Physics 11 & Physics 12

Question, Investigate, Discover!

A Teaching Resource

NOVA SCOTIA
Department of Education

Physics 11 and Physics 12:
A Teaching Resource

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Physics 11 and Physics 12: A Teaching Resource

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CONTENTS

INTRODUCTION

The curriculum described in *Foundation for the Atlantic Canada Science Curriculum* and in *Atlantic Canada Science Curriculum: Physics 11 and Physics 12* was planned and developed collaboratively by regional committees. The process for developing the common science curriculum for Atlantic Canada involved regional consultation with the stakeholders in the education system in each Atlantic province. The Atlantic Canada science curriculum is consistent with the science framework described in the pan-Canadian *Common Framework of Science Learning Outcomes K to 12.*

Physics 11 and Physics 12: A Teaching Resource is a practical curriculum support document designed to assist teachers in the effective delivery of the curriculum prescribed for Physics 11 and Physics 12. It includes a range of experiments and activities and related handouts for students.

Section 1: Science Readings is intended for students to do independently or in groups. Section 2 has suggestions for STSE projects. Section 3 includes suggested experiments and activities for Physics 11. Section 4 has exercises and investigations for Physics 11. Section 5 includes suggested experiments and activities for Physics 12.

This resource complements the curriculum guide, *Atlantic Canada Physics: Physics 11 and Physics 12* and the textbook, *McGraw-Hill Ryerson Physics*, that are being used in Nova Scotia schools.

SECTION 1: SCIENCE READINGS

Nuclear Reactors Worldwide

The following information relates to nuclear reactors in use worldwide. Read the material provided and answer the questions that follow. Some of the questions ask you to relate this material to what you have learned in class.

Reactors Operational Worldwide

Reactor type		Comment
Advanced gas-cooled reactor	AGR	15 operating worldwide
Boiling water reactor	BWR	95 operating
Gas-cooled reactor	GCR	21 operating in Japan and UK
Liquid metal fast breeder reactor	LMFBR	5 operating in Europe
Pressurized heavy water reactor	PHWR	operating in Canada and India
Pressurized water reactor	PWR	more than 300 operating worldwide
Chernobyl design	LGR	water-cooled/graphite-moderated

The CANDU reactor was designed by Atomic Energy Canada Limited (AECL) as an alternative to other designs that use slightly enriched uranium (2–5% U-235). The CANDU system does not require a pressure vessel and can, therefore, be built in countries where construction technology is limited. It is fueled with pellets of uranium dioxide made from natural uranium (0.7% U-235). It is cheaper to fuel and theoretically gives higher lifetime capacity. On the other hand, fuel burnup is much lower than pressurized water reactors (PWR) (less than 20%). The CANDU reactor has considerable redundancy built in, which permits longer operating cycles.

The design consists of a horizontal calandria (container) that has tubes for the fuel rods and cooling heavy water. These tubes are surrounded by heavy water, which acts as a moderator to slow down neutrons. Heavy water is two atoms of deuterium and one atom of oxygen. Since about 1.5% of all hydrogen atoms are deuterium isotopes, a separate plant must be built to separate heavy water molecules from large quantities of natural water. Since heavy water is a much better moderator than natural water, the reactor can function without enriched fuel. The cost of deuterium separation is offset by the lower costs of unenriched fuel.

Like the more common PWR, pumps circulate the cooling heavy water through a closed system to a steam generator beside the reactor. The moderator heavy water circulates through a separate heat exchange system.

The CANDU system uses a vacuum building as a separate containment protection feature. There is also more computer-based control in the operating system to protect the reactor. Because of the need for periodic service shutdowns, reactors are usually built in groups of two to eight per site. There are CANDU-powered generators in Ontario, Quebec, and New Brunswick.

1. The fission of uranium in nuclear reactors takes place according to the following equation.

   $${}^{1}_{0}\text{n} + {}^{235}_{92}\text{U} \rightarrow {}^{92}_{36}\text{Kr} + {}^{141}_{56}\text{Ba} + 3\,{}^{1}_{0}\text{n} + 200\ \text{MeV}$$

   What characteristic of this reaction leads us to call it a "chain" reaction?

2. What are two advantages of the CANDU reactor design over other types of reactors?

3. Using the uranium decay equation given in problem 1, determine the number of atoms of uranium that would have to decay to generate 6.0×10^{3} MeV?

4. What are two serious concerns relating to nuclear power stations? In three or four sentences for each, elaborate on the nature of the concern and the degree of risk.

5. One of the criticisms of the CANDU reactor is that it was designed to be sold to Third World countries that would then be markets for Canadian uranium and heavy water. This situation would result in the proliferation of nuclear technology, which could be diverted to military application.

   In 100–150 words, discuss the following points:

   - at least two design characteristics that lead to this conclusion
   - at least two concerns about the operation of nuclear facilities in developing countries
   - at least two controls or alternatives that might meet the energy needs in developing countries

Photoelectric Effect

In your physics studies, you have learned about the photoelectric effect. Under the right conditions, light shining on a metal surface, can result in the ejection of an electron from the surface of the metal.

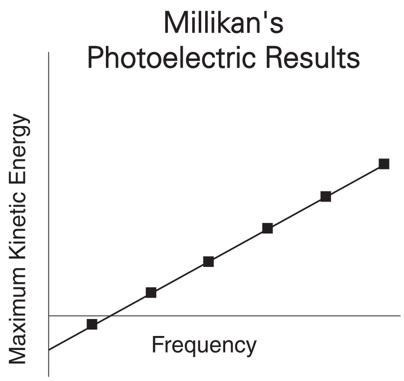
In 1902 a physicist named Philipp Lenard (1862–1947) used a sensitive apparatus to measure the current produced when ultraviolet light was directed onto the surface of a metal. Lenard's data showed that ultraviolet light with a constant intensity ejected electrons with a variety of energies, but that there was always a maximum energy. In further studies with a prism that restricted the light to a narrow range of frequencies, his data led him to the conclusion that the light of higher frequency always ejected electrons with a higher maximum kinetic energy than the maximum kinetic energy from light having lower frequency. Lenard discovered that the more intense the light, the greater the number of electrons emitted. He also discovered that the maximum kinetic energy of the ejected electrons depends only on the frequency of the light and not on the intensity of the light.

Later on, Albert Einstein (1879–1955) linked Max Planck's (1858–1947) quantum of energy and the photoelectric effect. Einstein proposed that light be considered as quanta or photons. By doing this Einstein was able to explain the photoelectric effect. According to Planck, the energy (E) is related to the frequency (f) by the formula $E=hf$ where h is the constant known as Planck's constant. Einstein explained that, since light of higher frequency would have more energy, then this would explain why the higher frequency light has a higher maximum kinetic energy than the lower frequency light seen by Lenard. As to the range of kinetic energies of the emitted electrons at any given frequency, Einstein suggested that since the kinetic energies of the emitted electrons varied, some of the energy must be converted to forms other than kinetic. Electrons farther from the surface of the metal use some of the energy from the photon to become surface electrons and then are ejected. Electrons with the most kinetic energy are the ones that are most loosely bound to the surface. Einstein called the minimum amount of energy needed to eject the electron the work function (W). The maximum kinetic energy would be the difference between the energy of the photon (hf) and the work function W.

