color mixing by addition and by pigment mixing. Explain the effect of illumination on the apparent color of an object.
- Draw and label a diagram that connects the additive primary colors Red, Green and Blue, with the colors Magenta, Cyan and Yellow.
- Determine the result of the combination of any two of the colors mentioned in above.
- Explain why the sky is blue, the clouds white, and the sunset red.

Reading Assignment: Conceptual Physical Science, 2nd Edition, Paul G. Hewitt, John Suchocki, Leslie A. Hewitt. Chapter 11, Section 3
Suggested Homework Assignment: Conceptual Physical Science, Chapter 11, Review Questions 15, 18, 28, 33 and Exercise: 20.

Students generally respond with enthusiasm to the material on color. This is another lesson that adapts well to a presentation consisting primarily of a series of demonstrations and questions directed to the students, with less formal lecture. Spend time on the idea of selective reflection and demonstrate the effect of changing illumination on the apparent color of objects. Roses, as described by Hewitt, are good objects for a demonstration because of the rather narrow range of frequencies reflected by the petals and the leaves. Describe selective reflection in terms of the resonance model used in the previous discussion of light absorption and transmission. Emphasize that it is the <u>resonant</u> frequencies that are being absorbed, not reflected. Discuss why leaves are green and what colors the chlorophyll must be absorbing.

Additive color mixing is a good classroom demonstration. You can use a commercial unit, such as the Sargent Welch Color apparatus, or overhead projectors as described in the Demonstration section below. Explain that the additive primary colors are determined by the structure of our eyes. While we recognize a wide range of colors, this perception is the result of the only three kinds of color receptors in our eyes -- one responding most strongly to red, one responding most strongly to green, and one responding most strongly to blue. Our brain combines the signals coming from these receptors and generates the perceived colors. It is this combining of colors that the demonstration replicates.

The text mentions color subtraction but has only a very limited discussion, even though this is the type of color mixing we most commonly experience in paints and printed materials. Since the prospective teachers in your class may also teach some art, this topic needs to be explained and linked to color addition. The Part IV suggested readings in the back of the book are a good source for expansion of this topic. There are commercial units for the demonstration of the subtractive primary colors (the Sargent Welch Filtergraph, for example), or you might even mix watercolors on an overhead projector as a demonstration.

Why is the sky blue, why are sunsets red, and why are the clouds white? If your students are prospective elementary school teachers, they'd better be able to answer those questions, hadn't they? The resonance model of light transmission again provides a good description of these effects. Point out the relationship between the size of the scattering particles and the wavelengths scattered. This accounts for the varying "blueness" of the sky at different times and different locations. Note that the sunset (and sunrise) colors are just the "leftovers" in the light after the scattering particles are through with it. Also point out that you can also see this effect for the rising and setting moon. (Sometimes quite dramatically when the moon is full.) Connect the relationship between the whiteness of the clouds and the size of the water droplets to the apparent whiteness of steam, automobile exhausts and cigarette smoke; and the larger collection of droplets that produce the darkness in storm clouds to the darker color that is sometimes seen in the smoke from factories or the exhaust from poorly tuned cars.

If time permits, discuss the differential response of the human eye to light intensity – why colors appear "washed out" or absent in moonlight, why most stars appear white to the naked eye but display colors in photographs taken through telescopes, and why we don't see quite as clearly in dim light. (Because vision in dim light is primarily due to the rods, which are not as closely spaced on the retina as the cones).

Demonstrations

In addition to the commercial demonstration equipment mentioned above, you might try the following.

Bring in the Sunday funnies and have the students look at the pictures with a 3X lens and note the four colors. Also have them bring in a packet of US postal stamps - they have three colored dots on a test strip at the bottom of the stamps. Sometimes the local newspapers have four-color transparency separations of a photograph that they are willing to donate. This allows you to assemble the full color picture in four steps. You can also vary the order of the steps and show the effect.

Use three overhead projectors with appropriate filters to repeat the traditional color addition pattern (red, green, blue). Where they overlap you should see white light. Place an obstruction, such as your hand, in the beams so that you create <u>three</u> shadows of the obstruction. Ask the students to explain why the shadows have the colors magenta, yellow, and cyan.

