

This course was submitted to UC Doorways 6/29/2010

FAME Public Charter School A-G Course Template

Course Title: a-g Physics w/ Lab

Prerequisites: Completion of Algebra 1 with a C or better

Brief Course Description - Briefly (in a short paragraph) describe the course focusing on content. This should look like something you would see in a course catalog. Type the information in the text box below. All text boxes will expand as needed.

This is a lab intensive introductory course in the foundations of physics. Emphasis is on the development of an understanding of physics principles, as well as problem solving with the use of mathematics. The laboratory work is designed to help students develop reasoning skills and the ability to understand and apply physics principles. The knowledge gained from the laboratory component will enable students to understand in practical and concrete ways how physics applies to our everyday lives. The study of mechanics will give insight into motion of vehicles, falling objects, friction, and spinning objects; thermodynamics studies will illuminate understanding of heat and temperature which applies to melting and freezing processes, engines and refrigerators; studies of vibrations and wave phenomena will show students how springs, pendulums and sound behave; our study of electromagnetism including electricity, magnetism and light will allow understanding of the workings of electric circuits, electrical charge, electromagnets, permanent magnets and how electricity and magnetism are related; the study of relativity will lead to an understanding that while Newton's Laws work on Earth, that there are new frontiers of exploration of physics beyond Newton that explain particle motion, particle collisions, particle accelerators, nuclear energy and space travel.

Textbooks

Include list of Primary and Secondary Texts. Make sure to note the books that will be read entirely and those that will be as excerpts. Textbook information is not necessary if your course is a Visual and Performing Arts course. Online texts or non-standard text materials should include a link to the online text.

Primary Textbooks

Title: Holt Physics

ISBN: 0030368162

Edition:

Publication Date: 2009

Publisher: Holt, Reinhardt, Winston

Author(s): Serway, Faughn

URL Resource(s):

or

Title: Physics Principles and Problems

ISBN: 0078807212

Edition: 1st

Publication Date: 2009

Publisher: Glencoe McGraw Hill

Author(s):

URL Resource(s):

Supplemental Instructional Materials - Please describe. If using online text or non-standard material, please provide the title of the material or webpage and the URL link.

Teacher's Edition ISBN for Holt Physics: 0030368170

Teacher's Edition ISBN for Physics Principles and Problems: 0078807220

Virtual Physics Laboratory

<http://www.physics.metu.edu.tr/~bucurgat/ntnujava/>

This website has over 50 physics applets, each of which is created to form the basis of a student lab experiment.

eScience Physics Lab Kit Version #3 (order number – KIT2020)

eScience Physics Lab Manual (comes on a CD Rom with kit)

www.esciencelabs.com

Course Objectives – what the students will know at the end of the course

1. To engage students in open-ended investigative processes by using scientific problem solving
2. To provide application of concepts students have seen in their study materials which reinforce and clarify scientific principles and concepts
3. To involve multiple senses in three-dimensional rather than two-dimensional learning experiences that are important for greater retention of concepts and for accommodation of different learning styles
4. To stimulate students to understand the nature of science including its unpredictability and complexity
5. To provide opportunities to engage in collaborative work and to model scientific attitudes and behaviors
6. To develop mastery of techniques and skills needed for potential science, engineering, and technology majors
7. To ensure science course transferability to four-year schools.

Course Goals and Major Student Outcomes – what the students will be able to do at the end of the course

Students will work towards mastering the California State Physics Content Standards. Student understanding of the standards will be measured by teachers, working collaboratively, to consider a multifaceted view of what constitutes a mature understanding of concepts. Upon completion of this course students will understand that:

1. Newton's law predicts the motion of most objects.
2. The laws of conservation of energy and momentum provide a way to predict and describe the movement.
3. Energy cannot be created or destroyed, although in many processes energy is transferred to the environment as heat.
4. Waves have characteristic properties that do not depend on the type of wave.
5. Electric and magnetic phenomena are related and have many practical applications.

Course Outline by Units of Study – the content you will cover arranged in units

The Science of Physics

Unit 1. The Realm of Physics

- A. Definition of Physics
- B. Measurements in experiments
- C. The language of physics

Mechanics: Motion and forces

Unit 1. Motion in One Dimension

- A. Displacement and velocity
- B. Acceleration
- C. Falling objects

Unit 2. Two-Dimensional Motion and Vectors

- A. Intro. to vectors
- B. Vector operations
- C. Projectile motion
- D. Relative motion

Unit 3. Forces and the Laws of Motion

- A. Changes in motion
- B. Newton's first law
- C. Newton's second and third laws
- D. Everyday forces

Unit 4. Work and Energy

- A. Work
- B. Energy
- C. Conservation of energy
- D. Work, energy, and power

Conservation of Energy and Momentum

Unit 1. Momentum and Collisions

- A. Momentum and impulse
- B. Conservation of momentum
- C. Elastic and inelastic collisions

Mechanics: Motion and forces

Unit 5. Rotational Motion and the Law of Gravity

- A. Measuring rotational motion
- B. Tangential and centripetal acceleration
- C. Causes of circular motion

Unit 6. Rotational Equilibrium and Dynamics

- A. Torque
- B. Rotation and inertia
- C. Rotational dynamics
- D. Simple machines

Heat and Thermodynamics

Unit 1. Heat

- A. Temperature
- B. Defining heat

- C. Changes in temperature and phase
- D. Controlling heat

Unit 2. Thermodynamics

- A. Relationships between heat and work
- B. Thermodynamic processes
- C. Efficiency of heat engines
- D. Entropy

Waves

Unit 1. Vibrations and Waves

- A. Simple harmonic motion
- B. Measuring simple harmonic motion
- C. Properties of waves
- D. Wave interactions

Unit 2. Sound

- A. Sound waves
- B. Sound intensity and resonance
- C. Harmonics

Unit 3. Light and Reflection

- A. Electromagnetic spectrum
- B. Polarization

Unit 4. Refraction

- A. Refraction

Unit 5. Interference and Diffraction

- A. Interference
- B. Diffraction

Electricity and Magnetism

Unit 1. Electric Forces and Fields

- A. Electric charge
- B. Electric force
- C. The electric field

Unit 2. Electrical Energy and Capacitance

- A. Electrical potential energy
- B. Potential difference
- C. Capacitance

Unit 3. Current and Resistance

- A. Electric current
- B. Resistance
- C. Electric power

Unit 4. Circuits and Circuit Elements

- A. Schematic diagrams and circuits
- B. Resistors in series or in parallel
- C. Complex resistor combinations

Unit 5. Magnetism

- A. Magnets and magnetic fields

- B. Electromagnetism and magnetic domains
- C. Magnetic force

Unit 6. Introduction and Alternating Current

- A. Induced current
- B. Alternating current, generator, and motors
- C. Inductance

Special Relativity

Unit 1. Special Relativity

- A. Relativity of time
- B. Calculating time dilation
- C. Experimental verification

Laboratory Activities

Laboratory Activities and Objectives

Lab: Scientific Method

- Understand how to make testable observations
- Understand the roles of a hypothesis and null hypothesis
- Understand how to conduct a successful experiment
- Understand the role of variables and control in an experiment
- Understand the importance of organized data collection
- Recognize what makes a successful analysis

CA STANDARDS for this lab:

Investigation & Experimentation - Grades 9 To 12

Science Content Standards.

1. Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing the content in the other four strands, students should develop their own questions and perform investigations. Students will:
 - a. Select and use appropriate tools and technology (such as computer-linked probes, spreadsheets, and graphing calculators) to perform tests, collect data, analyze relationships, and display data.
 - d. Formulate explanations by using logic and evidence.

Lab -The Black Box :

The *Scientific Method* is a logical, practical, reliable way of gaining knowledge. It is also a method used to answer questions. This method turns discovery science into hypothesis-driven inquiry. Every person uses the scientific method constantly to make decisions throughout their life.

Often in science what we study cannot be seen. Electrons, protons, and neutrons, for example, can't be seen but we can do experiments to prove their existence. In this experiment you and your partner will try to figure out what is inside a sealed black film box by doing your own experiments. You may NOT open the boxes! Remember to use all of your senses, except taste, when trying to figure out what is inside the container. Follow the directions carefully before you proceed. **Work in groups of 4 for this

lab.

Purpose: The purpose of this lab is to use the scientific method to figure out what is in the sealed box without opening it.

Materials: sealed empty box; various small objects

Equipment: balance, spring scale, magnets

Observations: List the observations that you can make about the sealed box.

Hypothesis: Our hypothesis is that there is a _____ in the sealed box.

*Decide criteria to accept/reject Design controls **Must be testable*

List step-by-step the procedures that you used to test your hypothesis. Collect data – must be qualitative and quantitative

1.

2.

3.

4.

5.

6.

7.

8.

Observations & Results: *Analyze results Summarize findings*

What do you think is inside the sealed box? What else can you do to find out without opening it?

Discussion/Conclusions: *Conclude whether hypothesis was supported or rejected*

Conclude what is in the box if you can, and tell your findings to instructor. Open your container. Were you correct? If you were wrong, what may have led you to the wrong conclusion?

Lab: Test Galileo's Hypothesis: Scientific Method

- Understand how to make testable observations
- Understand the roles of a hypothesis and null hypothesis
- Understand how to conduct a successful experiment
- Understand the role of variables and control in an experiment
- Understand the importance of organized data collection
- Recognize what makes a successful analysis

CA Physics Standard for this lab:

Investigation & Experimentation

Science Content Standards.

2. Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing the content in the other four strands, students should develop their own questions and perform investigations. Students will:
 - a. Identify and communicate sources of unavoidable experimental error.
 - b. Identify possible reasons for inconsistent results, such as sources of error or uncontrolled conditions.
 - c. Recognize the usefulness and limitations of models and theories as scientific representations of reality.
 - d. Know that when an observation does not agree with an accepted scientific theory, the observation is sometimes mistaken or fraudulent (e.g., the Piltdown Man fossil or unidentified flying objects) and that the theory is sometimes wrong (e.g., the Ptolemaic model of the movement of the Sun, Moon, and planets).

Lab: Test Galileo's Hypothesis

Galileo modeled the behavior of falling objects in order to develop a hypothesis about how objects fall. At the time Galileo published his work on falling objects, in 1638, scientists believed that a heavy object would fall faster than a lighter object. This is often referred to as Galileo's "thought experiment".

Purpose:

Illustrate the arguments for an against Galileo's "thought experiment".

Materials: pennies, tape, coffee filters, deep and clear container, water

Procedure: Stack 10 pennies and tape them together. Hold 1 penny in one hand and hold the stack of pennies in the other hand. Drop them simultaneously. Students listen carefully and decide which object hits the ground first. (It should be difficult to detect any difference in the falling time.)

Hold 1 coffee filter in one hand and a stack of 10 filters in the other hand; drop them simultaneously. This time, it should be easy to see that 10 filters fall faster than one. How could Galileo defend his hypothesis in the face of such evidence? (He identified the role of air resistance).

To demonstrate the concept of air resistance, show how water resists falling objects. The same principle applies in air:

Fill the clear container with water, and drop the single penny and the 10-penny stack into the water simultaneously. This time, the single penny will land on the bottom last. Have students use these experiments to defend or criticize the argument that heavy bodies fall faster than light ones.

Lab: Measurement (using stations with different equipment at each station)

- Learn how to use significant figures and understand their importance
- Make effective and useful measurements in a physics lab
- Compare accuracy versus precision
- Understand the meaning of significant digits
- Calculate accuracy

Measurements

Purpose: Give Students an overview of measurement concepts.

Materials: An assortment of measuring instruments including rulers, measuring tapes, various clocks, timers, metronomes, various bathroom scales, pan balance with standard masses, electronic balance, beam balance, thermometers of various sizes and ranges, ammeter, protractors, graduated cylinders of various sizes, measuring cups.

Procedure: Display the various instruments on lab tables arranged as stations. Class members are divided into teams. Each team starts at a different station. Every 7 minutes students rotate to a new station.

Some of the stations:

Lab station 1: measuring length.

Goal: determine the length of each of several objects. Students choose from ruler, tape measure, caliper and record weight using proper SI unit (mm, cm, m)

Lab station 2: measuring mass.

Goal: determine the mass of each of several objects. Students choose from electronic balance and triple-beam balance to determine mass in SI units (g, kg)

Lab station 3: measuring temperature

Goal: determine the temperature of each of several objects. Students measure the temperature of a hot liquid, a room temperature liquid, and a liquid cooled by ice using a variety of types of thermometer.

Lab station 4: measuring time: Students use clocks and stopwatch to measure elapsed time in seconds of a metronome which makes a certain number of "clicks" at several settings. Object is to compare the metronome timing with the other methods of timing.

Lab station 5: measuring volume: Students use measuring cups, and beakers, and graduated

cylinders to measure several amounts of water.

DATA TABLE: students record results on a data table using correct units.

Lab: Displacement

CA Physics Standard 1 a

Motion and Forces

1. Newton's laws predict the motion of most objects. As a basis for understanding this concept:

a. **Constant speed and average speed:** Students know how to solve problems that involve constant speed and average speed. Chapter 2. Sec.1 p. 45 (Average speed); 125-126 constant velocity, p.45-50 graphs

LAB: Direction of Displacement

Purpose: Demonstrate the importance of direction in reference to displacement.

Average speed equals displacement divided by time interval. Average velocity requires taking direction of motion into account.

Materials: One meter stick, 3 pieces of modeling clay, toothpicks, or paper clips, one toy car.

Procedure: Place the meter stick on edge so that the 0 mark is to the students' left and the students can see the numbers. Put the toothpick in one of the pieces of modeling clay to represent the initial position.

For positive displacement, place the initial position marker and car somewhere between 0 and 10 cm. Roll the car down the meter stick to some point past the 50cm mark and place the final position marker (the second piece of modeling clay) at the new position of the car.

Question for students: Calculate the displacement of the car. (It should be a positive number.)

For negative displacement, move the initial position marker to the car, and roll the car back toward the zero end of the meter stick. Stop the car and place the 3rd position marker.

Question for students: Calculate the displacement for the second leg of the trip. (It should be a negative number.)

Question for students: Calculate the car's total displacement

LAB: Relative Motion/ Frame of Reference

CA Standard:

Motion and Forces

2. Newton's laws predict the motion of most objects. As a basis for understanding this concept:
- a. **Constant speed and average speed:** Students know how to solve problems that involve constant speed and average speed.

Virtual Lab "Relative Motion" (frame of reference)

<http://www.physics.metu.edu.tr/~bucurgat/ntnujava/relativeVelocity/relativeVelocity.html>

An object may appear to have one motion to one observer and a different motion to a second observer, depending on how the two observers are moving with respect to one another. This java applet let the student view objects from different frames of reference.

The applet shows a river in the center of the screen (yellow dots are moving with water) a red boat is also moving with respect to the river. There is a person(blue) walking close to one side of the river, (S)he can swim across the river. The student can easily change frame of reference by moving his/her mouse to different regions. e.g. If mouse is moved within the river, the student becomes an observer moving with water. If mouse moved into the boat region, student becomes a "passenger" on the boat watching other objects move. The student can walk along with the virtual person, or just standing there on the ground.