$$Ek(max) = hf - W$$

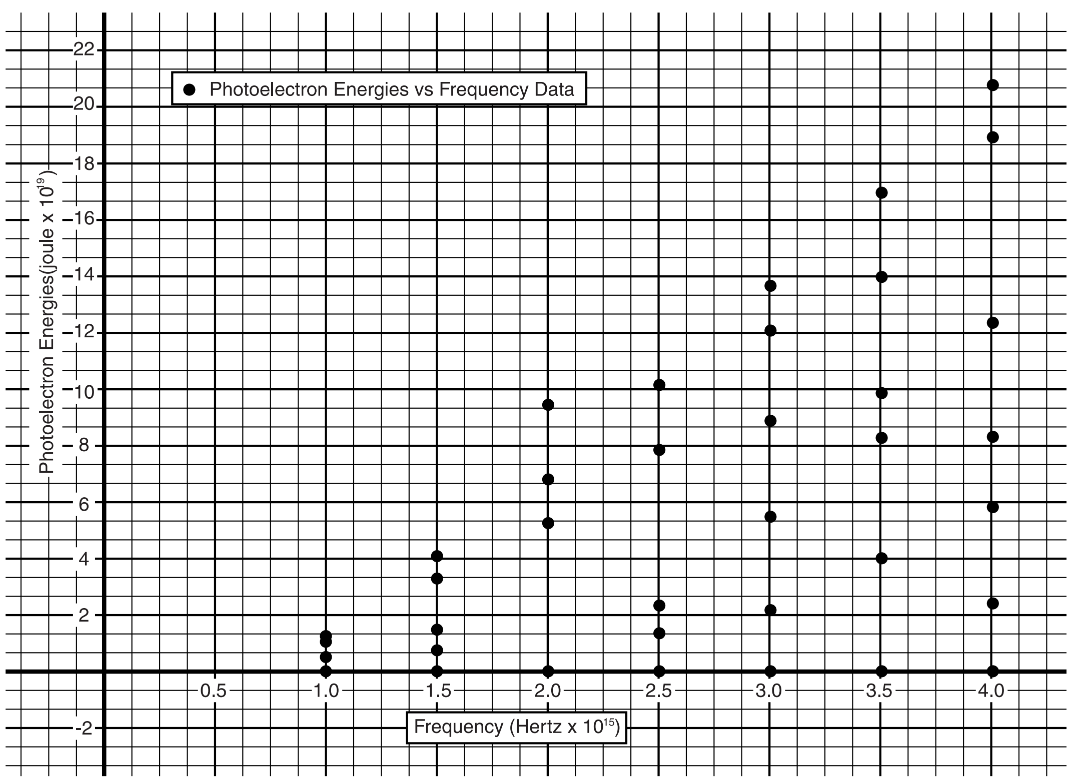
As a point of interest, not many physicists believed this quantum explanation because of the historical evidence that supported a wave model of light. If Einstein were correct then this would be supporting evidence for the particle model of light. Without a known charge on the electron at the time, Einstein's explanation could not be supported or contradicted.

Robert Millikan (1868–1953) measured the charge on an electron by 1916 and he used this to measure the kinetic energies of the ejected electrons. He then plotted graphs of the maximum kinetic energy vs. the frequency of the light. This is the graph that you are familiar with from your work in class.



- What does the slope of this graph represent?
- What does the *y*-intercept on this graph represent?
- What does the frequency at the point where the line crosses the *x*-axis represent?

In an experiment with an unknown metal, several frequencies of light were shone on the metal, and the following results were obtained:

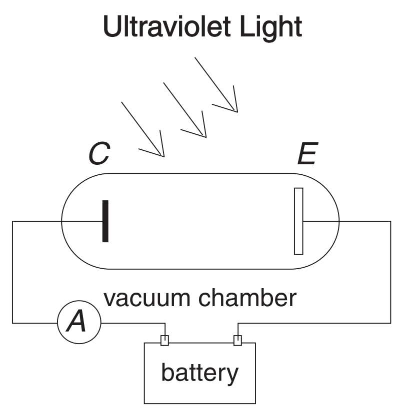


- What does the fact that there are several data points at each of the frequencies tested mean?
- By drawing an appropriate line or appropriate lines on this graph, find, state, and show on the graph the frequency below which no electrons would be emitted.

Based on the following chart of work functions for various metals, which metal is our unknown metal most likely to be? Explain your choice using some mathematical analysis and the graph.

Metal	**Work Function (J)**
Aluminum	6.8×10^{-19}
Barium	4.0×10^{-19}
Calcium	5.3×10^{-19}
Magnesium	5.9×10^{-19}
Sodium	3.6×10^{-19}
Zinc	8.5×10^{-19}

In measuring the energies of the ejected electrons, Lenard used an apparatus that included a glass vacuum tube with two electrodes inside the tube. Outside the tube, the electrodes were connected to a source of potential difference. Examine the following schematic diagram.



Ultraviolet light enters the tube and strikes the emitter *E*, and the ejected electrons then travel from the emitter (E) to the collector (C). Lenard confirmed that the electrons were leaving the emitter by making the emitter negative and the collector positive. When the ultraviolet light struck the emitter, a current was seen to flow. To further investigate the energies, Lenard reversed the connections on the battery so that the electric field between the electrodes would oppose the motion of the electrons. Starting with a small potential difference, he gradually increased the potential until no current flowed. At this point the electric field was opposing the flow of all electrons.

The potential difference that stopped all photoelectrons from flowing is now called the stopping potential.

- Using data from the graph, determine the speed with which the most energetic electrons were being emitted when the frequency of the light was 4.0×10^{15} Hz.
- Determine the stopping potential of the electrons if they have a frequency of 4.0×10^{15} Hz.

Generating Electricity

There is no doubt that this century will see an ever-increasing demand for energy worldwide. Producing and delivering the energy where it is needed will be a challenge. There will also be increasing concern for the environment. You have been asked to speak on the affirmative side in a debate of the following resolution.

Be it resolved: Canada should develop more nuclear-powered electric generating stations to meet the energy needs of the twenty-first century.

Prepare a 300–400-word draft of a speech in support of the resolution using the following information. Be sure to address these points: fuel supply now and for the future, fuel cost, impact on the environment, and risk to human life.

Supplementary Information

Energy Equivalents for Various Energy Sources

Source	Tonnes of coal to replace 1 T fuel
Breeder reactor	1 300 000
CANDU reactor	20 000
Light water reactor	16 000
Oil	1.5
Coal	1
Peat	0.25
Oil shale	0.15
Geothermal power	0.1

Relative Costs of Fuel (Canadian Dollars)

Year	Uranium 1 fuel bundle	Coal 400 T	Oil 1 800 barrels
1988	$3 055	$27 000	$33 000
1994	$2 000	$16 000	$22 000
2000	$2 400	$28 000	$50 000

Atmospheric Pollution and Solid Waste from World Energy Use
(millions of tonnes)

Source	Sulphur dioxide	Nitrogen oxides	Particulates	Monoxide	Carbon oxides	Waste
Coal	100	10	500	3	9 000	200
Gas	< 0.5	2	< 0.5	5	4 000	minor
Oil	40	10	2	200	9 000	1.5
Wood	0.2	3	100	200	5 000	50
Nuclear power	0	0	0	0	0	0.04
Hydro power	0	0	0	0	0	0

These figures are approximate. Gasoline use in vehicles produces about 200 000 000 tonnes of carbon dioxide yearly worldwide. In the waste column, only nuclear waste is totally managed and controlled.

Total Risk per Megawatt-Year Energy Output

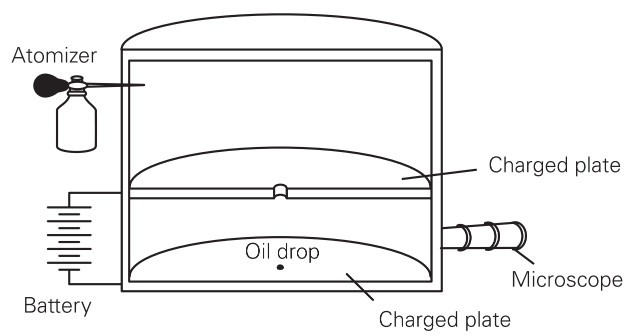
Source	Person days lost	Note
Coal	2 000	
Oil	1 800	
Nuclear power	10	too high; based on inappropriate low-dose hypothesis
Natural gas	7	too high; does not include disasters like earthquakes

Supply notes: No large scale hydro generators are planned. Natural Resources Canada estimates that Canada has a reserve of coal that could last 100 years. Worldwide reserves of oil are also estimated at 60–100 years. Canada's natural gas reserve is large and growing, but the price is close to the world price for oil. Uranium supply is ample for hundreds of years.

The Millikan Oil Drop Experiment

From 1909 to 1913, Robert Andrews Millikan performed a very important series of experiments that were dependent on the uniform electric field between a pair of parallel plates. The results of these experiments, together with his contributions to research on the photoelectric effect, led to his Nobel Prize in Physics in 1923. Millikan verified the existence of a fundamental electric charge, carried by the electron, and provided its precise charge. This had tremendous impact on the further development of the theory of the structure of matter.