To approximate the blue sky-red sunset effect, fill a two-gallon aquarium tank with water and add a little powdered milk to scatter light. Shine a bright flashlight or other white light source through the length of the tank. Turn it so that the students are looking at the light scattered perpendicular to light beam. It should have a pale bluish cast. Then turn the tank (or the light beam) so that the students see it end-on. It should have a dingy reddish cast. The larger size of the scattering particles prevents this demonstration from reproducing the scattered and transmitted colors accurately.

Color Lab

Purpose

To observe the spectrum produced by an incandescent light source and demonstrate the factors that determine the perceived colors of objects.

Introduction

As a freshman at Cambridge College, Isaac Newton performed a fundamental experiment on the nature of light. By passing sunlight through a prism, he demonstrated that white light could be dispersed into its component colors, red through violet. He then reversed the process by passing this spectrum through a second prism, recombining it into white light. Later experiments found that white light could also be dispersed into its components by a diffraction grating, a series of closely spaced lines etched onto a transparent surface such as glass or plastic. However, unlike a prism, a grating cannot be used to put the component wavelengths back together again.

The colors we perceive are determined by the response of our eyes to different wavelengths of light. We see light at the long wavelength end of the spectrum as red. As the wavelength of light decreases, the other colors of the spectrum are perceived. After red, the next longest wavelengths are seen as orange, then yellow, green, blue, and finally violet, the shortest visible wavelength.

Equipment / Materials

A prism and/or a diffraction grating, continuous light source (clear light bulb) plus a Variac to control the current, a set of absorption filters (Magenta, Yellow and Cyan; Red, Blue and Green). Some colored photographs, flowers etc.

Procedure

Start by looking through the grating (or prism) at the distribution of colors from the sun and from a clear light bulb (See warning below).

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WARNING! Some light sources, such as the sun, emit invisible ultraviolet rays that are harmful to your eyes. Do not stare directly at the source. If you are using a grating to examine the colors of the source, a simple trick will help you avoid injury. Normally you look directly through the transmission grating at the source, then off to the side (to the left or right) to see the colors. Put your hand out in front of you so that it blocks the source completely. Now, slide the grating slowly to the left (or right) while continuing to look through the grating. You will eventually see the color distribution of the source. Your eyes are more protected since the intensity of the light is reduced and the radiation is spread out laterally in the spectrum.

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1. The grating presents the colors in the order of increasing wavelength. Violet is the shortest wavelength while red is the longest wavelength. Observe and record the effect of lowering the voltage on the light bulb in terms of the distribution of colors. As you dim the light, how does the color of the filament change?

   ____

   As you dim the light, which color(s) in the spectrum dim(s) the most?

   ____

   Which color(s) remain(s) the brightest? ____________________

   The terms "white-hot" and "red-hot" are often used to describe the temperature of heated metals. Based on what you've observed, which of these to temperatures do you think would be the highest?

   ____

2. Now, observe the continuous spectrum from a white light bulb again, only this time look at the spectrum through each of the six filters. The filters pass selected bands of colors through while blocking other colors. The filter themselves have a color. For instance, the red filter transmits red light while absorbing the other regions of the spectrum. Record your observations:

   Red _________________ Green _______________

   Blue _________________

   Magenta ____________ Yellow ______________

   Cyan _______________

   Take each of the set of three absorption filters and overlap them pair-wise over a sheet of white paper. Record the combinations.

   Red & Green __________ Green & Blue __________

   Red & Blue __________

   Magenta & Yellow ________ Yellow & Cyan ___________

Magenta & Cyan __________

Examine a number of items using the two absorption filter sets. One would expect that a green leaf is green because it scatters (and transmits) green light effectively. A leaf should look bright when viewed through a green filter. Find a filter that makes the leaf look dark (non reflective, absorbing).

3. Finally, shine a beam of white light through a small fish tank of water (or a glass of water). Look at it straight on and from the side. Describe what you see:

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   Add some drops of milk to the water and repeat you observations. Describe what you see.

   ____.

   The milk scatters the light (just as the particles in the filters). Small particles suspended in the atmosphere have the same effect. The scattering is most pronounced when the light travels the longest possible path (morning, evening).

Questions

1. The sky is blue because of the selective scattering. Explain why the sun looks reddish yellow at sunset.

2. Describe how color photographs are printed using only magenta, yellow, cyan (and black).

Instructor Guide Session 23 Interference, Polarization

Objectives:

- Given one or more definitions, supply the vocabulary word(s) from the list [Constructive Interference, Destructive Interference, Superposition, Iridescence, Plane-Polarized] that best matches each definition.
- Describe the effect of wavelength on the diffraction pattern produced by an opening.
- Sketch the superposition of two identical waves in one and two dimensions and describe the conditions for constructive and destructive interference.
- Describe how the spacing of maximums and minimums in a two-source interference pattern varies with wavelength.
- Explain how colors are produced from thin film interference.
- Diagram the effect of light passing through (two) polarizing filters.