Instructions:

1. Click red boat, blue person, yellow dot in water.

A. Red Boat: when you are "riding in" the red boat, what does the MOTION of the river (yellow dots) and the person (blue) look like to you?

B. Blue person: when you are "walking with" the blue person, what does the MOTION of the river (yellow dots) and the boat (blue) look like to you?

C. Yellow Dots River: When you float with the current, what does the MOTION of the boat seem like, and the blue person?

LAB Newton's First Law

CA STANDARD:

Motion and Forces

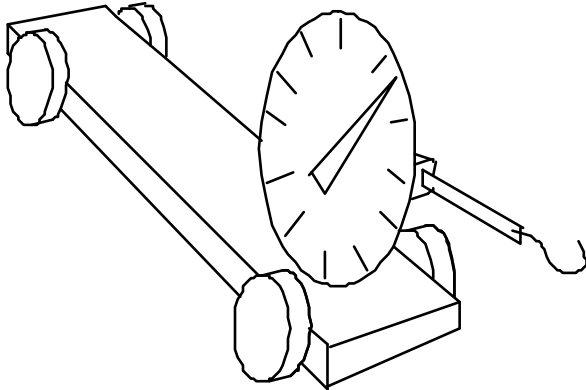
California Physics Standard 1b.

1. Newton's laws predict the motion of most objects.

As a basis for understanding this concept:

b. Students know when forces are balanced no acceleration occurs, and thus an object continues to move at a constant speed or stays at rest (Newton's First Law).

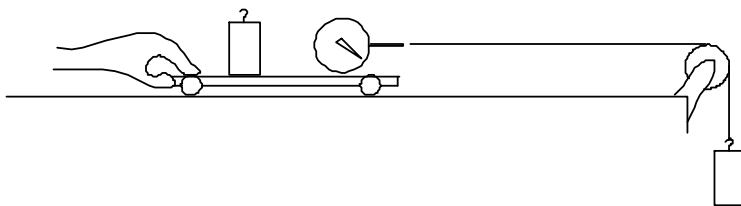
A very useful demonstration device to use frequently when discussing Newton laws is a low friction cart with a large spring balance attached.



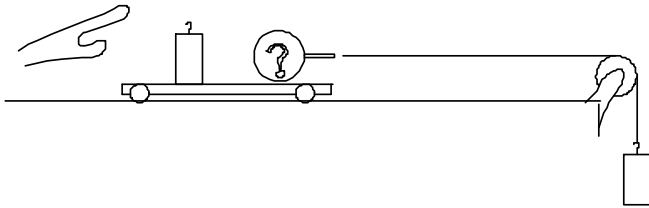
The wheels should be fairly frictionless and the entire cart should be able to support several kilogram masses. (A modified skateboard might work.) This cart can be used for quick demonstrations of the effect of changing mass and force on the acceleration of objects. With the cart loaded with several kilograms, a large force can be shown to accelerate it but when the force drops to zero, the cart will continue at about the same speed as when the force dropped to zero. If the approximate mass of the cart is determined (easy to do by using its spring balance to weigh itself and divide by “g”) quick qualitative demonstrations of Newton’s second law can be demonstrated.

low friction cart with a large spring balance attached. The wheels should be fairly frictionless and the entire cart should be able to support several kilogram masses. (A modified skateboard might work.) This cart can be used for quick demonstrations of the effect of changing mass and force on the acceleration of objects. With the cart loaded with several kilograms, a large force can be shown to accelerate it but when the force drops to zero, the cart will continue at about the same speed as when the force dropped to zero. If the approximate mass of the cart is determined (easy to do by using its spring balance to weigh itself and divide by “g”) quick qualitative demonstrations of Newton’s second law can be demonstrated.

A very simple demonstration to use with the “spring balance cart” that should help students to begin thinking about the meaning of balanced and unbalanced forces is to hold the cart as a hanging mass extends the scale giving a reading.



The students may realize that the scale reads the weight of the hanging mass but the important question is to ask is: “What will the scale read just after you release the cart?”



Many will conclude that now that the cart is accelerating, more force is required without appreciating that the forces were originally in opposite directions and the spring balance appeared to be measuring only the force supplied by the hanging mass.

When the cart is released, only the force supplied by the “hanging” mass is applied but since this mass is now accelerating downward, the tension in the string (as measured by the spring balance) must necessarily be reduced.

The next step in the discussion might be to have the students analyze the forces acting on the hanging mass before and after it begins accelerating downward.

LAB: Position, Velocity, and Acceleration Vectors

CA STANDARD:

Motion and Forces

California Physics Standard 1j.

1. Newton's laws predict the motion of most objects. As a basis for understanding this concept:

j. * **Vectors, components and sums:** Students know how to resolve two-dimensional vectors into their components and calculate the magnitude and direction of a vector from its components. **Chapter 3, Section 1 and 2, p 80-94**

Virtual Lab:

<http://www.physics.metu.edu.tr/~bucurgat/ntnujava/FreeRolling/FreeRolling.html>

Position, velocity and acceleration vectors: Free Rolling and Circular Motion

This applet shows the position, velocity and acceleration vectors of a point on the rim of a body rolling without slipping on a stationary surface.

1. The term freely rolling means that there is no slipping ($v=rw$) at the point of contact with the ground

--no skidding ($v>rw$) and no spinning in place ($w>v/r$),

where v,r and w are the linear speed, radius and

the angular speed of the rolling body.

2. The center of the wheel has a linear speed (with respect to ground)

equal to that of any point on its rim (with respect to center).

3. For circular motion (in the reference frame

moving with the velocity of the center of the rolling body) :

The acceleration a of a point always points in a direction

opposite the position vector r ,

and the velocity vector V is perpendicular to both of them.

4. Observe the velocity vectors of a point on the rim of the rolling body.

The white vector represents the velocity of the center with respect to ground and

the red vector represents the velocity of the point

with respect to the center.

The sum of these two vectors is the cyan vector

representing velocity of the point relative to ground.

5. The green curve shows the trajectory of a point on the rim.

Question #1: What is the angle between the vectors tangent to the circle and the circle?

Question #2: If this tangent represents instantaneous velocity of a motorcycle

driving in a circle, what does it tell us about acceleration when an object moves in a circle? (refer back to the definition of acceleration).

Question #3 What is the angle between the radius of the circle and the vector representing velocity around the circle.

Question #4 In the free rolling wheel, what path does the center of the wheel follow and what is its velocity vector?

LAB Newton's Second Law

CA STANDARD:

Motion and Forces

California Physics Standard 1c.

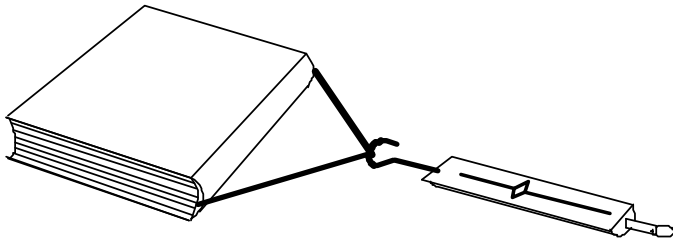
1. Newton's laws predict the motion of most objects.

As a basis for understanding this concept:

c. Students know to apply the law $F=ma$ to solve one-dimensional motion problems involving constant forces (Newton's Second Law).

LAB to introduce Newton's second law.

The following activity involves a minimum of equipment and will introduce students to the essential idea behind Newton's second law and give some idea of the influence of the force of friction. The equipment required is several books (it's best if they are all the same), a piece of string and a spring balance (or "force meter"), a meter stick and a stopwatch.



The basic idea behind the experiment is to measure the force necessary to pull a book across a tabletop at constant velocity and then increase this force by a measured amount and measure the resulting acceleration. More books can be piled on top of the first book to investigate how this increases the friction force and how the increased mass influences the force required to accelerate this mass.

Students should learn that a larger force is required to overcome standing friction than is required to move the book at constant velocity. They should also come to appreciate that the unbalanced force required to accelerate the book is the difference between the force required to move the book at constant velocity and the larger force required to accelerate it. Calculating the acceleration can be made from measuring the time for the book to move from rest while accelerating a measured distance. (Simply applying $s = \frac{1}{2}at^2$ will give an average acceleration). The results from this activity are not too accurate but the experience with such simple equipment can give rise to lots of discussions about the basics of friction and how an unbalanced force is required to cause a mass to

accelerate.

LAB Newton's Third Law

CA STANDARD:

Motion and Forces

California Physics Standard 1d

1. Newton's laws predict the motion of most objects.

As a basis for understanding this concept:

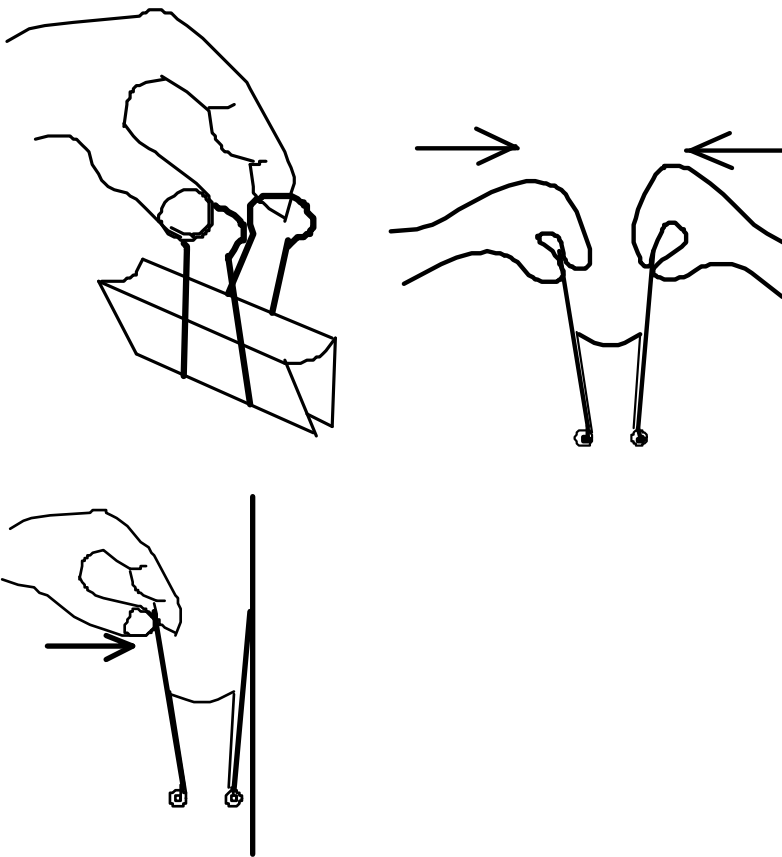
d. Students know when one object exerts a force on a second object, the second object always exerts a force of equal magnitude and opposite direction. (Newton's Third Law).

LAB Newton's Third Law:

Safety equipment required: SAFETY GOGGLES

Activity to show that for every action force, there is an equal and opposite reaction force.

It is probably best if students work in pairs. The only equipment required for each pair is a binder clip and a rubber band. When you open a binder clip you always push in one direction with your thumb and the opposite direction with your finger. These are equal and opposite forces.



Now try to open the binder clip having your partner push on one side of the clip and you on the other. (Carefully—don't let the clip slip and pop into someone's face!) If you are careful, you can do it. You and your partner are supplying equal and opposite forces and the clip will open.

How could just one person open the clip by only pushing on one side of the clip?

If you placed one side of the clip against a wall or down on the surface of a table, you could open the clip by pushing only on the other side. But what must the wall be doing to the other side of the clip? Just as your partner had to push on the other side of the clip to open it, so must the wall be pushing on the clip to open it. The amazing thing about Newton's third law is that on the one hand it is so simple but on the other if you don't appreciate that it is always true, you might not understand how walls and tables can push. The law also works for pulling (after all, a force is a push or a pull) and you can verify this by repeating the above experiments except by pulling on a rubber band.

LAB Effect of Gravity on objects at Surface of Earth

CA STANDARD:

Motion and Forces

California Physics Standard 1e

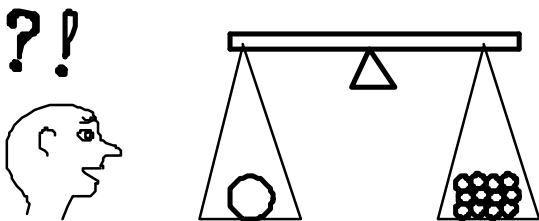
1. Newton's laws predict the motion of most objects.

As a basis for understanding this concept:

e. The relationship between the universal law of gravitation and the effect of gravity on an object at the surface of the Earth.

(Note: Framework is not concerned with the law of universal gravitation in this section. The only discussion is of objects falling with constant acceleration near the surface of the earth. If you are interested in the law of universal gravitation, see 1 m*.)

LAB: Drop objects of different weights



This is a demonstration of dropping two objects of different weight at the same time to compare the time it takes for them to reach the floor. I have a 1.5" steel sphere and a 0.5" steel sphere and start the discussion by asking: "how many of the smaller spheres will it take to weigh the same as the larger sphere?"

I have been amazed to learn how few students can give the correct answer. For dramatic effect I set up a simple balance and with a large number of the smaller steel spheres and establish that about 27 of the smaller spheres are required to weigh as much as the larger sphere.

After establishing the ratio of the masses of the two objects you plan to drop (27 in the case above) discuss with your students if they think the larger object will fall "27" times faster than the smaller object. They probably will disagree but this was one of the arguments Galileo suggests in his famous cannon ball vs. musket ball dialogue. Galileo even suggests the cannon ball will fall slightly faster but certainly not by a difference suggested by the ratio of their weights. When you

perform the simple dropping experiment, they should strike the floor at almost the same time (repeat for effect and be aware that letting go at even a slightly different time will influence the results.)

When all students are convinced that large objects and small objects fall at nearly the same rate of acceleration, have them discuss in groups why they think this is true.

An intuitive argument might suggest a large object would be expected to fall faster. But the large object also has more inertia hence would be expected to require more force to accelerate it. The amazing truth that whatever gives a larger object a larger force of attraction to the earth, also gives it a larger inertia, hence a larger resistance to acceleration. Newton found it truly amazing that the weight and inertia were always in the same ratio.

California Physics Standard 1f

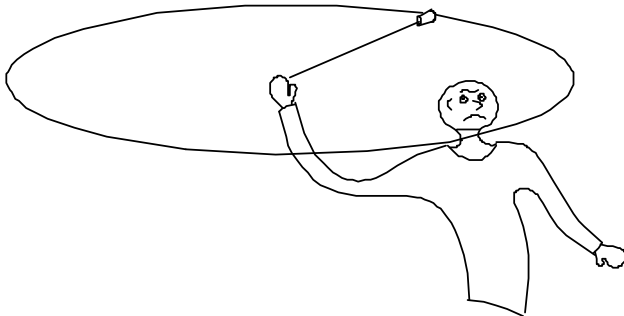
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As a basis for understanding this concept:

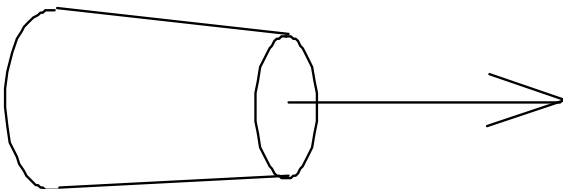
f. Students know applying a force to an object perpendicular to the direction of its motion causes the object to change direction but not speed (for example, the Earth's gravitational force causes a satellite in a circular orbit to change direction but not speed).