The experimental procedures used by Millikan were actually a modification of earlier techniques used by J. J. Thomson (1856–1940). A pair of parallel plates was very finely ground to smoothness, and a tiny hole was drilled in the top plate. An atomizer was mounted above the plates and used to spray tiny droplets of oil into the region above the plates. These droplets acquired an electric charge, presumably from friction, as they were sprayed. The whole apparatus was kept in a constant-temperature enclosure, and the region between the plates was illuminated with an arc lamp. The apparatus is illustrated below.



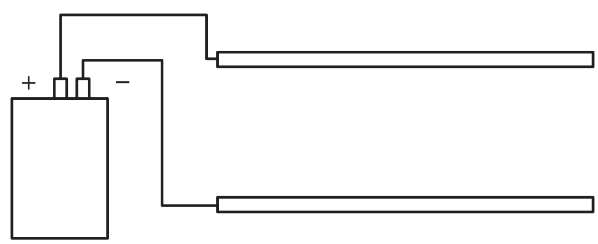
A droplet that fell through the hole and into the region between the two plates could be viewed through a small microscope. The droplet would very quickly reach terminal velocity as it fell under the influence of the force of gravity and the resistance of the air. This terminal velocity (v_0) could be measured by timing the drop as it fell between the lines on a scale in the eyepiece of the microscope.

Most of the droplets seemed to attain a negative charge, so the plates were connected to a variable power source that could generate from 3 000 V to 8 000 V of potential difference with the top plate being positive. In that way, a negatively charged drop could be made to reach an upward terminal velocity under the influences of the applied field and the effective weight of the drop. This second terminal velocity (v_1) was also recorded.

Millikan noted that the terminal velocity of the charged oil drops, which depended on the charge itself, varied from trial to trial. Over a very large number of trials, however, the velocity values could be grouped into categories. Each category represented an integral multiple of the lowest observed value. This led him to conclude that the charge on the oil drops themselves could be quantified as an integral multiple of one fundamental value. Millikan then used mathematical analysis to determine that value.

1. By what process was the oil drop in Millikan's experiment charged?

2. On the diagram below, draw electric field lines to indicate the electric field between two parallel plates.



3. If a certain oil drop has a charge of 4.80×10^{-19} C, and the electric field intensity between the plates is 2.62×10^{6} N/C, what is the electric force acting on the oil drop?

4. When the oil drop has achieved terminal velocity, it is no longer accelerating. Draw a free-body diagram showing all the forces that are acting on the oil drop in this state.

5. Show that the electric field intensity is given by: $E = \frac{mg}{q}$.

6. The electric field intensity between two parallel plates can be expressed as $E = \frac{v}{d}$, where V is the potential difference applied to the plates, and d is the plate separation. Equate the expression in question 5 with this expression and solve for q.

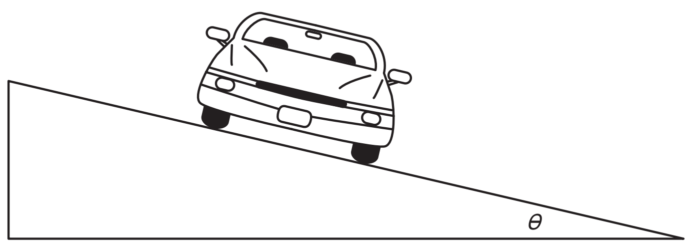
7. For one trial, Millikan used a potential difference of 4.20×10^{3} V, a plate separation of 1.60×10^{-3} m, and an oil drop of mass 3.00×10^{-15} kg. Determine the charge on the oil drop.

Designing Roadways

Engineers designing roadways must make careful calculations involving centripetal force at all curves, but especially at exit ramps from high-speed highways. The typical ramp is an approximately circular arc. Some force must be exerted towards the centre of the circle to make a vehicle follow the path. On a flat curve, this force is supplied by friction between the tires and the road surface. If the outer edge of the ramp is raised (a design called "banking"), the frictional force can be reduced or even eliminated.

1. If a vehicle, mass 2 500 kg, enters a ramp at a speed of 120 km/h, what is the magnitude of the centripetal force required to make it follow a curve of radius 160 m?

2. To the right of the diagram below, draw a labelled diagram of vectors representing the weight of the vehicle, the normal force, and the vertical and horizontal components of the *normal force*.



3. There is a derived expression which can be used to determine the bank angle that would completely eliminate the need for friction to provide the centripetal force. It is:

   $$\tan\theta = \frac{v^2}{rg}$$

   Using this formula, calculate the bank angle for the vehicle described in question 1.

4. The Daytona 500 is a major NASCAR race run on a track that has a radius at the top of the banked track of 316 m and a bank angle of 31°. At what speed, in km/h, must the race cars travel so that no friction is needed to provide centripetal force?

5. From the expressions for the components of the normal force, show an algebraic derivation of the bank angle formula shown in question 3.

6. Write about the societal implications of improperly designed roadways. Some ideas for discussion may include the following:

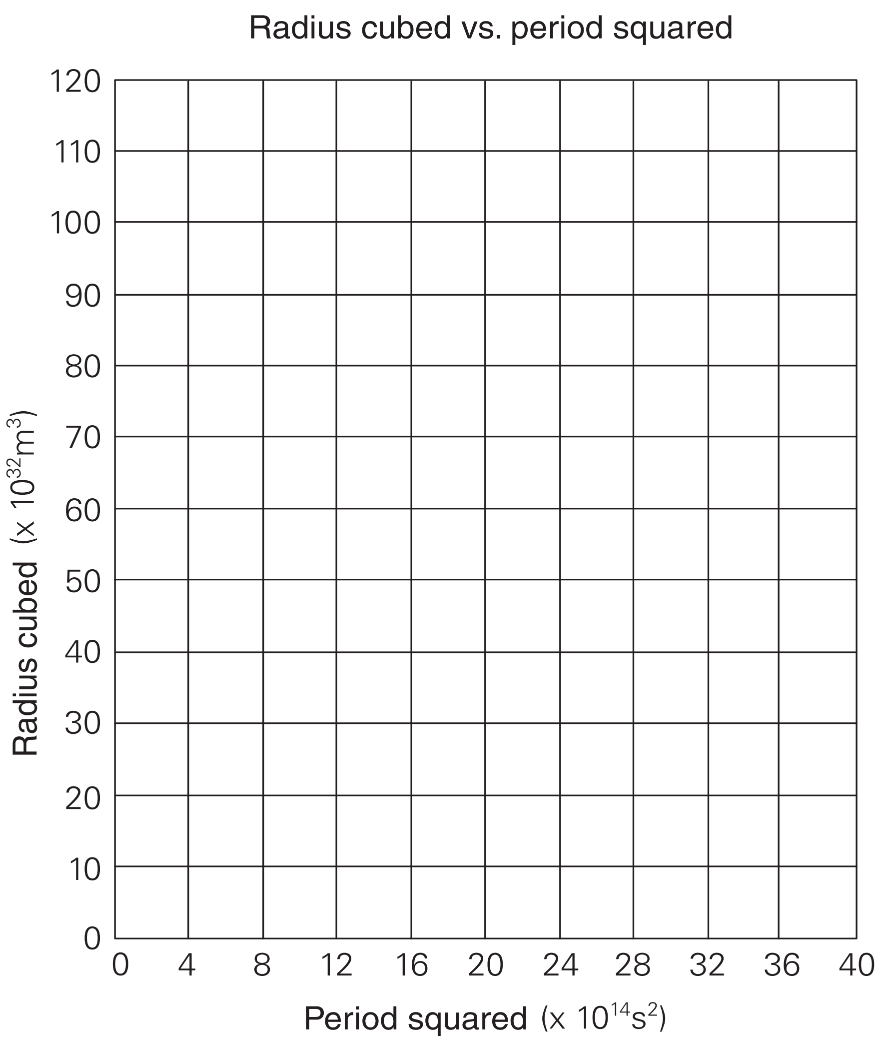
   - road design—road surfaces, number of lanes, banking on/off ramps and corners
   - traffic flow, time spent travelling
   - cost of building roads
   - environmental impact, land use, noise pollution, atmosphere pollution
   - accidents—personal injury, damage to property, cost to health care, insurance

The Planets

Planet	R (m)	T (s)	R^3 (m^3)	T^2 (s^2)
Mercury	5.79×10^{10}	7.60×10^{6}		
Venus	1.08×10^{11}	1.94×10^{7}		
Earth	1.49×10^{11}	3.16×10^{7}		
Mars	2.28×10^{11}	5.94×10^{7}		

1. Calculate R^3 and T^2 for each of the planets in the table above and put the values in the table.

2. Plot a graph of R^3 vs. T^2 on the grid below and show a line of best fit.



3. Calculate the slope of the best fit line and indicate the points used on the graph.

4. What does the slope represent?

5. Newton hypothesized that the centripetal force on a planet was provided by the gravitational force of attraction between the sun and a planet. Equate the expressions

   $F_c = \frac{4p^2Rm}{T^2}$ and $F_g = G\frac{m_1m_2}{d^2}$, where $d = R$, and solve for R^3.