Reading Assignment: Conceptual Physical Science, 2nd Edition, Paul G. Hewitt, John Suchocki, Leslie A. Hewitt. Chapter 11, Sections 4 - 6.
Suggested Homework Assignment: Conceptual Physical Science, Chapter 11, Review Questions 40, 44, 46; Exercises: 34, 39

This will be your students' second exposure to interference. Take advantage of this by beginning with a brief review of what they've already learned. Sketch sine waves on the board representing the conditions for constructive and destructive interference as you did before. Remind the students that waves that are in phase combine constructively, while those that differ by one-half wavelength, or any odd integral multiple of one-half wavelength, will cancel. Review the two-source interference pattern using the overhead transparency or ripple tank that you used in Session 19 and have the class compare this pattern to Young's sketch, as shown in the text. Ask them visualize the pattern as representing light waves. Point to locations where two wave crests overlap and ask them how the light intensity there would compare to that of a single source. Now point to a location where a wave crest overlaps a trough and ask them what they would see at that point.

Show a light inference pattern using a bright light source such as a sodium vapor lamp, or a laser with the beam spread as described below. Shine the light through two narrow slits and display the pattern on a wall or screen. If possible, use two different slit spacings to show the effect this has on the pattern. (You can make these slits by coating microscope slides with black paint and carefully making thin scratches on them with a razor blade.)

Point out that since the conditions for constructive and destructive interference depend on wavelength, different colors will have maximums at different locations. Blow soap bubbles for the class (or preferably, let them do it) and have them observe the rainbow colors in the bubbles. Then describe thin film interference and the relationship between film thickness and the interference pattern. Explain that they can see the same patterns on oil slicks and lenses that have anti-reflective coatings (some of your students may be wearing eyeglasses with these coatings).

Since you've begun your class presentation with a discussion of interference, you can now treat diffraction as just another illustration of an interference pattern, albeit a pattern produced by a very large number of sources distributed everywhere across the opening. Emphasize the relationship between wavelength, the size of the opening, and the size of the diffraction maximum. Use this relationship to explain why you can hear sound through a window or door, even if you aren't in the direct line-of-sight of the source.

In discussing polarization, tell the students that all electromagnetic radiation is polarized along the direction of motion of the source when it is produced. However, since most of the light we see is being produced by very large numbers of electrons vibrating in all directions, it has no preferred direction and is unpolarized. Some materials transmit light preferentially in one direction and can produce polarization. Reflection can also produce polarization, since the electrons reflecting the light are constrained to move parallel to the reflecting surface. Reflected light is thus polarized parallel to the surface causing the reflection.

Demonstrate polarization using two crossed polarizing filters. Explain that polarization is a property of transverse waves only, thus light can be polarized, but not sound. The usual polarizing filter-analyzer demonstration involves rotating the analyzer. Be sure to rotate through a complete 360 degrees. Further, spin the analyzer (or filter) about a diameter that lies along its symmetry axis to emphasize the bilateral symmetry of the polarization devices. Point out that polarized sunglass lenses are used to cut down the amount of reflected light from water, glass and other reflecting surfaces, while ordinary sunglasses just reduce the total light intensity.

Demonstrations

An alternative to Young's two-slit experiment is to generate the two sources from the two surfaces of a thin film. With a small laser, use a short focal length lens (a microscope objective, for example) to spread out the beam. Place a card with a small hole in it near the focal point of the lens. Allow the beam to fall on an optically flat glass slab, which is oriented perpendicular to the beam, so that light falls back on the card. A symmetric Fresnel "bullseye" pattern can be observed. Repeat with a thin sheet of glass such as microscope slide - the pattern will be more irregular and will reveal the small variation in thickness of the slide.

Demonstrate diffraction by having the students hold two adjacent fingers vertically and then look through the small space between them at a monochromatic source such as a laser spot on the wall. They can observe what happens when the fingers are slowly squeezed together. Also have them rotate the fingers to a horizontal position.