LAB: Stopper on a string

Materials: rubber stopper, string



A rubber stopper on a string is constantly useful when illustrating assorted concepts in circular motion. Since it is rubber, if you are careful, you can release it at an appropriate time and demonstrate that it will move off in a straight-line tangent to the curve at the point of release. It is advised that you arrange to have the stopper directly in front of you facing the class when you release it. Students who feel that the “outward centrifugal force” will cause the stopper to move at the class will be surprised to see it move off at a tangent, continuing in the same direction as it was going when released. As you rotate the stopper at constant speed, ask the class: “What must be the direction of the force the string is pulling on the stopper as I pull it into this circular path?”

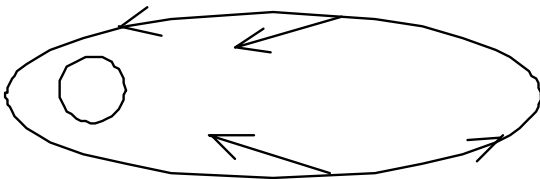


As you swing it around, emphasize how you are pulling on the string to keep the stopper turning in the circle and should you stop pulling at any time, the stopper will move off in a straight line.

Another simple demonstration that is lots of fun is to place a marble or a small steel ball inside of a metal can and race the marble around in the can by rapidly shaking you hand. Ask the students: “What is the direction of the force that the can must exert on the marble to keep it moving in a circle inside of the can?”

The Standard suggests discussing how the gravitational force acts at right angles to a satellite’s motion as it moves about the earth. However, this is true only if the satellite moves in a circular path. It would be very instructive to discuss what happens to the satellite when the gravitational force is not at right angles to its motion and, say, has a component of force tangent to its direction of motion. The illustration shows a satellite moving around the earth in top view. The motion of the satellite is counter clockwise.

When the satellite is in the “top” part of its orbit and moving to the left, the force of gravity has a component in its direction of motion and thus speeds the satellite up. Likewise when the satellite is in the “bottom” part of its orbit and moving to the right, a component of the force of gravity is against its direction of motion, slowing it down.



California Physics Standard 1g

1. Newton's laws predict the motion of most objects.

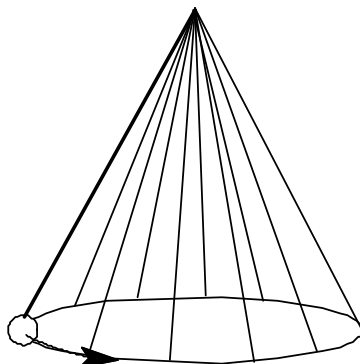
As a basis for understanding this concept:

g. Students know circular motion requires application of a constant force directed toward the center of the circle. (Note: Here the Standard means “constant” in magnitude only since a change in direction obviously changes the force.)

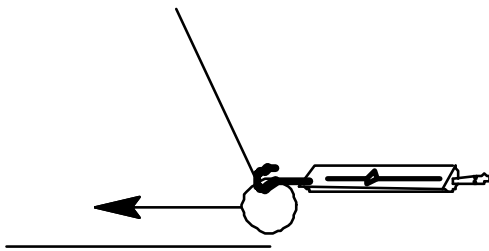
LAB: Conical Pendulum

The conical pendulum lab to study centripetal force.

A simple lab that gives reasonably good results involves the use of a “conical pendulum.” The essential equipment is a pendulum about 1 meter long, a meter stick, a clock with a sweep second



hand or a stop watch.



If basic trigonometry is a challenge, a spring balance can be used to eliminate the need for trig. The basic idea behind the lab is to set the pendulum moving in a circle so that the string of the pendulum sweeps out a cone. (Several launches may be necessary to have the pendulum move in a circle.) If the pendulum is near the floor, the radius of the circle can be measured and the time it takes for the pendulum to make a recorded number of cycles can be measured. Since the friction is so low, the orbits will repeat many times without appreciable decrease in the radius of the orbit. The experiment can be repeated using several different radii of the launch orbit. (Warning, students will not expect the period to come out the same no matter the radius!)

At this point, with a little trig, there is enough data to test the basic expression for centripetal acceleration. Classes without trig can use a spring balance to weigh the pendulum bob (dividing by “g” will yield its mass) and then use the spring balance to pull the bob aside to the assorted radii used earlier. This will give the inward directed force hence making it possible to compare with $F = m V_T^2/r$.

California Physics Standard 1g

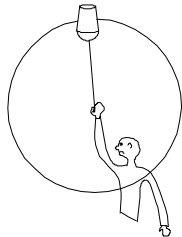
1. Newton's laws predict the motion of most objects.

As a basis for understanding this concept:

g. Students know circular motion requires application of a constant force directed toward the center of the circle. (Note: Here the Standard means “constant” in magnitude only since a change in direction obviously changes the force.)

LAB: Water bucket

A great demonstration is to place water into a bucket, or can you have fixed with a bail and attached to a string, and whirl it in a vertical circle at a fast enough speed to prevent the water from falling out. However, it is best to discuss with the class before you do the demonstration the rate you must accelerate the bucket downward in a straight line so that the bucket and the water fall at the same rate. (Students need to know that linear acceleration and centripetal acceleration are the same thing.)



California Physics Standard 1 i

1. Newton's laws predict the motion of most objects.

As a basis for understanding this concept, students know:

i. * How to solve two-dimensional trajectory problems

LAB: Monkey and Hunter

The idea behind the demonstration is that a gun is carefully aimed at a “monkey” that will drop from a “tree” exactly when the gun is fired. The bullet will always intercept the falling “monkey” no matter the initial speed of the bullet—as long as the bullet reaches the monkey while in flight. The gun is a blowgun consisting of a cylindrical tube with a close fitting steel ball. The end of the gun has an electrical contact that will break the circuit to an electromagnet when the steel ball leaves the barrel. The gun must be rigidly clamped and aimed precisely at the “monkey” while it hangs from the electromagnet. Since the time of flight of the bullet is exactly the same as the “monkey”, the bullet will fall away from its straight line path exactly the same distance that the “monkey” falls, insuring a hit.

California Physics Standard 1 k

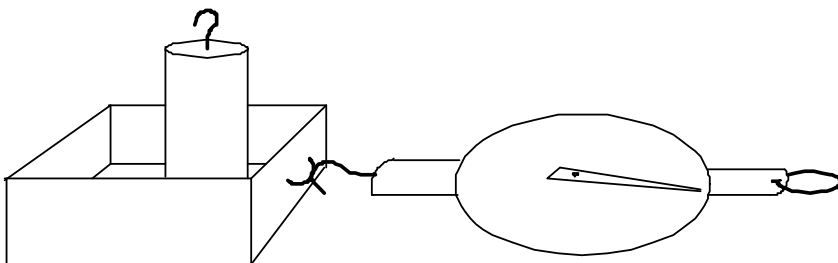
1. Newton's laws predict the motion of most objects.

As a basis for understanding this concept:

k* Students know how to solve two-dimensional problems involving balanced forces (statics).

LAB: STATIC FRICTION and KINETIC FRICTION

A simple demonstration of most aspects of friction can be made using a small cardboard box large enough to hold 4 cylindrical kilogram masses. Place a wire hook on one end of the box so a demonstration spring balance can easily pull it. With this device you can demonstrate how an increased normal force influences the force of sliding friction by simply loading more kilogram masses (that weigh “10 N”) into the box and observing the linear increase in the force required to pull the box. It also clearly shows the difference between static and sliding friction since as long as the box is not moving, you can apply any force. However, after it starts to move, the force will drop to a lower value and remain essentially the same no matter how fast you move it at constant velocity. Alternatively students can use spring balances and drag books.



California Physics Standard 1 k

1. Newton's laws predict the motion of most objects.

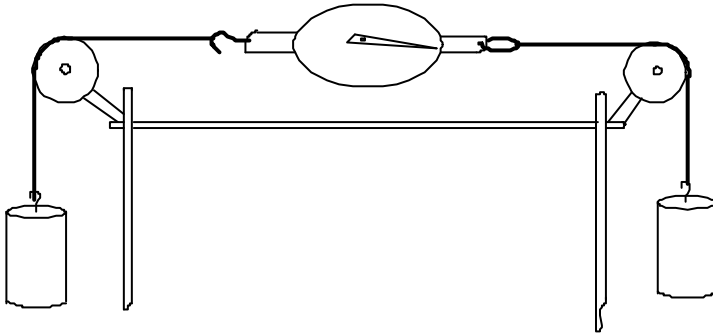
As a basis for understanding this concept:

k* Students know how to solve two-dimensional problems involving balanced forces (statics).

LAB: Tension

The concept of tension can be a little confusing when first encountered. To appreciate that this, “force of a string”, always pulls away from the object it is attached to yet at any point on the string it is equal and in opposite directions, requires a little thought and familiarity. The following demonstration might help students to come to a better understanding of tension.

With two low friction pulleys held apart using ring stand supports as illustrated, hook a string to either side of a large spring balance and pass these strings over the pulleys and have them support a kilogram mass on either end. Turn the spring balance so the students can't see what it reads and ask them for their conclusion as to the reading on the scale. (Before doing this demonstration, it is well to show the students what each mass weighs.)



Have the students vote as to their individual feelings about what the scale will read. Past experience suggests that you will get three answers: twice the weight of a single mass, the weight of a single mass and zero. Other answers can appear but these three are the most common. As you discuss why the reading is the weight of the mass, remind them of all the forces on the spring balance when you simply weigh the mass. (It is easy to forget that you are pulling up on the spring balance as the mass pulls down.)

California Physics Standard 1 k

1. Newton's laws predict the motion of most objects.

As a basis for understanding this concept:

k* Students know how to solve two-dimensional problems involving balanced forces (statics).

LAB: Tension, the impossibility of pulling a string perfectly horizontal

A typical problem involving tension (discussed in the California Science Framework) involves the tension in the support strings on a hanging picture. There are several ways to approach this problem, two of which are illustrated here. One is to look at the forces acting on the nail supporting the picture (illustrated above the picture.) The upward force must be the weight of the picture and assuming the tension in the string is the same on both sides and the angles are equal, it is easy to show: $2T\sin\theta = W$. Another way to look at this problem is illustrated to the right of the picture. Assuming that the right support holds half the weight of the picture, the vertical component of the

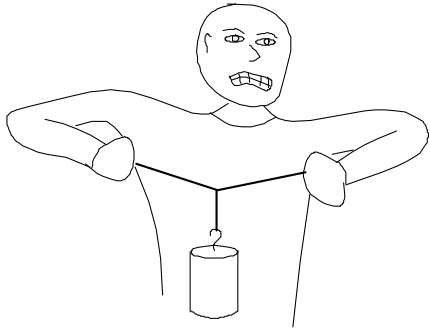
tension is given by:

$$T \sin \theta = 1/2 W.$$

A practical consequence of this is that telephone lines are always stretched with some droop between poles. Apparently, was this not the case, in winter, accumulations of ice could weight down the wires to an extent that the wires could break.

The hanging picture example can lead to a question: "Would it be possible to support the picture with the string straight and parallel to the floor?" That is, what happens to the tension in the string if we try to make θ zero?

This question quickly leads to the inverted question: Is it possible, by pulling outward to pull a string supporting a weight into a straight horizontal line. Finally, there is a popular demonstration involving a long strong rope held on either end by two strong students. Then invite a smaller less robust student to try to press the center of the rope to the floor as the two strong students attempt to hold the rope from touching the floor. If the rope is long enough, almost anyone will be able to pull the center of the rope down to the floor. A practical consequence of this is that telephone lines are always stretched with some droop between poles. Apparently, was this not the case, in winter, accumulations of ice could weight down the wires to an extent that the wires could break.



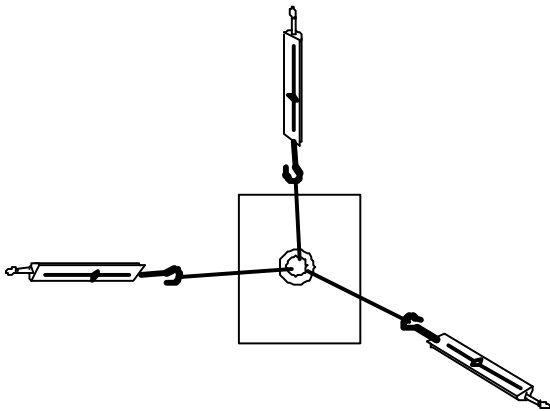
California Physics Standard 1 k

1. Newton's laws predict the motion of most objects.

As a basis for understanding this concept:

k* Students know how to solve two-dimensional problems involving balanced forces (statics).

LAB: A simple classroom experiment in statics involving vector addition.



A very nice experiment can be done in small groups with several spring balances, some string, a washer and a piece of paper. In the illustration three students pull outward on the washer carefully

holding a constant value while a fourth student sketches the position of the center of the washer, the direction the strings are pulling and writes on each string drawing the reading on each of the spring balances. This “data sketch” can now be used to construct the force vectors involved and test to see if they sum to zero. Other string and spring balance configurations can be easily repeated on a separate piece of paper.

California Physics Standard 1 I*

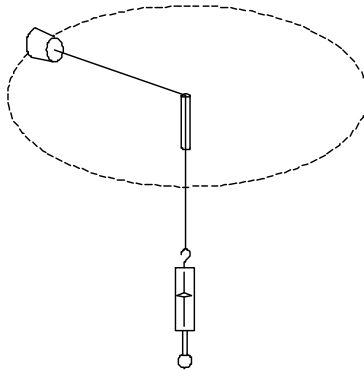
1. Newton's laws predict the motion of most objects.

As a basis for understanding this concept:

i.* Students know how to solve problems in circular motion, using the formula for centripetal acceleration in the following form: $a = v^2/r$.

LAB: Experiments to show that $a_c = v_T^2/r$.

The conical pendulum experiment discussed in 1 f previously is easy to do and gives fairly good results. Another popular experiment involves swinging a rubber stopper around using a fire polished glass cylinder (ask your Chemistry teacher for help) with a nylon string passing through the cylinder and, either known weights, or a spring balance providing the centripetal force. The essential idea is illustrated below.



The section of glass cylinder is fire polished on either end and the nylon string passes through it. Using a hand on the glass cylinder, the rubber stopper can be made to move in a circle and the other hand pulls down on the spring balance providing the centripetal force. The timing of several rotations and then pressing a thumb over the top of the glass cylinder will freeze the length of the string in order to measure the radius. The reading on the spring balance will give the centripetal force and the weight of the rubber stopper will give the rotating mass. With the time of a single revolution and the circumference of the circle, the tangential velocity can be calculated.