6. Given that the mass of the sun is 1.98×10^{30} kg, calculate $\frac{Gm}{4p^2}$.

7. Do the values found in questions 3 and 6 support Newton's hypothesis (as outlined in 5)? Explain your answer.

Section 2: Science, Technology, Society, and the Environment

STSE Topics

The following list is a starting place for STSE research and discussion and is not intended to be a definitive list.

Physics 11

Momentum and Energy

- airbags in cars
- bulletproof vest
- children's swings
- crumple zone in car
- disc brakes
- shock absorber
- baseball bat
- baseball
- golf ball
- golf club driver
- tennis racquet
- splitting mauls and axes
- seat belts
- crash helmets
- swim fins
- excavator
- baseball glove
- CD antiskip device
- bicycle tires
- car tires
- bicycle gears
- yo-yos
- hammers
- gym floors
- hockey sticks
- goalie masks
- can openers
- food mixers
- running shoes

Waves

- cell phones
- microwave ovens
- ocean-going oil drill rigs
- shoreline protection from waves
- musical instruments
- ship sonar
- ultrasound
- microwave oven
- hearing aid
- X-ray imaging
- hearing protection
- soundproofing
- speakers
- night vision
- radar
- bat cane for blind
- lasers

- fibre optic transmission
- FM/AM radio
- wave-generated power
- seismograph survey for oil
- laser surgery
- GPS
- CD technology
- stabilizing bridge against resonance
- stabilizing shorelines against waves
- laproscope
- earthquake seismology

Physics 12

- hydroelectric power generation
- thermoelectric power generation
- nuclear reactors for power generation
- solar power generation
- wind power generation
- launching rockets into space
- use of nuclear weapons
- use of electric appliances
- use of electric lights
- electric fields and health
- automobile collisions (two-dimensions)
- nuclear medicine
- Maglev trains
- engines—Wankel, diesel, gasoline, piston
- nuclear wastes: NIMBY (not in my backyard)
- radon gas in homes
- smoke detectors
- nuclear accidents (Three Mile Island, Chernobyl)
- MRI for imaging
- neutron imaging
- electron microscopy (TEM, SEM, scanning, tunnelling)
- X-ray imaging
- superconductors
- speaker technology
- electric motors
- xerographic process
- liquid crystal display
- particle accelerators
- radioactive dating
- radioactive tracing
- food sterilization using gamma radiation
- using radiation to produce genetic mutations

Rube Goldberg Machine

Name: ____

Group Members: ____________________________________

Problem

Design and construct a complicated machine to do a simple task.

Materials

Any recycled/recyclable materials found around home and garage.

Background

Rube Goldberg was a cartoonist famous for drawing complicated machines to complete simple tasks such as licking a stamp or picking and peeling an apple. Visit <www.rube-goldberg.com> to learn more about the potential of this project.

Procedure

Design and construct a complicated machine to complete a simple task. You may work in groups of three or two and should register your group with the teacher. The following requirements must be met to have a complete project:

- Maximum dimensions are 1.0 m × 1.0 m × 1.0 m.
- Use only recycled/recyclable materials.
- Have these components—at least one of each—1st, 2nd, 3rd class lever, inclined plane, pulley, mechanical wave, sound, light source, elastic collision with transfer of momentum.
- Complete a single simple common task by the end of the machine's run.

At the beginning of the machine's run, the group members should show the class the required components of the machine. You will have only two attempts to get your machine to complete its task.

Safety

- Instruction and supervision are required for use of tools and power tools.
- If using hot glue gun, do not get it on your skin.
- Open flames, explosive or flammable materials may not be used.

- Sharp points, blades, and edges must be enclosed so there is no possibility of personal injury.
- Any electricity may only be provided by 2-1.5 volt batteries.
- Any projectiles launched must be safely contained within the dimensions of the machine.

Scientific Vocabulary

1st class levers, 2nd class levers, 3rd class levers, inclined plane, pulley, mechanical wave, sound, light source, elastic collision with transfer of momentum, machine

Rube Goldberg Machine

Teacher Notes

Outcomes

Students will be expected to

- construct and test a prototype of a device and troubleshoot problems as they arise (214-14)
- analyse natural and technological systems to interpret their structure and dynamics (116-7)
- distinguish between problems that can be solved by the application of physics-related technologies and those that cannot (118-8)
- describe and evaluate the design of technological solutions and the way they function, using scientific principles (116-6)

Materials

Any recycled/recyclable materials found around the home and garage can be used for this project, if the project is done at home. If students do the project at school, then they will need to bring in their own materials. You may want to arrange with the school shops to use their room and tools if available.

Background

There are competitions at schools and universities for this project. One project took 45 steps to complete the simple task. The Rube Goldberg project could be done at the end of the year to review some of the knowledge gained during the course. It may be difficult to fit in with a semestered course due to time constraints.

Procedure

The project needs about three weeks of lead time including three weekends. This will allow groups to get together. During the classes where the projects are tested, you will need a place to keep projects so other students don't tamper with them.

Students should explain how the machine works and show the required components (at least one of each 1^{st}, 2^{nd}, 3^{rd} class lever, inclined plane, pulley, mechanical wave, sound, light source, and elastic collision with transfer of momentum).

Be prepared for a noisy, exciting class. Evaluation could be made in the following areas:

- the machine has all of the required components
- the materials are recycled/recyclable
- students explained how the machine works and identified components
- the machine completes the simple task it was supposed to do
- students cleaned/tidied up after the project was completed

Mousetrap-Powered Car Project

Name: ____________________

Group Members: ____________________

Problem

Design and construct a mousetrap-powered car that will travel the farthest.

Materials

Per group:

- 1 mousetrap
- minimum three wheels (CDs, records)
- axles
- wood or metal for the body
- hard wire
- fasteners/glue
- non-oil lubricant

Background

Building and racing mousetrap-powered cars has been tried at many levels from junior high to university. There are numerous websites available to check out potential designs. However, you may want to try it on your own first and then look for help if you need it.

Some hints for getting started: make the car so steering can be adjusted to make it run straight, extend the arm of the mousetrap spring to slow down the release time, reduce the friction on the axles, and keep the mass low.

Safety

- Be careful when using knives or saws to cut materials.
- If using hot glue, do not get it on your skin.

Procedure A

Either in groups of two or individually, design and construct an original mousetrap car that meets the following criteria: can only use a mousetrap as a power source (no elastics or other tension-storing device), must be self starting, distance travelled (minimum 5.0 m) is to be measured in a straight line. There are no other materials restrictions and no other limitations on design. A one-page explanation of how your car design meets criteria is due three weeks before race (value 20 points) and a one-page evaluation of the car's performance and modifications is due one week before race day (value 20 points).

On race day you will have two tries to get your car to complete the race. If it goes the minimum 5.0 m, 30 points will be awarded. If it goes 10.0 m or more, 45 points will be awarded. The remaining 15 points will be awarded on a pro-rated basis: 1^{st}–15 pts, 2^{nd}–14 pts, 3^{rd}–13 pts, etc. (ties receive the same number of points).