Inexpensive replica transmission gratings (Edmond Scientific is one supplier) can be handed out to the class to demonstrate multiple-slit interference. Have them look at several different light sources – a white light and gas discharge tubes.

Place some optically active material such as mica, Mylar or cellophane between crossed Polaroid filters. Crumple the Mylar or cellophane to make sure the thickness varies. Use an overhead projector to show the resulting rotation of the polarization axis. Rotating one of the filters will produce a varying pattern of colors.

Place a photograph or drawing under a piece of clear acrylic plastic. Arrange a light source to produce a strong glare on the surface of the plastic. Then have students rotate a Polaroid filter (old sunglass lenses will do) until the glare is blocked and the picture can be seen clearly. Ask them what the direction of the polarization axis of the filter is at that point.

Objectives:

- Given one or more definitions, supply the vocabulary word(s) from the list [Regular Reflection, Diffuse Reflection, Refraction, Refractive Index, Dispersion] that best match each definition.
- Sketch the reflection from a plane mirror. Show that the image in the mirror will be at the same distance behind the mirror as the original object was in front.
- Describe the relationship between the angle of refraction and the speeding up or slowing down of a light ray.
- Diagram and describe a mirage and the effect of atmospheric refraction on the setting sun.
- Explain the formation of a rainbow.
- Describe the image forming properties of positive and negative lenses, and of concave and convex mirrors.

Reading Assignment: Conceptual Physical Science, 2nd Edition, Paul G. Hewitt, John Suchocki, Leslie A. Hewitt. Chapter 12, Sections 1 - 5.
Suggested Homework Assignment: Conceptual Physical Science, Chapter 12, Review Questions: 4, 8, 11, 20, and Exercise 16.

Up until this point the behavior of light has been described in terms of its wave properties, but for many applications, including simple lenses and mirrors, it is more convenient to use a ray model. Changing to a picture of light rays traveling in straight lines may at first appear confusing to students, especially as the text switches back to the wave model from time to time, as in its treatment of refraction, for example. To help students make the connection between the two models, draw a series of plane wave fronts on the board. State that the light rays represent the direction the waves are traveling and use a different color of chalk to draw an arrow through the waves representing a ray. Point out that it is perpendicular to the wave fronts. Then do the same thing for a series of concentric circular waves radiating out from a source. Draw several rays in different directions pointing out radially from the source and show that these too are always perpendicular to the wave fronts.

Move on to the law of reflection and compare the behavior of a light ray to a ball bouncing off a wall. To show image formation by a mirror, use a flat piece of uncoated plastic or glass as a partially reflecting mirror. It has the advantage of reflecting light and, at the same time, allowing you to see behind the surface. Darken the room and place a bright light source in front of the mirror. Hold up a small light behind the mirror. Have the students tell you when the (virtual) image of the bright source and the small source coincide. Establish that the mirror produces an image of the source directly behind the mirror and at the same distance. Introduce a ray diagram that supports the relationship between object and image location.

Emphasize the relationship between the angle of refraction and the change in velocity of the light. As a ray strikes a surface where its speed changes, its direction also changes. For example, as a ray moves from air to glass it will bend in the direction of the normal. Applying symmetry, we expect that if the ray moves from the glass into the air, it will bend away from the normal. The rays will follow the same path in both cases. Since the rays coming from the air must lie in the range from zero to 90 degrees, then the refracted rays must lie in the range from zero to some maximum angle, A, less than 90 degrees (since the refracted ray is bent toward the normal). If the direction of the rays is reversed, then at an incident angle equal to A, the refracted angle will be 90 degrees. For an incident angle greater than A no ray can escape. This is the case of total internal reflection.

Connect the refractive diagram for a mirage with the atmospheric refractive diagram for the position of the sun. In the case of the mirage, light from the sky is bent away from the hot surface of the ground toward cooler air. The light ray bends toward the more dense air. The wave is slower in the higher density air. When you look down toward the ground it looks wet and shiny. You are looking at an image of a portion of the sky refracted upward from the ground. In the example of the setting of the sun, the light from the sun, which would pass overhead, is bent toward the more dense air. This makes the image of the setting sun appear to be higher in the sky.

Starting with a ray diagram of an object and its image in a plain mirror makes it easy to transition to a curved mirror. The simplest case to understand is to draw a mirror that has been slightly bent into a convex shape. Draw the normals to this curved surface at several points. Then sketch incoming rays and the reflected rays showing that the image position must be closer to the surface of the mirror.