California Physics Standard 2 a

2. The laws of conservation of energy and momentum provide a way to predict and describe the movement of objects. As a basis for understanding this concept:

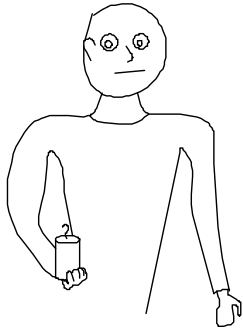
a. Students know how to calculate kinetic energy using the formula $E = 1/2mv^2$.

Note: We do not know why the Standards have chosen to use “E” for kinetic energy when “PE” is used for potential energy. We will use KE for kinetic energy and PE for potential energy in all the discussions that follow. It is useful to introduce the idea of energy through the concept of work. Once work is understood, it can be shown that energy is transferred through work.

LAB: Introducing the Concept of Work

Students need to know that force and work are different. Several different examples of applying forces, some when work is being done and others when work is not being done can help. Begin by holding a mass motionless and ask:

“I am exerting a force upward on this mass but am I doing any work?”



The discussion that follows might include that although I might get tired doing this, the basic definition of work says no. Next, slowly move the mass upward and ask if you are doing any work. This time, since the force is applied through a distance, work is done. Next hold the mass at a constant height and slowly move it in a horizontal direction and ask if you are doing any work. This time the answer is no since there is no component of force in the direction of motion. Now try to accelerate the mass in a horizontal direction and ask if while you were accelerating were you doing any work. All of these examples should help the students to come to an understanding that there must be a component of force in the direction of motion if work is done. Finally, hold the mass at arm's length and move it in a circle at constant speed. Here again no work is done since there is no force in the direction of motion. (A useful observation when trying to explain why satellites require no energy to keep orbiting.) In all of these examples the force has remained constant in value and this can lead to a basic definition of work. **Work equals force parallel times the distance the force moves.** In more advanced presentations you can include the possibility that the force could change in size while the work was done. Then give the more general definition: **Work equals the area under a force parallel vs. distance curve.** Students may have experienced the difference between simply pushing on something vs. pushing with the same force as the thing moves. (Such as pushing a car to start it.) In the second case you will get more tired since the energy in your body is being transferred to the moving object as you do work. End this introduction with a discussion of the units of work. In the mks system, one Joule equals the work done when one Newton acts through a distance of one meter.

The Standard seems to suggest that the important skill is knowing how to use the formula $KE = 1/2mv^2$. As well as plugging into formulas we would also hope students would be brought to understand that kinetic energy is the work done by an unbalanced force.

California Physics Standard 2 a

2. The laws of conservation of energy and momentum provide a way to predict and describe the movement of objects. As a basis for understanding this concept:

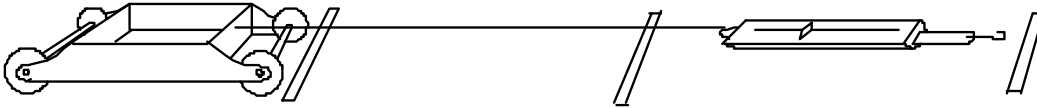
a. Students know how to calculate kinetic energy using the formula $E = 1/2mv^2$.

Note: We do not know why the Standards have chosen to use “E” for kinetic energy when “PE” is used for potential energy. We will use KE for kinetic energy and PE for potential energy in all the discussions that follow. It is useful to introduce the idea of energy through the concept of work. Once work is understood, it can be shown that energy is transferred through work.

LAB: Unbalanced Force turns into Kinetic Energy

The work of an unbalanced force turns into KE.

The experiment involves a small fairly frictionless cart, a spring balance, a stopwatch and a level surface long enough to allow for some acceleration followed by a measured distance at constant speed.



Measure the mass of the cart (perhaps including additional masses), and measure the distance between the two “accelerating distance tapes” and the distance between the two “coast velocity tapes”. The string attached to the cart is long enough to allow dropping the force to zero when the cart passes the second tape. The cart will be timed as it coasts at constant velocity between the second and third tape. The experiment can be repeated with different mass configurations but it is important to supply a constant force to the cart during the acceleration phase. This experiment can test to see if the work done in accelerating the cart equals the final kinetic energy of the cart. (Even though the results may not be great, students get to experience doing work and observing the resulting kinetic energy.)

The work of an unbalanced force equals change in kinetic energy. $F_U d = 1/2mv^2$

California Physics Standard 2 b

2. The laws of conservation of energy and momentum provide a way to predict and describe the movement of objects. As a basis for understanding this concept:

b. Students know how to calculate changes in gravitational potential energy near the Earth using the formula (change in potential energy) = mgh (h is the change in the elevation).

LAB: Work and Potential Energy near the surface of the Earth

A hand lifts a mass a vertical height, h . The hand exerts an upward force; F_H on the mass and gravity exerts a downward force mg on the mass. It is assumed that the mass is moving upward at constant speed, hence the upward force on the mass, F_H equals in magnitude the downward force of gravity, mg . Since work equals force in the direction of motion times, the distance the force moves, the work done by the hand is: $F_H h$. Since the magnitude of $F_H = mg$, it follows that the work done in lifting the mass is mgh . The work done in lifting the mass is stored and would be released later if the mass were dropped. Such stored energy is called potential energy and in this case, gravitational potential energy. Compressing a spring, or stretching a rubber band can also store energy. In these situations, the stored energy can always be related to the work done in storing the energy. However, when work is done against friction, the energy changes form and turns into heat, hence no potential energy results. In general, the work done against a “conservative force” is stored as potential energy. A crude way to define a “conservative force” is to say that it is a force that “remembers”. That is, the force will remain the same over time. The weight of a mass at a particular point in space will always remain the same, no matter how long you leave it there. A compressed spring will “remember” the work done in compressing it long after it was compressed, as stored potential energy. The force of friction, on the other hand, dissipates the energy expended when working

against it and is therefore a “non-conservative” force. The work done against a conservative force is stored as potential energy. When objects are moved near the surface of the earth, the vertical height lifted times the weight of the object will equal its change in gravitational potential energy.

$$\Delta PE = mgh$$

One very interesting consequence of how work is defined and how objects move in gravitational fields, is that the amount of work done, hence the potential energy stored, only depends upon the difference in height and not upon the distance moved. The following discussion should clarify that only the vertical height lifted influences gravitational potential energy.

California Physics Standard 2 c

2. The laws of conservation of energy and momentum provide a way to predict and describe the movement of objects. As a basis for understanding this concept:

c. How to solve problems involving conservation of energy in simple systems such as falling objects.

LAB: An experiment to show Potential Energy being converted to Kinetic Energy.

The idea behind this experiment is that a pendulum is elevated to a measured height and is released. When the bob reaches the lowest part of its swing, it is released and allowed to move as a projectile to strike the floor some distance away. The distance it freely falls vertically can be used to find the time of free fall and the distance it moves horizontally can be used to find its horizontal velocity.

With this data the initial potential energy can be compared with the kinetic energy of the bob just as it separates from the string and begins to move as a projectile.

One way to have the pendulum bob release at the lowest point of its swing is to bend a paper clip and attach it to the lower end of the string. Bend the clip so that it will have a long section pointing in a horizontal direction as illustrated on the left. Using a drilled pendulum bob, pass the horizontal section of the paper clip through the bob. This will support the bob during its downward swing but place a stop block that is firmly attached to the table exactly at the lowest point of the swing. This block will stop the paper clip and pendulum string but allow the pendulum bob to continue on in freely falling motion. (Some have used a sharp razor blade to cut the string at its lowest point but this will take some energy from the bob and requires retying after each run.)

California Physics Standard 2 c

2. The laws of conservation of energy and momentum provide a way to predict and describe the movement of objects. As a basis for understanding this concept:

c. How to solve problems involving conservation of energy in simple systems such as falling objects.

LAB: An experiment to Measure work to Potential Energy

An experiment is to arrange a way to use a spring balance to measure the force required to pull a pendulum away from its rest position and record this force at several measured distances along its curved path. A graph of force vs. distance is made. The area of this graph could be determined by “square counting” (observing the proper unit value of each square). This area in joules should equal the value of mgh , where “h” is the vertical height of the bob for each position along the curved path.

California Physics Standard 2 d

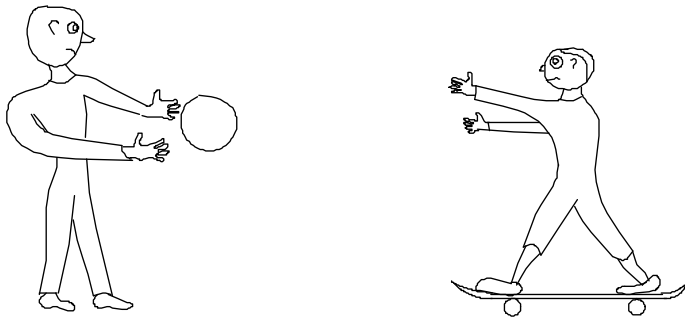
2. The laws of conservation of energy and momentum provide a way to predict and describe the movement of objects. As a basis for understanding this concept:

d. How to calculate momentum as product mv .

LAB Demonstrations: Agile student on skateboard

A well-coordinated and accomplished skateboarder can be a big help when introducing momentum. You will also need a bag of sand or a medicine ball like object.

A little practice may be required to make this effective. Have the skateboarder toss the ball away at assorted speeds and observe the resulting momentum. Toss the ball to the stationary skateboarder and observe the resulting transfer of momentum. Experiment with different speeds and different direction of motion of the skateboarder.



In the discussion that follows, concentrate on how momentum was transferred from the ball to the skateboarder and skateboarder to ball, both when tossed and received. Discuss what might have happened with different mass ratios of the ball and skateboarder. End the discussion by pointing out that the person standing on the ground at rest who tossed the ball (in most cases this will be the teacher) did not seem to move. Isn't this a violation of the conservation of momentum principle?! The ball seemed to gain momentum from nowhere. Stress this point again by running across the room and then abruptly come to a stop. Where did the momentum come from to get moving? Where did the momentum go when you stopped? This should be a good time to point out that the earth is a "giant skateboard" and in every case the momentum was transferred to and from the earth. However, since its mass is so large the momentum was conserved with a very small velocity of the earth. An interesting problem is to have the students compute the velocity of the earth as a result of you running in one direction at a given speed.

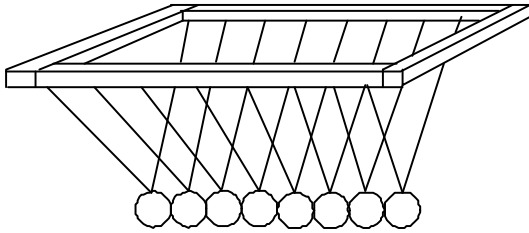
California Physics Standard 2 e

2. The laws of conservation of energy and momentum provide a way to predict and describe the movement of objects. As a basis for understanding this concept:

e. Momentum is a separately conserved quantity, different from energy.

LAB: Newton's Cradle

Newton's Cradle is a wonderful demonstration of the conservation of momentum and kinetic energy. The apparatus usually consists of an odd number of identical steel balls (7 is common) each suspended by a bifilar suspension from a sturdy frame. The balls are carefully aligned along a horizontal line, just touching. After you experiment with lifting and releasing a given number of balls and observing the same number rise on the opposite side, drop one from one side and two from the other and observe the result.



Lift one high and one low on the opposite side and observe the result. After demonstrating how the device always mirrors the initial conditions on the other side ask why, when you lift one on the left side, two never come out the right side at half the speed? This surely would conserve momentum. Hopefully the realization that this would not conserve kinetic energy will be discovered.

When the ball on one end is pulled aside and allowed to swing as a pendulum, it hits the next ball. But the outcome is fascinating, the one ball on the far end is knocked away from the others with the same speed as the first ball had initially and all of the other balls remain nearly at rest. If you pull back two balls and let them strike the others, two balls are knocked from the other end, and all the other balls remain nearly at rest.

Why does this happen?

Why are these the only outcomes that occur?

Why not others?

This apparatus is a special case: collisions between spherical balls of equal mass, size and composition. And those special conditions are responsible for the intriguing and special behavior we observe. We assume that the collision is elastic, that is, the sum of system kinetic and potential energies is conserved. We need not fuss about the fact that collisions are never perfectly elastic.

They can be close enough to perfect for this analysis to help us understand what's going on.

An interesting demonstration is to use a small rubber band and hold two balls together on the right side and only lift one ball on the left side. It is easy to hear the rapid clacking of the two balls as they use a different method to get rid of the extra kinetic energy.

Also show that if you start with say two balls on the left side drop it on to the main collection and then let the action continue without interaction for a long time, all the balls will be swinging together with a fraction of the motion of the original two balls. Momentum has been conserved but kinetic energy has been converted to heat and sound.

California Physics Standard 2 f

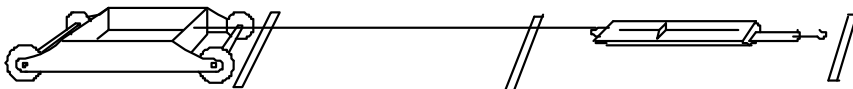
2. The laws of conservation of energy and momentum provide a way to predict and describe the movement of objects. As a basis for understanding this concept:

f. Students know how an unbalanced force on an object produces a change in its momentum.

LAB: Impulse equals Change in Momentum

This activity uses the same equipment as described in Standard 2a above, only times rather than distances are measured. Probably two stopwatches are required. One to measure the time of acceleration and the other to measure the time of coasting. As before, the string must be long enough to allow acceleration with a constant force but should also allow this force to drop to zero just as the cart enters coasting space. This experiment will definitely be a team effort with one student providing the force and two other students measuring the acceleration and coasting time. (If

available, a split stopwatch might require only one student.) If the friction is fairly low, the coasting distance divided by the coasting time will give the final velocity. Different masses can be used and the total mass of the cart plus included masses can be measured with the spring balance and dividing by g . This experiment should help students to see how the product of force and time equals the change in momentum just as the previous experiment should have illustrated how the product of force and distance equaled the change in kinetic energy.



California Physics Standard 2 f

2. The laws of conservation of energy and momentum provide a way to predict and describe the movement of objects. As a basis for understanding this concept:

f. Students know how an unbalanced force on an object produces a change in its momentum.

LAB: Bottle Rockets (Water Rockets)

Students can have a lot of fun building, testing and competing with one another with bottle rockets. The best way to find out about these is to engage in a web search for “bottle rockets” or “water rockets”. Often the URLs for related pages do not hold up but one that describe building the rocket and even includes a parachute is:

<http://www.lnhs.org/hayhurst/rockets/wrbook.htm>

And a NASA PDF download of how to build the launcher:

http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Bottle_Rocket_Launcher.html

The essential idea behind the bottle rocket is that an empty plastic soft drink bottle is fixed with fins to make a rocket. It is half filled with water and using a special launcher, it is pumped with air to provide the energy to expel the water through the inverted top of the bottle. The resulting application of energy and momentum makes a spectacular display as the rocket rises into the air. Many variables can be tested such as the amount of water, the amount of energy stored by pumping, the shape of the rocket and how all of this influences the height the rocket rises. We will be sure to observe the safety measures suggested in many of the articles on the web as well as in the NASA launch download.