Procedure B

An analysis of your car's motion during the race, in terms of physics principles, is required following race day. This may be qualitative or quantitative or both. Your teacher will set the requirements.

Scientific Vocabulary

displacement, velocity, acceleration, friction, wheel and axle, elastic potential energy, force, kinetic energy

Mousetrap-Powered Car Project

Teacher Notes

Outcomes

Students will be expected to

- construct and test a prototype of a device and troubleshoot problems as they arise (214-14)
- analyse and describe examples where energy- and momentum-related technologies were developed and improved over time (115-5, 116-4)
- describe and evaluate the design of technological solutions and the way they function using principles of energy and momentum (116-6)
- apply Newton's laws of motion to explain inertia and the relationships among force, mass, and acceleration (325-8)
- analyse natural and technological systems to interpret and explain their structure and dynamics (116-7)

Materials

In addition to the materials listed on the student sheet, for race day you will need a measuring tape and some masking tape to mark starting line and 5- and 10-metre lines, and a recording page for student results.

Background

Designing and building results in "kinesthetic learning," a very effective way of learning new ideas and skills in science. Students will have an opportunity to engage themselves in some very real problem-solving situations by completing and racing their mouse-trap car. Students commonly encounter the following problems (and their solutions) when working on this project.

- Steering adjustments are needed to keep the car going in a straight line (make one axle movable).
- Wheels spin if the arm of the mousetrap spring is too short (lengthen the spring arm).
- Wheels spin at the start (stretch a balloon over the CD wheel or use a larger wheel).
- The drive string spins on the axle (put pin on axle and loop end of string over it).
- The car won't start at the beginning of the race (axle pulley is too small in diameter, lever on spring arm is too long).

- There is too much friction on the axles (lubricate with graphite from pencil).
- The car does not go far (spring arm extension needs adjustment).

Procedure

The project takes about a month of time from start to finish, although students will probably do about 5–10 hours of work on the construction and fine tuning. Students can design the car during class time so you know they have started.

On race days students will need a place to put their car until class time and store the car after the race. They often like to keep the car out of sight until the race. For the race, some cars have travelled more than 35 metres. A long smooth floor such as the gym, cafeteria, or hallway is suitable. Students not racing their cars can do the measuring while you record results. Having a supply of glue, string, tape, a spare mousetrap, balloons, hard wire, etc., for repairs on the race day has been helpful.

Analysis

The analysis in terms of physics is helpful for students. This can be done as a class group after the race. A qualitative description of the events follows. Elastic potential energy is stored in the spring, and the arm applies a force to the string, which in turn applies a force to the axle.

The floor material applies friction to the wheel so it doesn't spin. The car accelerates positively while the force is being applied to the drive axle. Then the car travels at its maximum velocity for a few moments, but frictional forces cause negative acceleration until the car stops. The work done by the spring on the car is equal to the energy stored in the spring, which is equal to the energy you applied to the spring to wind it up.

Quantitatively, you could also have students measure the displacement of the car, time taken, calculate average velocity, calculate average acceleration, and perhaps percentage efficiency of the car.

Section 3: Experiments and Activities for Physics 11

Frames of Reference

Name: ____________________

Group Members: ____________________

Question

What is relative velocity?

Materials

- two toy cars (electric or battery) that travel at different speeds
- metre sticks
- timing device

Background

When a motion occurs, it is often treated in isolation. In reality, the motion of an object is related to its surroundings. A ball is tossed from back to front in a bus that is moving at a constant speed. A person on the bus observes the motion as if the bus was stationary. An observer on the street sees the motion of the ball and the bus against an apparently fixed streetscape. In fact, the Earth is both rotating and revolving in a solar system that is moving in an expanding universe. There is no ultimately stationary background against which to describe a motion. When the environment in which a motion takes place is identified, it is called a frame of reference. Newton's laws only apply if the frame of reference is stationary or moving at a constant speed (not accelerating). This is called an inertial frame of reference. The surface of the Earth is not changing speed so it is useful to treat it as a fixed, or inertial, frame. The bus in the example is not accelerating, so it is an inertial frame. If the bus was to accelerate either positively or negatively, what would happen to the apparent motion of the ball? Is a space shuttle during launch an inertial frame? Is an elevator which is just leaving a floor an inertial frame?

In this activity, you will study the motion of two toys that move at different constant speeds. You will make measurements of the speeds on a table considered a fixed frame and determine the relative velocities.

Procedure

Set up the two toy cars so that they can run along a table or on the floor, side by side in the same direction. Using the equipment provided, determine the velocity of both toy cars over a short distance. Be sure to use a long enough time interval (>5 seconds) to get an accurate value.

Results/Data

Complete the following table.

Toy	Displacement ($\triangle d$)	Time ($\triangle t$)	Velocity relative to table	Velocity of toy 1 relative to toy 2	Velocity of toy 2 relative to toy 1

Set up the two toys again so they can approach each other head on and complete the following table.

Toy	Displacement ($\triangle d$)	Time ($\triangle t$)	Velocity relative to table	Velocity of toy 1 relative to toy 2	Velocity of toy 2 relative to toy 1

Analysis

Suppose the faster toy car is set up one metre behind the slower toy car and they are going in the same direction. If the toy cars are started from rest simultaneously, predict how long it will take for the faster toy car to catch up with the slower one.

How fast is a person moving who is "standing still" at a point on the equator?

Stewiacke is about half way between the equator and the north pole. Would a stationary person in Stewiacke be moving at the same speed as at the equator? Answer this question, with appropriate calculations, on a separate sheet.

Conclusion

Explain the difference between the velocity of the toy cars to the starting point and the velocity of the toy car relative to the other toy car. How is the frame of reference different in each case?

Scientific Vocabulary

frame of reference, inertial frame of reference, displacement, velocity, magnitude, direction, vector, relative velocity

Frames of Reference

Teacher Notes

Outcomes

Students will be expected to

- identify the frame of reference for a given motion to distinguish fixed and moving frames (325-7)
- identify and investigate questions that arise from practical problems/issues involving motion (212-1)

Materials

Each group will require two toy cars that run at different but relatively constant speeds. Battery-powered toy cars are generally better than wind-up varieties. A metre stick and stopwatch or timer may be preferable probes and sensors for this activity. A supply of replacement batteries should be on hand.

Background

Also see student handout. When the toy cars are moving toward each other and the frame of reference is one of the toy cars, the other toy car is travelling at the velocity of the sum of the velocities. When the frame of reference is the table top or floor, then each toy car is travelling at its respective velocity. Again when the two two cars are travelling in the same direction and one toy car is the frame of reference, then the faster toy car is slow compared to the table top frame of reference. If the faster toy car is behind the slow toy car, it catches up slowly. If the fast toy car is in front of the slow toy car, it is slowly pulling away.

Procedure

Students will need ample room for each group set-up. The floor is preferable for this since the length of time the toy cars travel can be longer than on a table top. Tell the students not to hold the toy car back while the wheels are on the ground, since it will damage the drive mechanism of the toy car. The toy cars are available from large department stores at under $10 each. You may find toy cars with two-speed motors. Remove the batteries when not in use so the toy car doesn't turn on and wear out the battery while put away. Since data collection takes only part of a period, groups could share toy cars during the class while other groups are working at some of the questions in the activity.

Results

Since this is an exploratory activity, student responses can be limited to the completion of the worksheet. The values will depend upon the velocities of individual cars.

Analysis

See background information. The Earth's radius at equator is 6378.388 km. The circumference is = $\pi \times$ diameter. Therefore the circumference is $\pi \times 2(6378.388 \text{ km}) = 40\ 077 \text{ km}$.

In 24 hours a person will travel 40 077 km. Therefore, in one hour they will travel 40 077 km ÷ 24 h or about 1.670×10^3 km/h.