Trace a single light ray through a prism, showing that it will always be refracted toward the base. Then remind students that the amount of refraction depends on the change in velocity. Since the speed of light is less for violet light than for red light in a refracting medium, they will be refracted different amounts or *dispersed.*

To introduce the imaging properties of lenses, trace two parallel rays through two prisms placed base to base. Show that the rays will be bent toward each other and converge. Then draw a picture of the cross-section of a converging (positive) lens and suggest that it will produce the same sort of effect. Repeat this for two prisms placed apex to apex and compare the result to a diverging (negative) lens.

Group the optical elements that have the same imaging properties together: start with a convex mirror and a negative lens - they only produce virtual images smaller than the object. The images are oriented in the same direction as the object. The more complex case is that of a concave mirror or a positive lens - they both can produce real, inverted images that can be smaller, larger, or the same size as the object - and they can produce virtual images larger than the object, oriented in the same direction as the object. Concentrate on the image forming properties rather than on either the shape (concave, convex etc.) or on the mechanism (reflection, refraction).

Demonstrations

To explain the reflecting property of a flat mirror, show the students a block print of a simple word, such as TAO (the way of the mirror!) on a transparency. Place a white sheet behind it. Hold it in front of a mirror and show it to the group. Ask them to predict what they will see in the mirror. Has the mirror "reversed” the lettering? Remove the white backing. Let them see that they read the word TAO on the transparency and that the image formed by the mirror also reads TAO. Now in slow motion turn the transparency 180 degrees. They will read OAT on the transparency and see that the image formed by the mirror also reads OAT. The law of the mirror is that the mirror produces an image that is a contact print of what is placed in front of it.

Place a short focal length lens (a microscope objective) in front of a small laser. Place a long piece (or better yet a spool) of plastic fiber optic so that the end of the fiber is at the focal point of the lens. The fiber will light up along its entire length. The scattering is from imperfections that reduce the transmission of the light trapped by total internal reflection.

Fill a two-gallon aquarium tank with water. Add a little powdered dry milk to scatter the light. Shine a laser beam down onto the surface at angle to show refraction after the beam enters the water. To demonstrate total internal reflection, place a mirror at the bottom of the tank so that light reflected from the mirror strikes the water surface at an angle greater than the critical angle. Shift the laser beam so that the angle is less than the critical angle and the light emerges from the water surface.

Use a large positive lens to project the image of a light source on a wall or screen. Demonstrate that there is no position for a diverging lens that will also produce an image.

Plane Mirror Lab

Purpose

To illustrate the image forming properties of a mirror and introduce the ray model.

Introduction

Although light has wave properties, its wave behavior is not always apparent. Whenever the obstacles or openings that light waves encounter are large as compared to their wavelength, light can be represented by rays traveling in straight lines from their source. This is certainly the case in most everyday applications of lenses and mirrors, and the ray model is the approach we will use in the study of reflection and refraction.

Equipment / Materials

A partially reflecting mirror in the form of a thin plastic or glass sheet (~4" x 6") and a holder (putty or clay works) to keep sheet upright (Half a plastic audio tape holder will work fine and it stands up on its own), a small flashlight-size light bulb or LED mounted about 2" above the tabletop and facing horizontally, a battery for the light source, a ruler or straight edge and a large (~3'x3') sheet of butcher style paper.

Procedure

1. Tape butcher paper to a tabletop and draw a line at 45 ^{o} diagonal across its surface. Position the partially reflecting mirror along the line near its center. Place the light source about 6" directly in front of the mirror. Mark the position of the source and label it S1. Look into the mirror at the image of the source. Move a pencil behind the mirror and adjust its position so that it coincides with the image of the source. Mark the position of the image and label it I1. Select a half dozen other scattered source positions (continuing to label them S2, S3, etc.) and find and label the corresponding image positions. What is the relationship between the location of the source and the location of the image?

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2. Cut a narrow slot in a 3"x5" card. Place the card in front of the mirror with the slot at the center of the mirror. Mark the slot position on the paper. Place the source at one of your previous positions but not directly in front of the mirror. Draw a line on the paper starting from the source and ending at the location of the slot. Draw an arrowhead at the slot position. The line with the arrowhead represents the flow of light from the source to the mirror (it is a "ray" of light). Now, look through the mirror and locate the image. Mark on the paper the position of your eye when you are able to see the image. Draw a line starting at the position of the slot and ending with

an arrowhead at the position of your eye. The line represents the flow of light that is reflected from the mirror. Draw a line perpendicular to the mirror at the location of the slot. How do the angles made with this perpendicular by the two rays compare?