California Physics Standard 2 g

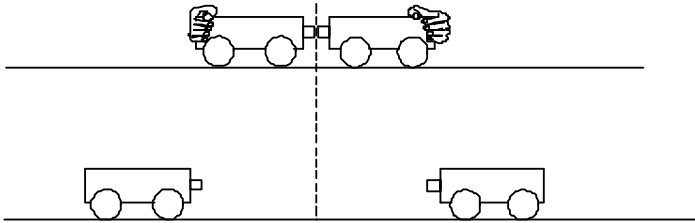
2. The laws of conservation of energy and momentum provide a way to predict and describe the movement of objects. As a basis for understanding this concept:

g. Students know how to solve problems involving elastic and inelastic collisions in one dimension using the principles of conservation of momentum and energy.

LAB: Two Carts on a Low Friction Track

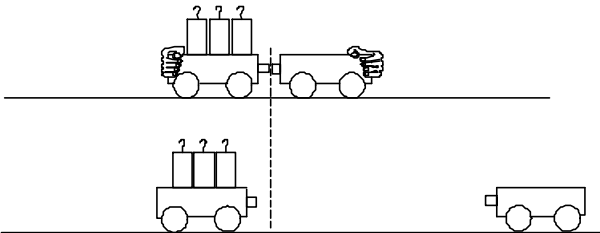
Explaining the basics of momentum and energy conservation during elastic and inelastic collisions can be much enhanced with two carts on a low friction track. The carts are fitted with repelling magnets on one end and Velcro on the other to help with the demonstrations. The essential specification is that the two carts have low friction wheels, they are able to be weighted differently, they have elastic and inelastic “bumpers” and they can be confined to move in one direction with a linear track. The track can be easily elevated and leveled so the entire class can see it.

Using two carts of the same mass with magnets repelling, press the carts together and release them at the same time. Discuss how the repulsive forces must be equal (Newton's 3rd Law) and the times the carts act on each cart must be equal, hence each must receive the same impulse in opposite directions.



Since the magnitude of the impulse on each cart is the same, they will each receive the same momentum in opposite directions and will move at the same speed. Now repeat this “explosion” only with one of the carts weighted. This time the impulse will still be the same on each cart hence the change in momentum will be the same but the speeds of each will be different, in inverse proportion to the masses.

A very interesting demonstration can be performed with this apparatus by carefully balancing the carts and track on a fulcrum before the explosion and then releasing the carts. If carefully done, they will remain balanced for a short while showing that the center of mass is unchanged—an important concept when discussing rocket propulsion.



It is important to stress that in elastic collisions, kinetic energy as well as momentum is conserved. The forces that act between the colliding bodies are conservative and will return all of the energy that was temporarily stored when the bodies were at their closest distance separation. (Another way of saying a spring or magnet interaction is “perfectly elastic” is to say the force depends only upon separation. Springs are elastic since their restoring force depends only on the distance they are compressed or stretched. Balls of putty exert one force when they are compressed but do not return this force and do not elastically expand again.) Students might appreciate the following argument involving work to show that the kinetic energy that is temporarily stored as potential energy when the objects are at minimum separation will all be returned if the bumpers are perfectly elastic.

California Physics Standard 2 h*

The laws of conservation of energy and momentum provide a way to predict and describe the movement of objects. As a basis for understanding this concept:

h.* how to solve problems involving conservation of energy in simple systems with various sources of potential energy, such as capacitors and springs.

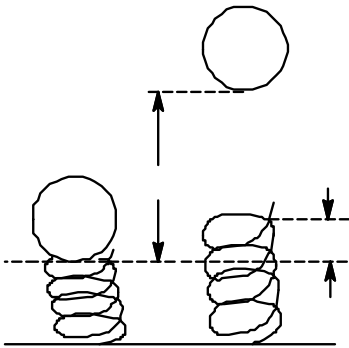
LAB: Law of Conservation of Energy and Momentum

Materials: a properly chosen compressible spring, a ball, a spring balance and a meterstick.

The students determine the spring constant using the meterstick and the spring balance. After determining the mass of the ball they press it down a measured distance on the spring and see if it rises to the predicted height when released.

A sphere of mass m is pushed down on a spring of force constant k a distance x below its normal uncompressed length. The ball is released and rises into the air. If the spring is anchored to the floor and delivers all of its energy to the sphere, how high does the sphere rise above its initial position? You are given m , g , x and k .

The solution involves simply equating the spring potential energy when compressed to the sphere's gravitational potential energy at its highest position. The equation that describes the force vs. displacement for a spring (Hooke's Law) is: $F = -kx$ where k is the spring constant and is defined as $\Delta F/\Delta x$ for a particular spring.



California Physics Standard 2 I*

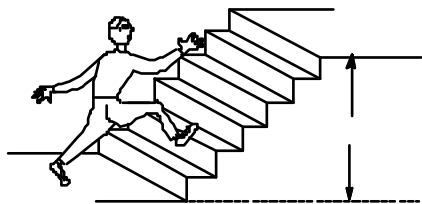
The laws of conservation of energy and momentum provide a way to predict and describe the movement of objects. As a basis for understanding this concept:

i. Work, power and efficiency.

Students should know that power is the rate of doing work or expending energy. Students should not confuse the concepts of power and energy and should be able to compute the efficiency of various processes.

LAB: Measuring a Student's Power

A simple exercise that students seem to have a lot of fun doing is to have them run up a flight of stairs of known vertical height while being timed to measure their power.



The student will start from rest and run up the stairs while another student measures the time. If the weight of the running student is W , the height of the stairs, h , the time to run the stairs, t , then the

power developed will be $P = Wh/t$. If W is in pounds, h in ft. and t in seconds, then the power will be in foot pounds/sec. Dividing this by 550 will give the power in horsepower. Students usually prefer finding out their power in units of HP but these can be easily converted to kilowatts. Almost always the heavier students develop the most power much to the disappointment of the smaller, faster students.

California Physics Standard 3 a

Heat and Thermodynamics

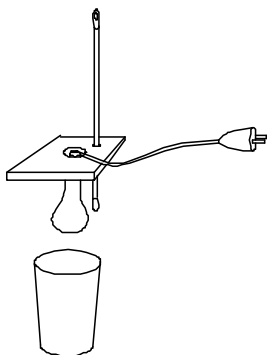
3. Energy cannot be created or destroyed although in many processes energy is transferred to the environment as heat. As a basis for understanding this concept:

a. Students know heat flow and work are two forms of energy transfer between systems.

LAB: Measure the Relationship Between Work and Heat

Commercial apparatus is available to reproduce Joule's determination of the mechanical equivalent of heat, but a fairly simple and inexpensive duplicate of this experiment can be made using a standard 60-watt light bulb.

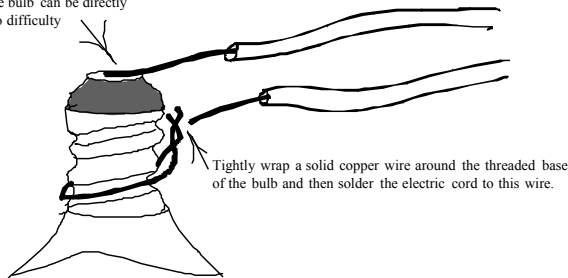
The basic apparatus is a 60 watt light bulb that has been attached to a line cord through a hole in a piece of $\frac{3}{4}$ " soft wood. (Details on how to attach the cord below.) Using silicon calking, the base of the bulb is glued to the wood and covers the electrical attachment to the bulb. A hole through the wood allows a thermometer to be pass through it. Using a Styrofoam cup large enough to accommodate the bulb, an amount of water is filled in the cup to completely submerge the bulb when lowered into the cup. (Do not plug in the bulb until it is completely submerged in the water.) The idea behind the experiment is to carefully time how long the bulb is on while submerged in the water. The temperature change is recorded during the time the bulb is on. Multiplying the power of the bulb times the seconds it was on would give the joules of energy put into the bulb. The mass of the water times the temperature change will give the amount of heat delivered to the water.



One error in this experiment will be the energy loss as visible light through the sides of the cup. Lining the cup with aluminum foil can minimize this. Also, to minimize the effect of loss heat through the walls of the cup, one could start the experiment with the temperature below room temperature and heat it to the same temperature above room temperature. Below is an illustration of how to attach the line cord to the light bulb. A socket can be used but this method is less expensive. If the entire base of the bulb, below and above the wood is covered with silicon calk, the apparatus will be quite safe.

Illustration of detail of apparatus to measure relationship between work and heat:

The center of the bulb can be directly soldered with no difficulty



Tightly wrap a solid copper wire around the threaded base of the bulb and then solder the electric cord to this wire.

California Physics Standard 3 b

Heat and Thermodynamics

3. Energy cannot be created or destroyed although in many processes energy is transferred to the environment as heat. As a basis for understanding this concept:

b. Students know the work done by a heat engine that is working in a cycle is the difference between the heat flow into the engine at high temperature and the heat flow out at a lower temperature (First Law of Thermodynamics) and that this is an example of the law of conservation of energy.

LAB: Models of the kind of engines used in automobiles

This standard seems to be approaching the first law of thermodynamics with a specific intent to discuss heat engines. Students appreciate this more if they can learn about practical heat engines like the internal combustion engines they encounter every day in their cars. Since auto shops are less common in today's schools, working models of such engines are hard to find. This is a model of a gasoline engine from Cynmar Scientific (www.cynmar.com). (022-39329 a "Petrol Engine Model") and/or 022-39327 for a "Diesel Engine Model". Students can learn a lot by turning the crank on these models and coming to a better understanding of what is going on under the hood of their car.

Also there is an animation here:

<http://auto.howstuffworks.com/engine1.htm>

I n t e r n a l C o m b u s t i o n
T h e p r i n c i p l e b e h i n d a n y
r e c i p r o c a t i n g i n t e r n a l c o m b u s t i o n
e n g i n e : I f y o u p u t a t i n y a m o u n t
o f h i g h - e n e r g y f u e l (l i k e

gasoline) in a small, enclosed space and ignite it, an incredible amount of energy is released in the form of expanding gas. If you can create a cycle that allows you to set off explosions like this hundreds of times per minute, and if you can harness that energy in a useful way, what you have is the core of a car engine!

QUESTION for students: In what way does this illustrate the First Law of Thermodynamics?

California Physics Standard 3 c

Heat and Thermodynamics

3. Energy cannot be created or destroyed although in many processes energy is transferred to the environment as heat. As a basis for understanding this concept:

c. Students know the internal energy of an object includes the energy of random motion of the object's atoms and molecules, often referred to as thermal energy. The greater the temperature of the object, the greater the energy of motion of the atoms and molecules that make up the object. 3. Energy cannot be created or destroyed although in many processes energy is transferred to the environment as heat. As a basis for understanding this concept:

c. Students know the internal energy of an object includes the energy of random motion of the object's atoms and molecules, often referred to as thermal energy. The greater the temperature of the object, the greater the energy of motion of the atoms and molecules that make up the object.

LAB: Brownian Motion

Equipment needed: Compound microscope

Materials: India Ink, distilled water, microscope slides

Student activity to illustrate Brownian motion:

1. Take a drop of real "India Ink" (not just any black ink), and dilute it in half with distilled water.
2. Place a drop of this "solution" onto a slide and cover it with cover slip.
3. Under a light microscope, you should see small black specks that are jiggling around. THAT is "Brownian Motion." It is the basis of diffusion.

This experiment might give a student an opportunity to experiment with different fluid concentrations and perhaps even the temperature of the fluid.

California Physics Standard 3 d

Heat and Thermodynamics

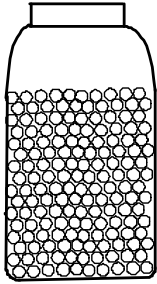
3. Energy cannot be created or destroyed although in many processes energy is transferred to the environment as heat. As a basis for understanding this concept:

d. Students know most processes tend to decrease the order of a system over time, and energy levels are eventually distributed uniformly.

LAB: Model to illustrate decreased order of a system over time

Students are no doubt familiar that a deck of cards that has been completely organized into suits by number will begin to randomize in a single shuffle. Repeated shuffling will only end in other random organizations. Students are easily convinced that no amount of further shuffling would end

in have the cards reorganize into the original arrangement. A related classroom demonstration is to take a large clear jar filled with marbles of equal size but of two different colors. Black and white beans work well for this demonstration.



After carefully filling the jar half full with one color bean, fill the rest of the jar with the other color. Show this to the class and ask what will happen if you shake the jar. They will correctly assert that the beans will get mixed up. You confirm their assertions by shaking the jar and mixing the beans. Now ask, how long will I have to shake the jar to return the beans to their original configuration? They probably will suggest that this can never happen. The discussion that follows should help them to realize that the original arrangement is one of the possible configurations but that there are so many other possible configurations that lead to mixing that returning the beans to the original configuration is, although possible, highly improbable.

Just as the beans tend to go from a highly organized state to a more mixed up state, a conductor which is hot on one end and cold on the other will, if left for some time, come to an equilibrium temperature. The collisions of the rapid moving molecules on one end with the slower moving molecules on the other with cause the heat energy to transfer in such a way that most of the molecules will end up moving at median velocity.

If students are asked to sort the beans back to their original configuration, it takes energy for the student to do it. When viewed from a larger picture, the biological processes involved as the students sort the beans causes the universe as a whole to become more disorganized.

California Physics Standard 3 e

Heat and Thermodynamics

3. Energy cannot be created or destroyed, although in many processes energy is transferred to the environment as heat. As a basis for understanding this concept:

e. Students know entropy is a quantity that measures the order or disorder of a system, and is larger for a more disordered system.

LAB: Entropy

Entropy is a fundamental idea in physics. It states that the energy in a system will equalize in distribution as time passes until the energy is equally distributed across the system and order natural moves to chaos. Entropy is a measure of the amount of disorder in a system. To demonstrate this, place some ice cubes in warm water, the temperature of which you have measured.

An ice cube has a lot of order. When it melts it loses its structure and order. It melts to become

water which has much more disorder than the ice cube. If it evaporates it has even more disorder and hence greater entropy (disorder).

When the ice cubes melt, measure the temperature of the water again. You should find that the ice has cooled the warm water. More importantly, the water and ice have equalized in temperature and equilibrium has been attained in the system, demonstrating entropy. Heat always flows from hot to cold, never cold to hot. Extension is that when energy is converted, some energy is lost as heat.

Work in = work out plus heat

California Physics Standard 3 f

Heat and Thermodynamics

3. Energy cannot be created or destroyed, although in many processes, energy is transferred to the environment as heat.

As a basis for understanding this concept:

f* Students know the statement “Entropy tends to increase” is a law of statistical probability that governs all closed systems (second law of thermodynamics).