References

- *McGraw-Hill Ryerson Physics*, McGraw-Hill Ryerson Limited (2003), Section 2.1, pp. 30–24 and Section 5.1, pp. 156–157
- *Fundamentals of Physics,* Combined Edition, Martindale, Heath, Eastman (1992), pp. 193–194
- *Physics,* Fifth Edition, Giancoli (1998), p. 66

Acceleration of Gravity

Name: ______________________________

Group Members: ______________________________

Question

How does the velocity of an object change when it is falling freely under the influence only of gravity?

Materials

- sonic ranger
- large ball
- metre stick

Procedure

Set up the equipment so that you can conduct trials from heights of 1.0 m, 1.5 m, and 2.0 m above the ranger. The ranger must be placed on the floor in such a way that it is protected from the falling ball. If the ranger is placed on the bottom of a box that is much smaller than the ball, or surrounded by stacks of books, it can be protected from impact. Make sure your set-up is approved by the teacher before commencing your trials. At each height, do three trials and examine the graph of velocity vs. time.

Results (data, graphs, observations)

Make a data table to record each trial for the various heights.

- time
- change in displacement from zero
- average velocity
- average acceleration
- overall average acceleration

Analysis and Conclusion

Print or reproduce by hand one velocity-time graph for each drop height on which all three trials are plotted. Determine the best fit slope for each trial. Can you measure the consistency/reliability of the results of this experiment? Write a summary of your analysis and conclusion, indicating clearly how it is based on the data.

Scientific Vocabulary

displacement, velocity, acceleration, trials, data consistency, data reliability, velocity time graph, best fit slope, average acceleration

Acceleration of Gravity

Teacher Notes

Outcomes

Students will be expected to

- use vectors to represent position, displacement, velocity, and acceleration (325-5)
- use instruments effectively and accurately for collecting data (213-3)
- compile and organize data, using data tables and graphs, to facilitate interpretation of the data (213-5)
- interpret patterns and trends in data and infer or calculate linear and non-linear relationships among variables (214-5)
- compare theoretical and empirical values and account for discrepancies (214-7)
- analyse and describe vertical motion using the principles of kinematics (116-2)

Purpose

This activity will determine the acceleration of an object due to gravity.

Question

How does the velocity of an object change, when it is falling freely under the influence of only gravity?

Materials

- sonic ranger
- large ball
- metre stick

A large air ball or volleyball will work well for this experiment. Its mass should be such that the air friction is insignificant, so a beach ball may not give good results. This investigation can be conducted using a variety of techniques. Ticker tape is particularly susceptible to friction.

An ultrasonic sensor connected to either a graphing calculator or a computer can effectively record data and generate graphs. The intent is to determine the average acceleration (best fit slope) over three trials for each of three different heights. The overall average will then be the result of nine trials. Students may need to be reminded that the best results will be obtained if the ball is released cleanly, and not pushed or "travelled with," especially for the 1.0-m drop.

Procedure

Set up the equipment so that you can conduct trials from heights of 1.0 m, 1.5 m, and 2.0 m above the ranger. *You may prefer to use 1.5–2.5 m as ceiling height permits*. The ranger must be placed on the floor in such a way that it is protected from the falling ball. If the ranger is placed on the bottom of a box that is much smaller than the ball, or surrounded by stacks of books, it can be protected from impact. At each height, do three trials and examine the graph of velocity vs. time.

A photogate and ladder system can be used, but it should not be used as the primary technique at the beginning.

Results (data, graphs, observations)

The data table for each drop might look like the following:

–1.0 m drop	**Time (s)**	**Total displacement (m)**	**Velocity (m/s)**	**Acceleration (m/s²)**
Trial 1				
Trial 2				
Trial 3				
Trial 4				
Average				

Students may want to do more trials if they are not getting consistent data. They might construct three different tables to accommodate the three different drops, or combine the data into one larger table, or even enter the data into a spreadsheet.

Analysis and Conclusion

Students should be encouraged to study the data table for patterns. Are the 2.0-m-drop trials comparable to the 1.0-m-drop trials? What is the range of values in the individual trials? among the averages?

References

- *McGraw-Hill Ryerson Physics*, McGraw-Hill Ryerson (2003), Section 2.4, pp. 61–73
- *Physics, Principles and Problems*, Merrill (1992), pp. 71–77
- *Fundamentals of Physics,* Combined Edition, Martindale, Heath, Eastman (1992), p. 76

Newton's Second Law

Name: ______________________________

Group Members: ______________________________

Purpose

This activity will determine the relationship among the mass of an object, an applied force, and the resulting acceleration.

Question

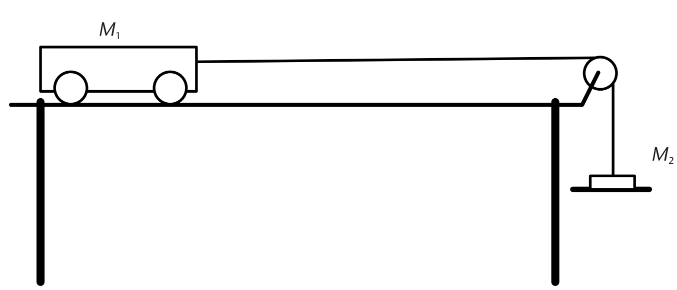
When a force is applied to an object of known mass, how does the velocity of the object change?

Hypothesis

In your written report, state a hypothesis which suggests how acceleration responds to applied force and object mass. In other words, what do you think will happen to the acceleration if the force is increased? Will acceleration increase in a linear, proportional way? Will there be an exponential relationship? Will acceleration decrease if force is increased? In the same manner, predict what specific relationship between acceleration and object mass you anticipate.

Materials

- dynamics cart
- pulley or Smart Pulley
- string
- mass hanger and selection of masses
- recording device



Procedure 1

Set up the cart and mass hanger as shown. Depending on the technology available, set up the equipment you will use to record the motion of the system. *The total mass of cart, hanger, and hung masses must remain the same during all trials*. To study the relation between driving force and mass, you will want at least five different *M*2 loads to supply the driving force (manipulated variable).

It is also useful for later analysis to use incremental steps in changing the driving force.

You should give some thought to what combination of small masses you will need. For example, if you want to use increments of 200-g mass (1.96 N gravitational force), the first trial must be done with the hanger loaded to a total of 200 g. If the hanger alone has a mass of 50 g, you must add 150 g to it. From then on, you can add 200-g masses. In this example, four 200-g masses, one 100 g, and one 50 g would be required. In the first trial, the 150 g is placed on the hanger and the remaining four 200-g masses *must be on the cart*. For succeeding trials, masses are moved from the cart to the hanger, thus keeping the total mass constant. Using the equipment available, determine the acceleration of the system.

Procedure 2

Using the same apparatus, conduct trials in which the driving force remains the same and the total mass is changed. As in the last procedure, it is useful to set up the trials so that incremental changes are made in the manipulated variable. You may have to use trial and error to determine how large the increments should be to give five substantially different trials.

Results (data, graphs, observations)

Complete a copy of these data tables in your report.

Force (N)	**Trial 1 acceleration (m/s^2)**	**Trial 2 acceleration (m/s^2)**	**Trial 3 acceleration (m/s^2)**	**Average acceleration (m/s^2)**
Single (1.96 N)				
Double				
Triple				
Four times				
Five times				
			Average acceleration	

Mass (kg)	**Trial 1 acceleration (m/s^2)**	**Trial 2 acceleration (m/s^2)**	**Trial 3 acceleration (m/s^2)**	**Average acceleration (m/s^2)**
Total mass 1				
Total mass 2				
Total mass 3				
Total mass 4				
Total mass 5				
			Average acceleration	

Analysis and Conclusion

First examine both data tables. When the manipulated variable changes, how does the responding variable change? Do both increase? Is there a numerical pattern?

Graph 1: From the first data table, create a graph of acceleration vs. force. Using a graphing calculator or computer software, determine how the data are related. What is the numerical value and the unit of the slope? Write an equation for the relationship between force and acceleration. Under what condition does this equation apply? **Hint**: what variable was controlled during these trials? Is there any connection between the controlled variable and the slope of this graph?

Graph 2: From the second data table, create a graph of acceleration versus mass. What is the shape of this graph? Determine the inverse of each total mass (1/mass) and create a graph (Graph 3) of acceleration versus 1/mass. Can you determine an equation relating mass and acceleration?