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Move the slot to one edge of the mirror and repeat the procedure that produces a ray diagram, then move the slot to the other edge of the mirror and repeat the procedure a third time. You will have three rays coming from the mirror. Use a straight edge to trace the rays back behind the mirror, using dotted lines for the extension of the rays behind the mirror. The dotted lines are called *virtual* rays as they represent the apparent paths of the reflected rays, not the actual paths of the rays. They should converge (cross) at the same point. How does this point compare to the location of the image?

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Questions

1. In the ray model, does the light flow from the image through the mirror? Can you trace the light flow from the image by means of a 3"x5" card?

2. What is the difference between a real and a virtual ray? Draw an example of each.

Objectives:

- Given one or more definitions, supply the vocabulary word(s) from the list [Photoelectric Effect, Photons, Quantum, Atomic Spectra, Ground State] that best matches each definition.
- Identify the wave model predictions for the photoelectric effect that are contradicted by the experimental results. Explain how these results are consistent with the quantum model.
- Use the Bohr model of the atom to explain the emission of light as photons. Relate the frequency of the light emitted to energy level transitions in the atom.
- Describe the wave properties associated with particles and the relationship between wavelength and the momentum of a particle.

Reading Assignment: Conceptual Physical Science, 2nd Edition, Paul G. Hewitt, John Suchocki, Leslie A. Hewitt, Chapter 12, Section 6 and Chapter 13, Sections 5 and 6.
Suggested Homework Assignment: Conceptual Physical Science, Chapter 12, Review Questions: 35, 36 and Exercise 42, Chapter 13, Review Question 24 and Exercises 22, 24.

The wave model described in the preceding lessons can successfully account for the transmission, reflection and refraction of light, and for the interference properties it exhibits. However, this is not the complete story. When light interacts with matter another model is needed. The emission or absorption of light only occurs in discrete amounts of energy. So in these interactions with matter light behaves as if it consisted of tiny particles, or *photons*.

Stress the point that these two models are not in competition. They apply in different circumstances. The wave and particle models of the behavior of light are complementary: Light behaves as a particle when it is emitted from a source or absorbed, but it behaves as a wave while traveling through space from its source. This dual behavior may raise the question in your students' minds as to what light <u>really</u> is. (Certainly it raised this question in the minds of many scientists over the years). Perhaps the most accurate answer is that what light <u>really</u> is, is *light*. What the wave and particle models are describing is its *behavior*, not its *nature*. In other words, light is something that exhibits wave properties under certain conditions, and particle properties under other conditions. Moreover, this behavior is not unique to light. As Louis de Broglie first suggested, all those things that we've been calling particles -- electrons, atoms, all matter -- also exhibit this duality. They all have associated wave properties.

To introduce the concept of photons, describe the photoelectric effect results predicted by the wave theory: Electrons would not always be immediately observed when light strikes the metal; it would take time to build up the energy from the incident wave before electrons started to be emitted (compare this to boiling off water molecules as steam); increasing the intensity (amplitude) of the light would increase the energy (velocity) of the ejected electrons; and waves of different color (frequency), but with equal intensity, would, on the average, carry the same energy and would produce the same energy in the ejected electrons.

Then state the experimental results. The speed of response appears to be instantaneous, faster than the best instrumentation. Varying the intensity over six orders of magnitude gives the same energy for each electron. Higher intensity produces more electrons, not more energetic electrons, but color makes all the difference. Red produces no ejected electrons at all, and ultraviolet produces the highest velocity electrons.

Einstein's particle model might be presented by having the energy carried by each particle (photon) represented by a coin: red photons--> 25 cents, blue photons--> 50 cents (about twice the frequency and twice the energy.) Each photon transfers all of its energy (its coin) to an electron, but the electron must give up some energy to escape the metal. Suppose that it costs 35 cents to “get through the gate," so to speak, to get outside the metal surface. Then an electron that interacted with a blue photon would have 15 cents “change” of residual energy left after it got outside the metal. But electrons that interact with red photons could never get through the gate since they have only 25 cents of energy. They remain trapped inside the metal. This suggests that there is a threshold energy associated with the metal. To the extent that electrons only interact with single photons, an increase in the light intensity can only increase the number of excited electrons, not alter their individual energy. If the energy per photon is not great enough to overcome the threshold, no electrons will be emitted, no matter how great the intensity.