LAB: Statistical Interpretation of Entropy Package

<http://www.compadre.org/OSP/document/ServeFile.cfm?ID=10161&DocID=1737>

The Statistical Interpretation of Entropy Launcher package is a self-contained file for teaching the basic concept of the statistical interpretation of entropy. The file contains ready-to-run Easy Java Simulations (EJS) programs and curricular materials. The curricular materials describe a simple hands-on coin flip experiment that can help student become familiar with the basic statistical ideas involved in the approach to equilibrium and the second law of thermodynamics. The materials also describe how the EJS programs can be used to extend this simple experiment and explore these concepts at a deeper level. The EJS programs include simulations of the coin flip experiment, the expansion of an ideal gas in a box, the mixing of hot and cold ideal gases, and the action of Maxwell's Demon.

The materials in this resource are described in an article titled "The Statistical Interpretation of Entropy: An Activity" to be published in The Physics Teacher.

California Physics Standard 3 g*

Heat and Thermodynamics

Energy cannot be created or destroyed, although in many processes energy is transferred to the environment as heat. As a basis for understanding this concept:

3. g* Students know how to solve problems involving heat flow, work, and efficiency in a heat engine and know that all real engines lose some heat to their surroundings.

LAB: Pressure-Volume Graph of car engine

This is a model of a gasoline engine from Cynmar Scientific (www.cynmar.com). (022-39329 a “Petrol Engine Model”) and/or 022-39327 for a “Diesel Engine Model”. Students can learn a lot by turning the crank on these models and coming to a better understanding of what is going on under the hood of their car.

Also there is an animation here:

<http://auto.howstuffworks.com/engine1.htm>

This introduction to a real engine seems to be a good point of departure for the more abstract discussion that follows. First, consider the Pressure -Volume graph of the engine cycle: The cycle begins at 1 when the fuel air mixture is compressed to 2. At this point the fuel air mixture is ignited introducing a large amount of heat, ΔQ_H into the cylinder with a corresponding large increase in pressure to 3. From 3 to 4 the high pressure heated combustion products are allowed to expand against the piston delivering work to the crankshaft of the engine. From 4 to 1 the exhaust valve opens and any excess heat ΔQ_C leaves the cylinder and the pressure is returned to the original atmospheric pressure. The area inside of this closed curve equals the work done by the engine. ΔQ_H is the heat that enters the engine and ΔQ_C represents the heat that leaves the engine. As with all heat engines, the first law of thermodynamics says that the difference between ΔQ_H and ΔQ_C will equal the work extracted from the engine. The second law of thermodynamics demands that the engine will only operate if heat flows from a high temperature source (the exploding fuel air mixture) to a low temperature source (the exhaust into the environment.)

The efficiency of any heat engine will be the work produced by the engine, W , divided by the heat introduced into the engine from the high temperature source, ΔQ_H . Since ΔQ_C is lost to the environment, only ΔQ_H is of interest. Designing the most efficient engine requires an understanding of how to get the most out of the heat put into the engine and minimizing the heat that must be wasted in the exhaust. It would be nice if we could design an engine that would not waste any energy in the exhaust but the second law of thermodynamics demands that we can't have heat flow through the engine unless we have a lower temperature sink to which the heat energy can flow. So the question of engine efficiency reduces to: What is the maximum work that can be extracted from an engine operating between a given high temperature source and low temperature sink?

California Physics Standard 4 a

Waves

4. Waves have characteristic properties that do not depend on the type of wave.

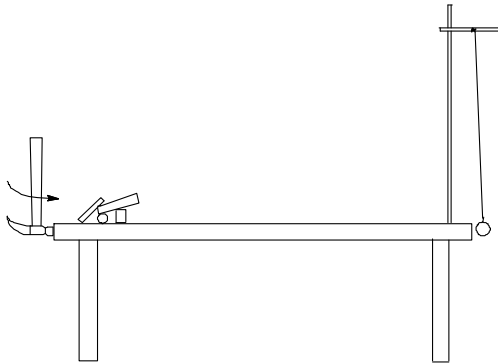
As a basis for understanding this concept:

a. Students know waves carry energy from one place to another.

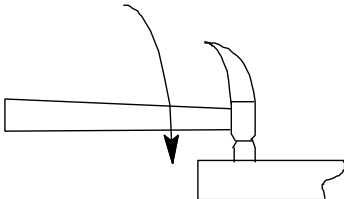
LAB: Energy transmitted without net motion of the medium

Students are probably familiar with the stunt called “the wave” performed by fans at a football game. The cheerleader directs successive columns of fans to stand up, wave and then to sit down, giving the impression that something is moving across the stadium. Certain types of lights in signs can give the appearance of motion if they are turned off and on in an appropriate sequence. The important thing to stress with these examples is that the motion is only apparent. Nothing really moves in the direction of “wave travel.” Animations that illustrate both longitudinal and transverse wave motion for students to view are here:

<http://paws.kettering.edu/~drussell/Demos/waves-intro/waves-intro.html>



A demonstration to show that energy can be transmitted without any net motion of the medium uses a substantial table with a pendulum suspended so it lightly touches the table, as illustrated on the right. A few pieces of loosely stacked junk that will rattle making a noise is placed on the left end of the table. When the end of the table is struck with a hammer, the pendulum will bounce away from the table but the junk on the left end will make no noise.



If, however, the hammer is struck with a downward blow on the table, the noise producing junk will rattle but the pendulum will not bounce off of the end of the table. This is both a good introduction to the fact that energy is transferred without any net motion of the medium as well as transverse and longitudinal waves.

California Physics Standard 4 b

Waves

4. Waves have characteristic properties that do not depend on the type of wave.

As a basis for understanding this concept:

b. Students know how to identify transverse and longitudinal waves in mechanical media such as springs, ropes, and the Earth (seismic waves).

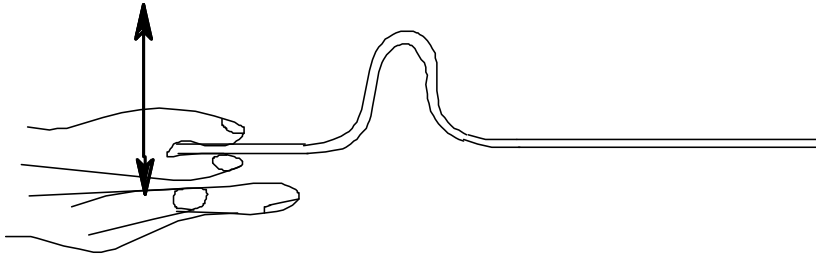
LAB: Producing Longitudinal and transverse pulses

Animation of wave motion in time and space:

<http://paws.kettering.edu/~drussell/Demos/wave-x-t/wave-x-t.html>

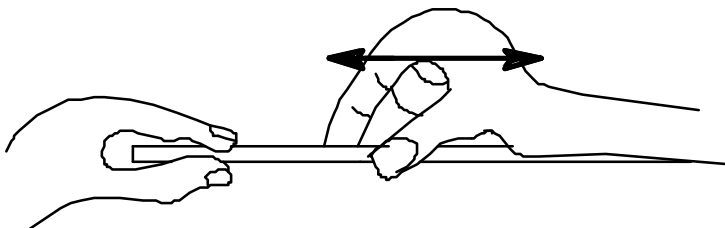
Equipment: Longitudinal and transverse pulses can be easily demonstrated with a coiled metal spring (often called a snake spring) or, not quite as well, with a Slinky.

Top view of spring on floor:

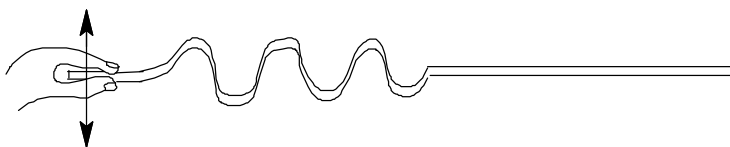


The essential idea to stress is that the particles in a longitudinal wave move back and forth in the same direction as the wave travels and in a transverse wave, the particles move perpendicular (or transverse) to the direction of wave travel. Longitudinal and transverse pulses can be easily demonstrated with a coiled metal spring (often called a snake spring) or, not quite as well, with a slinky. Place the spring on the floor and use your hand to create a quick transverse pulse. The technique is to move outward and back as rapidly as possible, stopping your hand with your other hand when it returns to the central position. Using this technique, different sized pulses can be created (both in amplitude and pulse length) and it is easy to demonstrate that no matter the size or shape of the pulse, it always moves at the same speed.

It is also possible to produce a longitudinal pulse in a snake spring by gathering spring coils into a tight compressed bunch along the direction of the spring and quickly releasing this bunch of coils.



One interesting additional demonstration with pulses in a spring is to show that transverse pulses travel slower than longitudinal pulses. It is possible to pull the spring to one side and to compress some spring coils into a single “transverse and longitudinal” bunch. When this bunch is released, a noticeable difference in the arrival time of the pulses at the other end will be observed. This demonstration can be extended to a discussion of the difference in speeds of the P and S earthquake waves. It is best to show students how waves travel with a quick burst of three or four wavelengths so they can see them travel down the spring, reflect off of the fixed end at the other end of the spring and return to the starting point. Transverse waves show this best as illustrated below:



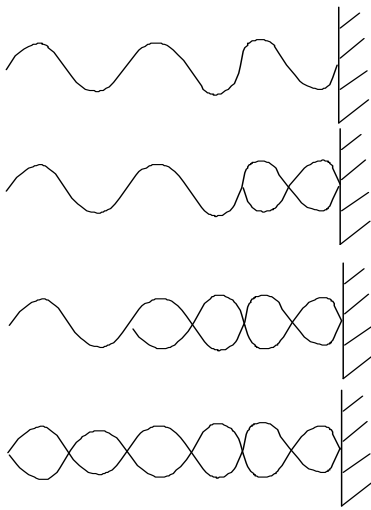
Allowing this small transverse wave train to move down to the end of the spring and return will enable the students to see clearly that the waves appear to move, yet if a small piece of string were tied to any point on the spring, it will also be clear that it only moves transverse to the direction of wave travel.

Using a pulse, it is also instructive to show students that the pulse inverts in phase as it reflects from a fixed end. This also happens with the small wave train but it is not so obvious. This exercise will prepare the students for a better understanding of standing waves.

Producing standing waves:

Although the standards do not specifically address standing waves, this would be a good time to show students the basics of standing waves. The basics of standing waves are essential to understanding musical instruments, room acoustics, TV antennas and many other related topics.

The key to producing standing waves is that waves returning from the reflected end begin to form an interference pattern with the waves that are being generated. This will become apparent if a wave train is generated (as in the previous section) followed by a continuously generated set of waves of the same frequency. If done properly, the students will see the initial wave train move down the spring but as the reflected wave begins to return, nodes and antinodes will be produced in succession as the reflected wave returns to the source.



1. The initial wave train is launched and is seen to travel down the spring until it reaches the fixed end.
2. As the reflections, inverted in phase, begin to return, the first nodes are seen to develop.
3. As the reflected wave continues back to the source and the source continues generating new waves, the standing wave pattern becomes more apparent.
4. Continued generation of the same frequency waves sets up a “permanent” standing wave.

With a little practice, you can learn to feel the returning waves and adjust your generating frequency to form standing waves of different frequencies. Any college physics text will illustrate the appearance of the first few standing waves produced in this way. Stress that the nodes always do not move, and the antinodes move with the maximum possible amplitude.

California Physics Standard 4 c

Waves

4. Waves have characteristic properties that do not depend on the type of wave.

As a basis for understanding this concept:

c. Students know how to solve problems involving wavelength, frequency, and wave speed.

This standard seems largely to focus on having the student use a formula. However, it is important that students understand that in a uniform medium, waves travel at a speed that is independent of amplitude, wavelength and frequency. Also, take some time to make sure they understand the meaning of amplitude, wavelength (λ) and frequency (f).

The relationship $v = f\lambda$ can be used to solve such problems. Notice that amplitude does not influence wave speed. Frequency, f , is measured in hertz, which is another name for sec^{-1} or, cycles per second. When the wavelength, λ , is measured in meters and the frequency in hertz, the wave speed will be in meter/sec.

It is interesting to consider what happens when a wave suddenly encounters a medium with a different wave velocity. This frequently happens when light passes from air into water or even when an ocean wave passes over a reef. Illustrated below is a representation of a transverse wave (perhaps light) that suddenly encounters a medium in which the wave speed is less.

It is important to appreciate that the frequency does not change. If the wave speed in the new medium is less, the wavelength will be correspondingly smaller. In the illustration, as the velocity slows, the wavelength decreases.

LAB: Reflection of Waves from Boundaries:

<http://paws.kettering.edu/~drussell/Demos/reflect/reflect.html>

When an object, like a ball, is thrown against a rigid wall it bounces back. This "reflection" of the object can be analyzed in terms of momentum and energy conservation. If the collision between ball and wall is perfectly elastic, then all the incident energy and momentum is reflected, and the ball bounces back with the same speed. If the collision is inelastic, then the wall (or ball) absorbs some of the incident energy and momentum and the ball does not bounce back with the same speed.

Waves also carry energy and momentum, and whenever a wave encounters an obstacle, they are reflected by the obstacle. This reflection of waves is responsible for echoes, radar detectors, and for allowing standing waves which are so important to sound production in musical instruments.

Students study the 2 animations and answer questions:

What happens when a pulse travels on a string without a fixed end? Describe the appearance of the wave and the string.

What happens when a wave pulse encounters a rigid obstacle at the end? How does the reflected wave differ from the incoming wave?

What is the major difference between these cases?

What occurs if the boundary is soft?

California Physics Standard 4 d

Waves

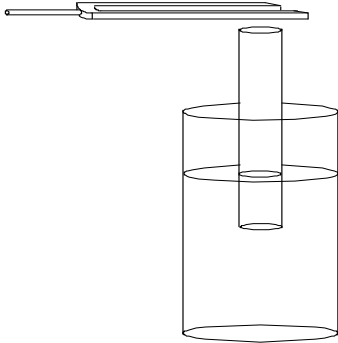
4. Waves have characteristic properties that do not depend on the type of wave.

As a basis for understanding this concept

d. Students understand sound is a longitudinal wave whose speed depends on the properties of the medium in which it propagates.

LAB: Measuring the velocity of sound, resonance method.

A simple but quite accurate experiment is to measure the velocity of sound using a resonant method. A metal or glass tube has one end immersed into a container of water. The distance from the top of the tube to the surface of the water is adjusted to produce resonance with a tuning fork.



For best results the fork should be held as illustrated very close to the top of the tube. The tube is adjusted until the volume of air inside the tube between the top of the water and the top of the tube loudly resonates with the fork. It can be argued (see below) that the distance from the top of the tube to the surface of the water (L) is one-fourth the wavelength of the sound produced. With the frequency of the fork (f) the velocity of sound can be calculated from $v = f \lambda$. That is, $v = 4 f L$. There is a slight correction for the diameter of the tube but if the tube is long compared to its diameter, the correction will be small.