What does the slope of this graph mean?

Can you think of a way to relate all three variables at the same time? It is possible to combine the two manipulated variables by determining the ratio of $\frac{F}{m}$ for each of the ten trials conducted. It is then possible to do a graph that uses all trials. It may be better for analysis purposes to put $\frac{F}{m}$ on the *y*-axis and acceleration on the *x*-axis. What does this graph tell you?

Scientific Vocabulary

hypothesis, manipulated variable, responding variable, trials, dynamics cart, pulley, gravitational force, applied force, mass, velocity, acceleration, average acceleration, linear relationship, exponential relationship

Newton's Second Law

Teacher Notes

Outcomes

Students will be expected to

- evaluate and select appropriate instruments for collecting evidence and appropriate processes for problem solving, inquiring, and decision making (212-8)
- carry out procedures controlling the major variables and adapting or extending procedures where required (213-2)
- use instruments effectively and accurately for collecting data (213-3)
- compile and display evidence and information, by hand or computer, in a variety of formats, including diagrams, flow charts, tables, graphs, and scatter plots (214-3)
- design an experiment, select and use appropriate tools, carry out procedures, compile and organize data, and interpret patterns in the data to answer a question posed regarding the conservation of energy (214-11)
- interpret patterns and trends in data and infer or calculate linear and non-linear relationships among variables (214-5)

Hypothesis

A hypothesis is a statement that may disproved. The question, How does acceleration change if force is increased? may be changed to a hypothesis, An object's acceleration changes when the force applied to the object is changed. If the force applied is changed but the object's acceleration does not, then the hypothesis is disproved.

A prediction from the hypothesis might be, An object's acceleration will increase when the force applied is increased.

Procedure 1

There are many ways to determine the acceleration for these trials. Graphing calculators or computers can be used to collect data and create a velocity vs. time graph for slope analysis. Since the initial velocity of the trials is 0, acceleration can be determined from:

$$\vec{a} = \frac{2\vec{d}}{t^2}$$

The displacement can be determined using a ticker-tape timer, a marked distance on the table, or photogates.

Procedure 2

These trials are easier to complete, and could be done first. It is important that the change in mass be large enough to create substantially different accelerations. Old textbooks of about the same mass as the cart can be used as “standard” weights.

Analysis and Conclusion

Because of the importance of Newton’s second law and the quality of the data that can be obtained, this is a good opportunity to emphasize analytical techniques.

Students should be helped to move beyond simply presenting the data in a table to interpreting the data based on numerical patterns that are evident. They should be able to distinguish direct from inverse presentations. They should be able to distinguish linear from exponential patterns. They should be able to answer questions such as: if the x-value is doubled, what change results on the y-axis? They should be able to infer relationships from the data.

The graphs serve to make observations about the data more specific. For example, from the data, it is clear that $a \alpha F$. A graph with a zero intercept allows the observation that the relationship is proportional: $a = kF$. The slope permits the writing of an equation with a proportionality constant. The slope of the first graph turns out to be the inverse of the constant mass. Using the value and the dimension of the actual slope, can students make this observation? In the second set, the slope of a graph of a vs. $\frac{1}{m}$ is obviously equal to the constant force.

It is worth the time to coach students in their analysis and the requirements of a well-written summary.

Momentum: In-Line Explosions and Collisions

Name: ____

Group Members: ______________________________________

Question

What happens during in-line explosions and collisions?

Materials

- two dynamics carts (one with plunger)
- two ticker timers or two motion sensors
- masses to add to the carts
- equipment for determining velocities of the carts
- level

Background

Newton recognized that velocity alone was not a complete description of the motion of an object. When a 1-tonne car collides with a 10-tonne truck, that difference is demonstrated. Newton recognized that mass must be taken into account. He developed the notion of "quantity of motion," the product of mass and velocity, which we now call momentum. The familiar equation for Newton's second law can be reorganized

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

$$\vec{F} = m\frac{\Delta\vec{v}}{\Delta t}$$

$$\vec{F}\Delta t = m\Delta v = m\vec{v_2} - m\vec{v_1}$$

(impulse) = (change in momentum)

Any change in the *mv* product (the momentum) must be equal to the product of the applied force and the time interval. This $\vec{F}\Delta t$ product is called **impulse**. In this investigation, we will make some inferences about impulse but we will not measure it directly.

Procedure 1

To study explosions, position the two carts touching end to end in the middle of the table with the plunger compressed. When the plunger release is tapped, the spring will expand and push the carts apart. When the spring is no longer touching the other cart, no further change in velocity will result. You will need to know the mass of each cart and the velocities before and after the explosion. It is possible to set up two ticker timers or motion sensors at the ends of the table to record the motions. It is also possible to time the motion of the carts over a measured distance.

First mark the centre point on the table with masking tape. Second, mark the table under the leading edge of each cart. Third, mark a point on the table beyond the leading edge of each cart about as far away as the extended plunger is long. (This eliminates the distance during which the carts are accelerating.) Finally, mark a point well away from each cart near the ends of the table (20 cm or more). Use a stop timer to determine the time each cart takes to pass over the measured distance. You can then calculate the velocity after explosion for each cart.

How can you express the velocities, since they are in opposite directions? It may take three trials to establish a good average value for each cart. If more than one timer is available, a different member of your group can be assigned to each cart. Old books with about the same mass as the empty dynamics cart works well as unit masses.

Note: *The table you are using must be as level as possible. Use wood shims or folded paper to level it end to end.*

Complete the following data tables.

Trial	M_1 (kg)	V_{1i} (m/s)	V_{1f} (m/s)	M_2 (kg)	V_{2i} (m/s)	V_{2f} (m/s)
1. $C + 2$, $C + 2$						
2. $C + 1$, $C + 1$						
3. $C + 0$, $C + 0$						
4. $C + 1$, $C + 3$						
5. $C + 2$, $C + 1$						
6. $C + 2$, $C + 2$ moving						
7. $C + 1$, $C + 1$ moving						

Trial	$\overline{P}_{1i}$ kg-m/s	$\overline{P}_{1f}$ kg-m/s	$\Delta\overline{P}_1$ kg-m/s	$\overline{P}_{2i}$ kg-m/s	$\overline{P}_{2f}$ kg-m/s	$\Delta\overline{P}_2$ kg-m/s	$\overline{P}_{total}$ (before) kg-m/s	$\overline{P}_{total}$ (after) kg-m/s
1.								
2.								
3.								
4.								
5.								
6.								

Analysis 1

In a given trial, how does the change in momentum for one cart compare with the change in momentum for the other cart? Looking at all the trials, can you make a general conclusion regarding change in momentum? How is the total momentum of the system after explosion related to the total momentum before the explosion? Can you express mathematically the variation between individual trials and the general relationship you have identified?

Conclusion

Summarize in one or two statements what generally happens to momentum in an explosion.

Procedure 2

In this part of the experiment you are to examine what happens to momentum when a moving cart hits a stationary cart and: i) they stick together or ii) they separate after impact. Trials in which the “target” cart is also moving could be done as an extension. Your teacher will indicate which combinations you should do trials for. Be sure to keep a record of which combinations match the numbered trials in the table. In each case, you will have to do some practice trials to select a good velocity for cart 1 so that the motion after impact can be measured. To make the carts stick together on impact, double-sided carpet tape could be used on one or both carts. To make the carts separate after impact, make sure the plunger is out on one of the carts. You must determine the mass and the velocity before and after impact for each cart.

Complete the tables on the next page.

Trial	M_1 moving cart (kg)	V_{1i} (m/s)	V_{1f} (m/s)	M_2 stationary cart (kg)	V_{2i} (m/s)	V_{2f} (m/s)
1. $C + 2$, $C + 2$						
2. $C + 1$, $C + 0$						
3. $C + 2$, $C + 0$						
4. $C + 1$, $C + 3$						
5.						
6.						

Trial	$\overline{P}_{1i}$ kg-m/s	$\overline{P}_{1f}$ kg-m/s	$\Delta\overline{P}_1$ kg-m/s	$\overline{P}_{2i}$ kg-m/s	$\overline{P}_{2f}$ kg-m/s	$\Delta\overline{P}_2$ kg-m/s	$\overline{P}_{total}$ (before) kg-m/s	$\overline{P}_{total}$ (after) kg-m/s
1.								
2.								
3.								
4.								
5.								
6.								