Turn now to the emission of light and the Bohr model of the atom. The first four sections of Chapter 13 are not included in the reading assignment since this lesson is focused on the emission and absorption of light, not the atomic nature of matter. You may assign them as background if you wish, but the only relevant material they contain is description of the nuclear atom and electrons. Students should already be familiar enough with these ideas that you can simply begin by drawing a picture of an electron orbiting a Hydrogen nucleus. Refer to the material from the electricity lessons and point out that the potential energy of the two charges depends on their distance of separation. Quiz the class on which is the higher energy state: an orbit closer in or one further out from the nucleus.

Describe Bohr’s picture of an electron emitting a photon by dropping from a higher (more distant) orbit to a lower orbit. Using Plank’s relationship from the photoelectric effect, explain that this would correspond to a photon of a specific frequency (color). Draw several orbits and illustrate two different transitions, a lower energy one and a higher energy transition. To help emphasize the frequency-color relationship, show the high-energy transition with a blue or violet arrow and the lower energy transition with a red arrow, as is done in the text. Show the line spectra generated by different elements, either using slides or gas discharge tubes as described below. Again, point out that each color corresponds to a different frequency and therefore to a different energy transition. Since only certain colors are observed, not a complete spectrum, only certain energy transitions are possible. The orbits are quantized.

Introduce de Broglie’s hypothesis concerning the wavelengths associated with particles and show that this could result in standing “electron waves," permitting only those orbits that corresponded to integral numbers of electron wavelengths, thus explaining Bohr’s quantized orbits. Finally, state that subsequent experiments have demonstrated these wave properties for beams of electrons and other particles. We don’t see wave properties for baseballs or golf balls because the wavelengths associated with large objects are extremely small (although some of your students who golf may think they’ve had a short putt “diffract” around the cup!).

Demonstrations

A simple Helium-Neon laser produces more intensity per unit bandwidth than any star. Shine a laser on a standard photoelectric effect cell and show that it produces no current. Then use a dim Mercury lamp or UV source and show that it easily produces a current.

Set up several gas discharge tubes (Helium, Neon and Mercury, for example). Give each student an inexpensive replica grating (source: Edmunds Scientific or Central Scientific). Have them look at each discharge tube while you point out the most prominent lines. Ask them to identify which represent higher-energy transitions and which represent lower-energy transitions.

Lens and Mirror Lab

Purpose

To illustrate the common imaging properties of a convergent (positive) lens and a convergent mirror.

Introduction

Imaging can be accomplished by several means. A lens uses refraction while a mirror uses reflection. Lenses and mirrors can be divided into two types of imaging devices: convergent or divergent.

Convergent systems take parallel light from a distant source and focus it down to a very small spot-like image. In the case of a convergent lens, sometimes called a "positive" lens by opticians, the spot is on the opposite side of the lens from the source. A convergent lens refracts (bends) the light inward to a focus. A convergent mirror will also focus light from a distant source to a point image, but in this case, the focus is reflected back to the same side as the source. Both the lens and the mirror focus light to bright spot that can be displayed on a screen. Images that can be focused on a screen are termed real images.

Divergent systems take parallel light from a distant source and spread it out as if it were radiating out from a very small spot. In the case of a divergent lens, sometimes called a "negative" lens by opticians, the spot is on the same side of the lens as the source and you must look through the lens to see the image. A divergent lens refracts (bends) the light outward from the focus. For a divergent mirror the light is reflected back to the same side as the source, but like a divergent lens, you must look into the mirror to see the image. Both the lens and the mirror produce an image that cannot be displayed on a screen. These are termed virtual images.

Equipment / Materials

Convergent lens and mirror (of approximately the same focal length), light source, screen (or 3"x4" card), meter stick.

Procedure

1. Set up a light source as far away as possible from your convergent lens. Move the screen back and forth until you find the small spot of light. Record the distance from the middle of the lens to the screen as the focal length (typically 10 to 20 centimeters). Repeat for the convergent mirror. Here a problem may arise. If you use a large screen, you may block all the light going to the mirror. Cut a screen size that is smaller than the mirror diameter and measure the focal length.

   Lens focal length f = ___________ cm

Mirror focal length f = ___________ cm

2. The focal length plays an important role in the size of the image that is formed. Set the light source so that it is <u>two</u> focal lengths away from the lens. Find the location of the image. Measure the size of the image. The magnification of the image, M, is a ratio of image size to the source size.