One way to argue that the distance from the top of the tube to the surface of the water is one-fourth the wavelength is to point out that a standing wave has been established inside of the tube with a node at closed end formed by the water and an antinode at the open end near the tuning fork. The distance between a node in a standing wave and the next antinode is one-fourth of a wavelength.

Another argument that might appeal to some students is to carefully bounce a ball and point out that your hand goes through one half cycle from the time the ball leaves your hand to when the ball returns to your hand. This is a form of resonance. When you allow your hand to go through one half cycle, the ball moves from your hand, to the floor and back again, just when your hand is at the top of its swing ready to push the ball back down. But the total distance the ball has moved in this half cycle is down to the floor (a distance L) and back to your hand, (a total distance $2L$). In half a cycle ($f/2$) the ball moves a distance $2L$. Therefore, in a full cycle, the ball will move a total distance $4L$.

California Physics Standard 4 e

Waves

4. Waves have characteristic properties that do not depend on the type of wave.

As a basis for understanding this concept:

e. Students know radio waves, light and X-rays are different wavelength bands in the spectrum of electromagnetic waves

whose speed in vacuum is approximately 3×10^8 m/s (186,000 miles/second).

LAB: Computer lab to understand Electromagnetic Spectrum

This lesson on the EM spectrum will give more emphasis to the wave nature of all electromagnetic waves. The discussion of the electromagnetic spectrum almost requires a large chart to refer to during the lesson so instead this will be a computer-based lesson. There are numerous web pages that present the EM spectrum in different levels of detail. Students will start here:

http://imagine.gsfc.nasa.gov/docs/science/know_11/emspectrum.html

Questions:

Looking at the right side of the chart which shows wavelength and frequency, what happens to frequency as wave length decreases?

What formula relates wavelength and frequency?

What are the units for wavelength? What are the units for frequency?

How does am radio compare to fm and microwaves?

How are radio waves and gamma wave the same? How are they different?

Why do we have to go to space to see all of the electromagnetic spectrum?

California Physics Standard 4 f

Waves

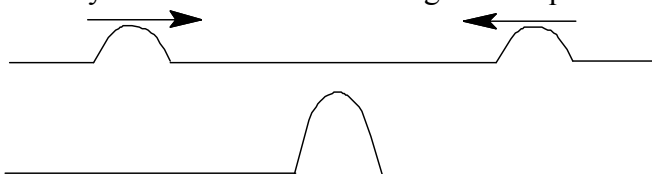
4. Waves have characteristic properties that do not depend on the type of wave.

As a basis for understanding this concept:

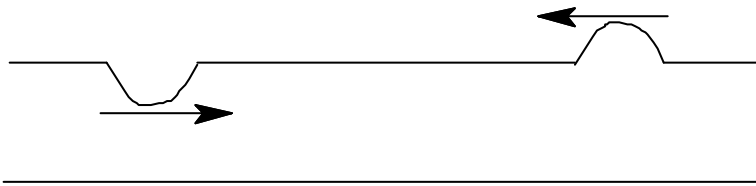
f. Students know how to identify the characteristic properties of waves: interference (beats), diffraction, refraction, Doppler effect, and polarization.

LAB: Interference

When waves from different sources come together in the same place, they combine to form a single wave. This combination can lead to a momentary reinforcement, called constructive interference or perhaps a momentary cancellation called destructive interference. This effect can be easily demonstrated using pulses on a snake spring. With a student at the other end of the spring, carefully instruct them on how to generate quick transverse pulses.



Coordinate launch times so teacher and student start the pulses at the same time. If the pulses are in phase, they will double in amplitude when they cross in the center of the spring.



Now have the student continue to launch the same pulse as before only you reverse the phase of your pulse. This time the combined pulse will give no displacement.

After the pulses cross over in the center of the spring, point out that they spring back into life and retain the same phase as they had before they interfered. When waves interfere, they will return to their original condition after they cross over one another.

Students then study these animations:

<http://paws.kettering.edu/~drussell/Demos/superposition/superposition.html>

Students: describe each type of interference.

California Physics Standard 5 a

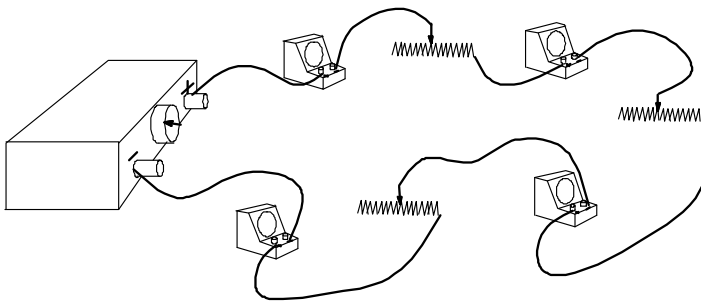
Electricity and Magnetism

5. Electric and magnetic phenomena are related and have many practical applications. As a basis for understanding this concept:

a. Students know how to predict the voltage or current in simple direct current electric circuits (DC) constructed from batteries, wires, resistors, and capacitors.

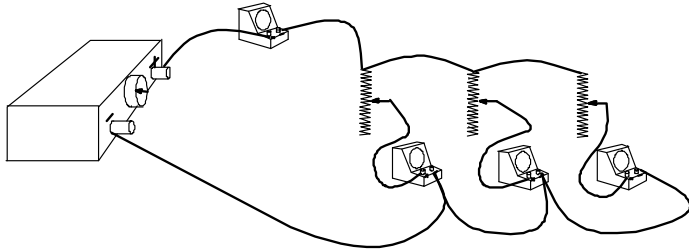
LAB: Comparing current and voltage in a series and parallel circuit.

In a series configuration wire several identical ammeters in series with several identical adjustable rheostats. Before the demonstration discuss with the class how the rheostat (or adjustable resistor) works and carefully adjust them so they obviously have nearly the same resistance. Turn on the power supply and show that the ammeters all read the same value.



Select one of the rheostats, probably the one in the center, and ask the class what will happen to the current if you change this one only. Frequently, most students will answer that only the ammeters after the selected rheostat will change. When you change this rheostat and the students see that all ammeters change to read the same amount, you should be in a good position to discuss how the current in a series circuit is the same everywhere in the circuit. A follow up exercise is to measure the voltage across each rheostat and show that the sum of the individual voltages will sum to equal the total potential difference across the power supply.

Now repeat the above demonstration only place the rheostats in parallel as illustrated on the left. Here the currents may be different and can be adjusted to make any particular value. The ammeter on the top will always read the sum of the individual currents. If a voltmeter is placed across any individual rheostat, it will always read the same value as the voltage across the power supply.



After current has been defined as charge per time, $I = q/t$, and potential difference has been defined as electrical potential energy per charge, $V = PE/q$, it is finally appropriate to define resistance as the ratio of the potential difference across something to the current that passes through the thing, or $R = V/I$. Many devices will maintain a constant ratio of voltage to current over a wide range of values and are said to be “ohmic” (since they appear to obey Ohm’s law.) However, many devices do not display a constant ratio of voltage to current and are called “non-ohmic”. Although Ohm’s law works for many things, most of the interesting devices used in electronics rely on their non-ohmic behavior to produce desired results. The Ohm is the unit of resistance and one Ohm is a Volt per Amp.

California Physics Standard 5 b Electricity and Magnetism

5. Electric and magnetic phenomena are related and have many practical applications. As a basis for understanding this concept:

b. Students know how to solve problems involving Ohm’ law.

LAB: Ohm’s Law Laboratory Activity

This lab will require a battery; three resistors, an ammeter and a voltmeter, and several clip leads. The students will measure the potential difference of the battery and then calculate the expected currents and voltages that will result when the three resistors are wired in any of the configurations discussed above. After they complete their calculations, they can gain real experience with the meters by properly wiring them at assorted points in the circuit. Make sure students clearly understand what it means to wire the ammeter in series with the resistor being tested. To prevent unnecessary drain on the battery suggest that it be connected only when making measurements and choose resistors that are in the neighborhood of 10 ohm to 100 ohm.

Should you choose to use a single multi-meter for this experiment, it is particularly important that students understand that the meter function selector is not simply turned to read amps while still connected across a resistor. It must be disconnected, set to read amps and then wired in series with the resistor to be tested. Finally, if the resistors you are using are small, do not use the mA connection, rather use the A connection. The resistance of the meter when in the mA connection is

often large enough to cause significant error in the readings.

The problem is to find the current through and voltage across the 8 ohm and 4 ohm resistor in a series circuit with 12V battery and resistors of 8 ohm and 4 ohm. (Values were chosen so the arithmetic is easy.) First it should be obvious that the resistors are in series since the current must pass through each resistor in turn as it moves from one side of the source of potential difference to the other. Most students also find it “obvious” that the total resistance of the circuit is the sum of the two resistors in series. (Deriving the expression $R_{\text{equiv series}} = R_1 + R_2 + R_3 = \dots R_n$ might be appropriate.) From Ohm’s law $I = V/R = (8 + 4)/12 = 1$ amp, it can be seen that a current of one amp passes through each resistor. Again using Ohm’s law $V = IR = 1(8)$ or $1(4)$ it can be seen that the top resistor has 8 volts across it and the bottom resistor has 4 volts across it. It can also be seen that the sum of the potential differences across each resistor adds to give the total source voltage. Now the same components are rewired to form a parallel circuit. (The resistors are in parallel since the current has alternate paths to pass through before they return to the battery.) In this case the voltage across each resistor must be 12 V and repeated application of $I = V/R$ gives $12/8=1.5$ amps and $12/4 = 3$ amps through each resistor.

California Physics Standard 5 c

Electricity and Magnetism

5. Electric and magnetic phenomena are related and have many practical applications. As a basis for understanding this concept:

c. Students know any resistive element in a DC circuit dissipates energy which heats the resistor. Students can calculate the power (rate of energy dissipation) in any resistive circuit element by using the formula Power = (potential difference IR) times (current I) = I^2R .

LAB: The power of assorted electrical appliances used around the home.

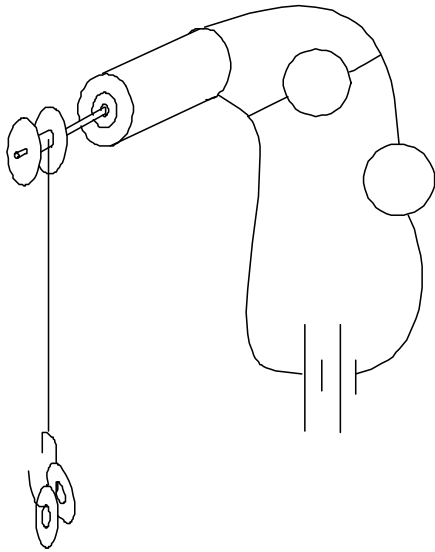
Give students an assignment to discover the power, voltage, and current requirements of assorted appliances used around their home. In most cases the voltage will be about 120 volts but the current will probably have to be computed using the stated power of the appliance. Also have them estimate the average length of time the appliance is used per month to discover the energy used. Help them to understand that a Kilowatt-hour is a unit of energy and that it equals $10^3 \times 60\text{minutes./hour} \times 60\text{sec./minute} = 3.6 \times 10^6$ joule. Have them try to discover how much energy is used in a monthly electric bill.

LAB: Measuring the efficiency of a small electric motor.

A small electric motor that operates on around 3V DC can be used to measure its power efficiency. A small pulley can be made using a short section of dowel with two circles of cardboard glued to either end. This pulley can be drilled along its axis to enable a tight fit to the motor shaft. Using a piece of thread with a bent paperclip on the lower end, a few washers can be hooked to the paperclip and the weight adjusted to enable the motor to pull the washers up at a constant speed. By measuring the time and distance the washers are lifted in a single run, together with the voltage and current through the motor windings, the power into the motor can be computed ($P = VI$)* as well as the output power ($P = Wh/t$). The weight of each washer will have to be measured and adjustments will have to be made to find the correct load to have a constant power in. Students can experiment with different loads perhaps to find an optimum efficiency.

[Since Voltage = Work/Charge and Current(I) = Charge /time, it follows that their product =

power.]



California Physics Standard 5 d Electricity and Magnetism

5. Electric and magnetic phenomena are related and have many practical applications. As a basis for understanding this concept:

d. Students know the properties of transistors and their role in electric circuits.

1. Transistors can be used as switches or amplifiers in electric circuits.
2. The transistor has replaced the vacuum tube in most modern electronic applications.
3. And perhaps that a modern integrated circuit used in a computer probably has over one million transistors etched into it.

A **switch** is a device that can be made to have a very large resistance when “open” and a very small resistance when “closed”.

An **amplifier** is a device that takes a small (electrical) signal and changes it to a large (electrical) signal. The amplifier does not violate the conservation of energy principle; it simply allows a small signal to control the output of a more powerful source of energy.

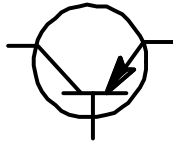
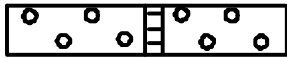
A **transistor** is a device that can change its effective resistance¹ by the application of an electrical signal. (We shall see that this amazing property can turn the transistor into a high speed switch, necessary for digital electronics and computers, **or** can allow the transistor to be used as an amplifier, essential in analog electronics applications.)

There are two basic types of transistors, the **NPN** and the **PNP**. Their symbols are illustrated below: (A helpful mnemonic is to note that the arrow in the NPN is “Not Pointing iN”)

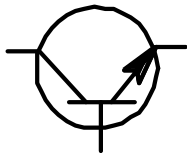
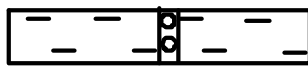
A quick explanation of how the transistor works follows: The power source is connected across emitter and collector with the collector reverse biased. (For example, the collector in an NPN transistor would be connected to the positive pole of the battery and the emitter to the negative pole.) The transistor will not conduct since the base collector diode is reverse biased. However, the holes in the P type base are driven toward the N type emitter and if the plus signal voltage is higher

than 0.7 volts (for silicon) the holes will cross the junction, combine with the electrons in the emitter and give them enough energy to cross into the base. Since the base is very thin, the electrons can be given enough energy to cross into the collector and cause a current. A very small signal voltage can cause a current into the much higher voltage power circuit, amplifying the signal.

PNP



NPN



The transistor is a three terminal device and the essential thing to remember about its performance is that a small electric signal applied to the base of the transistor can cause a very large change in the resistance of the transistor, as measured across the emitter and the collector.

LAB: Series Circuit with resistance replaced by a transistor

To understand how this might be useful, let's look again at the simple electric circuit involving a battery and two resistors in series. When a transistor replaces the lower resistor, a small change in the input voltage can cause a large change in the output voltage. There are details that must be added to this circuit before it can be used as an amplifier or a switch, but the important idea to appreciate is that a small signal on the input to the transistor's base can make a large change in its resistance and therefore make a large change in the output voltage across the transistor. We will discuss the physics behind what makes a transistor display this property later, but for now, the essential idea to understand is that a small change in the electrical signal at the base of a transistor can cause a very large change in the resistance of the transistor, as measured across the emitter and collector.