   Image location s' = _____ cm

   Source size = _____ cm   Image size = _____ cm

   Magnification M = ______ (no units, dimensionless)

   Now slowly move the source from a distance of two focal lengths from the lens to larger distances. Describe what happens to the image location and magnification.

   Lens: Greater than two focal lengths

   The image location

   ____

   The image Magnification

   ____

   Reset the source to a distance of two focal lengths from the lens. Very slowly move the source toward one focal length and describe what happens.

   Lens: Between two and one focal length

   The image location

   ____

   The image Magnification

   ____

3. Repeat the source movement for the mirror.

   Mirror: Greater than two focal lengths

   The image location

____

The image Magnification

____

Reset the source to a distance of two focal lengths from the mirror. Very slowly move the source toward one focal length and describe what happens.

Mirror: Between two and one focal length

The image location

____

The image Magnification

____

Questions

1. Pick a couple of source locations, one greater than the twice the focal length and one between one and two focal lengths. Measure the source locations, image locations and magnification carefully. What relationship can you find between magnification and the source and image distances?

____

2. Move the source inside the focal length. Can you focus an image on the screen? What sort of image is produced?

____

Session 26 – Fourth Exam

Sample Fourth Exam Questions

For each definition below, enter the most appropriate word or words in the corresponding blank.

1.________________The fundamental particle that characterizes light.

2.________________The central positively charged core of an atom. The place where most of the matter is located.

3.________________The bending of an oblique ray of light when it passes from one transparent medium to another.

4.________________Type of lens that always produces an image smaller than the original object.

5.________________Type of image formed by a convex mirror.

6.________________Effect in which electrons are ejected from certain metal surfaces when exposed to light.

7.________________Shape of mirror that can produce magnified images.

8.________________Type of spectrum emitted from a heated (incandescent) solid.

9.________________A type of image formed by light rays that do not converge at the location of the image.

10.______________Minimum angle of incidence for which a light ray is totally reflected within a medium.

11.______________Image formed by light rays that converge at the location of the image.

12______________The region of the electromagnetic spectrum just beyond the red part of the visible spectrum.

13______________An effect confirming the transverse nature of light waves.

14._____________ A high frequency region just beyond visible light.

15.______________ The bending of light as it passes around an obstacle or through a narrow opening.

MULTIPLE CHOICE / TRUE-FALSE.

For each item below, enter the letter corresponding to the correct answer in the blank provided.

_____16. Water waves, sound, and light all produce interference patterns.
A. True B. False.

_____17. Of the colors listed below, the one corresponding to the shortest wavelength is
A. red B. yellow C. green D. blue

_____18. All substances (including you) emit electromagnetic radiation.
A. True B. False

_____19. The photoelectric effect and blackbody radiation are best described by a
A. Wave model B. Quantum model C. Neither theory can explain both.

_____20. Radio (AM, FM), and Television are part of the same spectrum as light.
A. True B. False.

_____21. The colors seen in soap bubbles are an example of
A. reflection B. refraction C. interference D. polarization.

_____22. Doubling the frequency of a light wave reduces the wavelength to half of its original value.
A. True B. False.

_____23. Doubling the frequency of a light wave reduces the energy of a photon to half of its original value.
A. True B. False.

_____24. Complimentary colors are:
A. two colors that combine to produce cancellation.
B. two colors that combine to produce white light.
C. any two of the additive primary colors.
D. any two of the subtractive primary colors.

_____25. The blue color of the sky and the red color of the sunset are illustrations of:
A. light scattering B. light interference C. complimentary colors

_____26. According to the Bohr model of hydrogen, a given line in the hydrogen spectrum corresponds to:

A. a specific electron orbital transition.
B. a photon of a specific frequency.
C. both of the above.
D. neither of the above.

_____27. Two beams of light have the <u>same total energy per second</u>. One beam is consists of red light and the other is violet.

A. The red light consists of more photons per second.
B. The violet light consists of more photons per second.
C. They have the same number of photons per second.

_____28. The color of the light given off by an incandescent solid depends on its temperature.

A. True B. False.

_____29. Light that is polarized by reflection has its plane of polarization perpendicular to the reflecting surface.

A. True B. False.

_____30. Compared to light, when passing through an opening, radio waves diffract

A. more B. less C. the same amount.