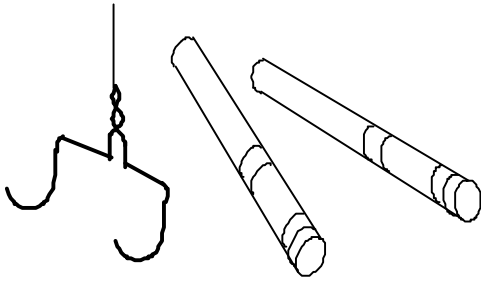
California Physics Standard 5 e Electricity and Magnetism

5. Electric and magnetic phenomena are related and have many practical applications. As a basis for understanding this concept:

e. Students know charged particles are sources of electric fields and experience forces due to the electric fields from other charges.

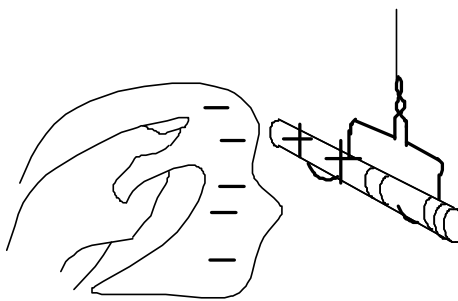
LAB: Basics of Electric Charge

A simple to construct yet very effective apparatus to investigate the forces between charges is illustrated below.



The “cradle” on the far left is made from a piece of soft iron wire or copper wire and the two “wands” are made from thin pieces of plastic sheet. One wand is made from acetate and the other from vinyl. (These can be purchased from plastic supply houses in sheets 0.010” thick.) Roll the thin plastic sheet into cylinders and tape them on one end with scotch tape. Holding the taped end in one hand and rubbing the other end with a paper towel will produce opposite charges on each wand. The cradle is supported with thin monofilament nylon fishing leader and can either be attached to a support stand or perhaps another student can hold it, allowing the cradle to rotate freely. Rubbing one of the wands and carefully placing it in the cradle, then bringing another wand that has also been rubbed with paper near it will cause an attractive or repulsive rotation depending upon whether the charged wands are the “same” or “opposite”.

To show that rubbing the paper on the plastic wand does not “create” charges but only separates them, bring the recently rubbed paper near the associated wand and note that the paper will always attract the wand. This is true no matter which plastic material you begin with. Finally, to illustrate the basics of electrostatic induction, bring a charged wand near the uncharged metal cradle. Students may be surprised to see that the cradle will always be attracted no matter which rod is used. Since the cradle is a conductor, the charged wand will attract the opposite charges to the near end and force the same charges to the far end, always causing attraction. (The separation of plus and minus charges in a conductor by an electric field is called electrostatic induction.)



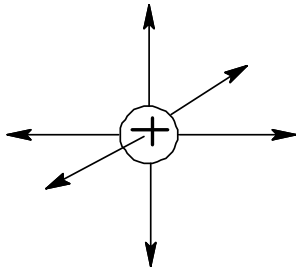
Electric Field

Understanding the physics behind electric circuits, transistors and many different electrical devices is greatly enhanced by having an appreciation of the concept of the electric field. Newton did not have the field concept and discussed gravity only as “action at a distance”. With the work of Michael Faraday, a new and powerful way of looking at the force of gravity, electrical and magnetic forces as well as many other physical ideas, was born.

Newton admitted he did not know why the earth could attract the moon at such a great distance or

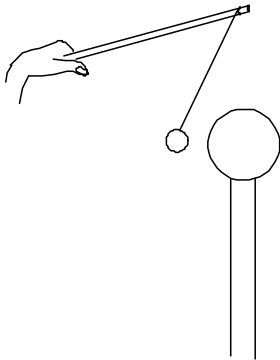
why the earth could attract an apple without any visible connection between them. Although he described in great detail how this “action at a distance” operated, he did not explain why it operated the way it did. Faraday’s insight was to suggest that the space surrounding a charged object was actually modified by the charge. Although this still did not explain why the space was modified, it provided a way to visualize and calculate how this modified space could affect other charged objects. Faraday suggested that the electric field could be illustrated with directed lines. The direction of the lines would represent the direction that a plus charge would be forced in the field, and how close the lines were together represented the strength of the field. Consider the electric field around a single positive charge:

The illustration is supposed to represent three-dimensional space. The field lines are directed outward because if another plus charge (or test charge) were placed anywhere around the charge, the force on it would be directed outward. The lines are close together near the charge and far apart at a great distance from the charge. This represents that the force on the test charge would be strong near and weaker at a greater distance. (In fact, these lines will spread out as $1/r^2$.)



LAB: Introduction to the Electric Field

Charge a Van de Graaff and turn it off. Using a stick with a small conducting sphere hanging from it by a piece of fishing leader, bring the small sphere near and let it acquire charge by conduction. The sphere will jump away and can be moved around the Van de Graaff illustrating the presence of the electric field. While holding the small sphere near the Van de Graaff under the force of the field, ground the Van de Graaff and the small sphere will fall. This illustrates that the electric field was a result of the charge on the Van de Graaff. This very simple demonstration can help students to appreciate the action of the invisible electric field.



California Physics Standard 5 m*

Electricity and Magnetism

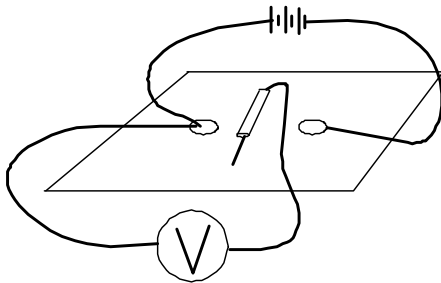
Electric and magnetic phenomena are related and have many practical applications. As a basis for understanding this concept:

m. * Students know static electric fields have as their source some arrangement of electric charges.

LAB: Mapping equipotential lines around static charge configurations:

The basic idea behind this lab is to use a special conducting paper (Sargent Welch WL1960A 25 sheets for \$15) that has a uniform resistance per unit area. A simple charge configuration is painted on this paper with conducting paint.

These “charges” are connected to a battery or low voltage power supply that establishes a current flow throughout the surface of the conducting paper. Using an inexpensive DC voltmeter with one probe attached to a reference “charge” the other probe can be moved about on the paper keeping the voltage reading constant, therefore plotting out an equipotential line. This plotting can be repeated for several different constant potential traces, mapping out several different equipotential lines.



The result of this exercise is to produce many different equipotential lines and constructing lines everywhere perpendicular to the equipotential lines can generate the electric field lines from the charge configuration. A point to stress with all field line sketches is that in the real world, all fields are three-dimensional. The electric field lines and lines extending into three-dimensional space and the equipotential lines are really equipotential surfaces.

California Physics Standard 5 n

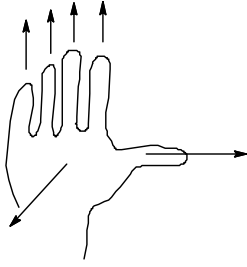
Electricity and Magnetism

Electric and Magnetic phenomena are related and have many practical applications. As a basis for understanding this concept:

n. * Students know the magnitude of the force on a moving particle (with charge q) in a magnetic field is $qvB \sin(\alpha)$ where α is the angle between v and B (v and B are the magnitudes of vectors v and B , respectively), and students use the right-hand rule to find the direction of this force.

LAB: Hand waving and the direction of force on a moving charge

It should be discussed that the right hand is used in two different ways when attempting to describe the relationship between moving charges and the magnetic field. In section 5g we discussed how to use the right hand to determine the direction of a magnetic field that resulted from a current (or a moving charge.) Now we assume the magnetic field already exists and we will be using the right hand to find the direction of the force on a charge moving through the field. This can easily confuse students if the two different uses of the right hand rule are not discussed.

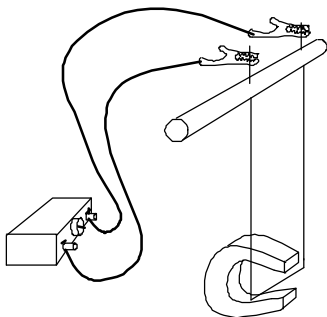


There are several different ways of stating this mnemonic but we like the following called the “flat hand rule” to distinguish it from the “curled finger rule” previously used to describe the magnetic field around a current.

The field, B , velocity, V and force F form a three-dimensional coordinate system. The palm of your (flat) right hand is used to push things; hence it is logical to have it represent the direction of the force. When you thumb a ride, you point your thumb in the direction of your intended velocity; hence the direction of your thumb is the direction of the velocity. Finally, your fingers (begins with “F”) point in the direction of the Field. Hence fingers in the direction of the field, thumb in the direction of velocity and palm in the direction of force describe a positive charge moving through a magnetic field. If the charge is negative, use the left hand.

LAB: To illustrate how moving charges are affected by B fields:

Illustrated below is a demonstration that can effectively show the direction of the Lorentz force. It requires a strong magnet and a power supply that can produce a short burst of current in the 10-amp range. The suspended loop of wire is bent so a horizontal section passes through the most intense region of the magnetic field. The suspended wire is supported by a wooden dowel that has been drilled to pass the wire enabling easy connection of the power supply leads with clips. The dowel is supported by a ring stand and the magnet should be firmly held so it won’t move. Changing the clips can easily reverse direction of the current. Using a compass needle determine the direction of the magnetic field of the magnet. Knowing the polarity of the power connections, the direction of the current will be known. Before you momentarily turn on the power, have the students use the right hand rule to predict the direction they will move in the field. After the first demonstration, perhaps reverse the direction of the current and/or turn the magnet upside down.



The units of electric field intensity, E and magnetic field intensity, B :

The electric field intensity is defined by: $E = F/q$ and the electric field intensity unit has no special name. It is simply a Newton/Coulomb. However, the unit of magnetic field intensity is the Tesla. If a charge of one Coulomb moves at a velocity of one meter per second at right angles to a

magnetic field of one Tesla, it will experience a force of one Newton. Using the Lorentz force expression gives $B = F/qv = \text{N/Cm s}^{-1} = \text{N-s/C-m}$ or one Tesla = one Newton sec/Coulomb-meter. (There are several other names for the unit of magnetic field intensity and they all mean the same thing. These are given here just for reference: Tesla= Weber/m² = Newton/amp-meter. A common unit of magnetic field intensity is the Gauss. One Tesla = 10⁴ Gauss. The intensity of the earth's magnetic field at the earth's surface is about one half a Gauss.)

California Physics Standard 5 o

Electricity and Magnetism

5. Electric and magnetic phenomena are related and have many practical applications. As a basis for understanding this concept:

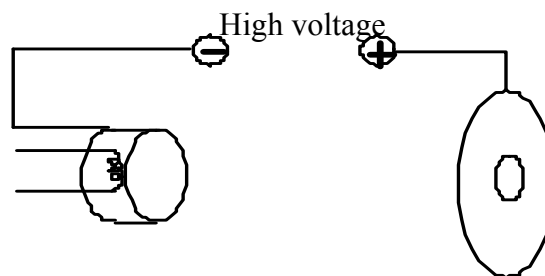
o. * Students know how to apply the concepts of electrical and gravitational potential energy to solve problems involving conservation of energy.

LAB: Electron Gun CRT

In Sections 2a, b and c we discussed ways of presenting the relationship between work, kinetic energy and potential energy in a gravitational field. This section simply extends this discussion to charges in electric fields. The key idea here is that “voltage” or potential difference is work (or potential energy) per charge. $V = PE/q$. If we move a charge against the force exerted by an electric field we give the charge energy and the work done per charge is called voltage, or perhaps more correctly, potential difference.

An electron gun as an example of energy exchanges in an electric field:

Older television sets, and computers produce their images through the interaction of high velocity electrons and a phosphor coating on the inside face of a cathode ray tube.



The essential electron gun structure is illustrated above. The can on the left has a hot filament inside of it that causes electrons to be emitted from the surface of this can. Since this can is connected to the negative side of a very high voltage, it is called the cathode. The electrode on the far right with the hole in it is attached to the positive side of the high voltage and is called the accelerating anode. An intense electric field exists between the accelerating anode and the cathode that causes the electrons to achieve a high velocity as they move in this field. (Other structures called “focusing electrodes” are between the cathode and accelerating anode that create an appropriate electric field to force the electrons to pass through the hole in the accelerating anode.) Computing the energy and speed of the electrons as they pass through the hole in the accelerating anode is a simple application of $V = PE/q$. The negatively charged electron will move against the E

field toward the accelerating anode, gaining kinetic energy as it loses potential energy. When it passes through the hole, all the PE will be converted to KE so, from $V = PE/q$:

$$PE = Vq = \frac{1}{2}mv^2 \quad \text{or,} \quad v = \sqrt{2Vq/m}$$

A typical accelerating voltage in a large TV set is around 10,000 volts. Using the charge and mass of the electron in the above gives:

$$\text{Approximate electron speed, } v = \sqrt{2 \times 10^4 (1.6 \times 10^{-19} / 9.1 \times 10^{-31})} = 10^8 \text{ m/sec}$$

This is approaching the speed of light and although the Standards do not address special relativity, it is interesting to note that even in an ordinary TV set, relativity can play a role. One of several links on the web to “electron gun CRT” is:

<http://electronics.howstuffworks.com/question694.htm>

Key Assignments

In addition to chapter readings, assignments, quizzes, and tests, students will complete the following:

- All labs must be completed. All questions that are presented in the laboratory manuals must be completed and a thorough write up (per the directions in the lab manual) of each of the labs must be submitted and retained in the student’s portfolio
- Research Projects: Students will complete one research project each semester on a physics topic of choice related to their units of study. The project will include a demonstration of a physics principle covered by their topic which relates to the standards presented during the semester. The instructor must approve the topic in advance. Each report must demonstrate the use of a least three resources.
- Students will demonstrate competence in making necessary calculations as required in each unit studied.
- Students will make one presentation per semester describing a study of current physics

Instructional Methods and Strategies

Students will be expected to develop and present work as described in the lab activities section and under the key assignments section as well as those required in the textbook/curriculum used. Students will work independently through the text as a primary resource. In order to support this process teachers will provide each student:

*Direct instruction in the form of lecture

*Opportunities to discuss and define complex issues

*Modeling of activities and expected outcomes

*A variety of print and non-print resources including the use of technology as a research tool

- *Modeling of study strategies appropriate for different learning styles
- *Discussions around points of view
- *Opportunities to summarize, analyze, compare/contrast, describe, classify, and persuade
- *Opportunities for practice in preparation for presentations plus the actual presentations

Assessment Methods and Strategies

A variety of assessment tools may be used. Written work, as described in the key assignments, will be graded using a standard rubric. Assessment tools include but are not limited to:

- Criterion-based chapter tests and quizzes.
- Comprehensive quizzes, mid-term and end of semester exams.
- Laboratory reports and tests.
- Research reports and presentations.
- Class participation and in-class assignments.