Analysis 2

As in Analysis 1, what can you deduce from the data about the changes in momentum for each cart? How does the total momentum of the system before impact compare with the total momentum after?

Conclusion

Do the same general conclusions you reached after procedure 1 also hold true in these cases?

Scientific Vocabulary

momentum, change in momentum, impulse momentum, conservation of momentum, ticker timer, motion sensor, in-line explosion, collision, dynamics cart

Momentum: In-Line Explosions and Collisions
Teacher Notes

Outcome

Students will be expected to

- apply quantitatively the law of conservation of momentum to one-dimensional collisions and explosions (326-3)

Procedure 1

Even if an air track is available, it may be wise to let students do a preliminary exploration with the traditional dynamics carts. If the technology is available to measure velocities quickly, more situations can be investigated. Repeating each trial several times will give students the chance to gauge the reliability of their results. Percentage of difference or some other measure of variation should be used. Just as students tend to trust all the digits in a calculator display, they can easily misinterpret results obtained using electronic sensors. They need to see that the precision of the instrument is only one factor affecting results.

The trial column in the data table is organized by load, where *C* + 2 indicates cart plus two equal-mass books. It is intended to show the variety of possible combinations. Trials 2 and 3 could be eliminated if time is short.

Trial	M_1 (kg)	V_{1i} (m/s)	V_{1f} (m/s)	M_2 (kg)	V_{2i} (m/s)	V_{2f} (m/s)
1. *C* + 2, *C* + 2						
2. *C* + 1, *C* + 1						
3. *C* + 0, *C* + 0						
4. *C* + 1, *C* + 3						
5. *C* + 2, *C* + 1						
6. *C* + 2, *C* + 2 moving						
7. *C* +1, *C* + 1 moving						

Trial	$\overline{P}_{1i}$ kg-m/s	$\overline{P}_{1f}$ kg-m/s	$\Delta\overline{P}_1$ kg-m/s	$\overline{P}_{2i}$ kg-m/s	$\overline{P}_{2f}$ kg-m/s	$\Delta\overline{P}_2$ kg-m/s	$\overline{P}_{total}$ (before) kg-m/s	$\overline{P}_{total}$ (after) kg-m/s
1.								
2.								
3.								
4.								
5.								
6.								

Procedure 2

Situations in which one cart is stationary should be enough to demonstrate conservation of momentum in collisions. However, depending on time, equipment, and the need for enrichment, head-on collisions between two moving carts can be attempted. Each case must be attempted first to set original velocity high enough to give each cart measurable velocity after impact. Unless there is a means of giving the moving cart exactly the same velocity each time, repeating trials will not be possible.

A rubber band slingshot launcher can be improvised, or a flexible ruler can be pulled back a specific amount to drive the cart. This kind of improvisation is typical of the problem solving that must occur in a real laboratory situation.

Analysis

The interpretation of patterns in data tables is an important skill. Students need to be encouraged to look for patterns in the numbers, and to recognize the ideal case in experimental data. To do this they need to distinguish between minor experimental differences and significant patterns. Anecdotal observations should also be encouraged.

Conclusion

Students need to learn that a conclusion is a summary of the results, referring directly to the purpose of the investigation.

Work, Energy, and Power

Name: ____

Group Members: ____________________________________

Question

What is the work, the energy, and the power of a particular event and what is their relationship?

Materials

- dynamics cart or Hall's carriage
- equipment for determining time and velocity
- inclined plane
- level

Background

The terms work, energy, and power are part of everyday language. The use of the terms is not precise. Does anyone really "work" for eight hours? Why is the electrical utility called the "power" corporation? As you work through these activities, you should learn the precise definitions of the terms as they are used in physics and relate them to real situations.

Work is the name given to the product of applied force and displacement. If a force of 12 N is applied to a certain object and the object moves 2.0 m, then we say that 24 N-m, or joules, of work is done. The N-m has been named joule (J) in honour of British physicist J. P. Joule. If you exert a large force for a long time on an object that you cannot move, you may get tired but you will do no work.

When work is done, a resulting change in energy occurs. This is called the work-energy theorem. It may be a change in kinetic energy, or some form of potential energy.

$$\vec{F}\Delta\vec{d} = \frac{mv_2^2}{2} - \frac{mv_1^2}{2}$$

(work equals change in kinetic energy)

$$\vec{F}\Delta\vec{d} = m\vec{g}\Delta\vec{h}$$

(work equals change in gravitational potential energy)

When the work done is related to the time interval in which it is accomplished, the ratio is called **power**. Power can be thought of as the rate of doing work. If 24 J of work is done in a 5.0-second interval, the power is 4.8 J/s, or watts. The J/s has been named the watt in honour of James Watt, who developed the first steam engine. In everyday experience, we often think of power as a "big work" over "small length of time" ratio. For example, a "powerful" car can go from zero to 100 km/hr (a specific change in kinetic energy) in 5.0 s. A more typical family car might take 13 s.

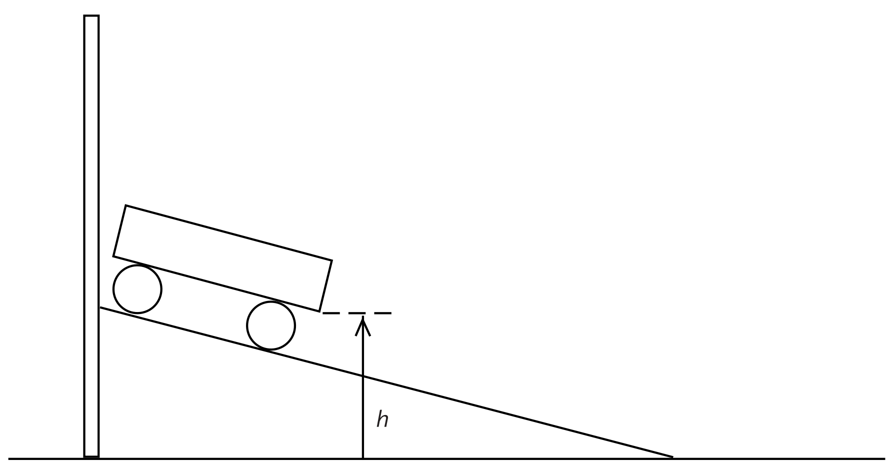
The smaller the length of time, the greater the power.

Procedure

Check that your table is level, or do the trials on the floor. Is the floor level? Set up a ramp with a long slope and put a motion sensor 1–2 m away from the bottom to measure the velocity of the cart when it reaches the bottom. A long ramp will give the best results. You will need to determine the mass of the cart for each trial, the height as indicated, and the velocity on the floor. Complete the data table on the next page.

Safety

Don't let the carts roll off of the table or run into the motion sensor.



	Trial 1	**Trial 2** **larger mass**	**Trial 3** **larger height**
Mass of car			
Height			
Time on ramp			
Force of gravity on cart			
Potential energy of cart at top			
Work done while on ramp			
Kinetic energy of cart at bottom			
Power			

Analysis

In a given trial, how does the kinetic energy of the cart on the level surface compare to the work done by the gravitational force while the cart is on the ramp? Which trial is the most "powerful"? When we say that a lightbulb is 100 watts, what do we mean? A home theatre sound system is advertised at 400 watts. Explain. A certain Dodge Viper is rated at 500 horsepower. How is "horsepower" related to "watt"?

Conclusion

Summarize, in one or two statements, the general relationship among work, power, and energy.

Scientific Vocabulary

motion sensor, dynamics cart, velocity, force, displacement, work, power, watt, joule, mass, height, kinetic energy, potential energy, force of gravity

Work, Energy, and Power

Teacher Notes

Outcomes

Students will be expected to

- analyse quantitatively the relationships among force, distance, and work (325-9)
- analyse quantitatively the relationships among work, time, and power (325-10)

Background

As a general rule, the ramp should be at least four times the length of the cart. The bottom edge should be tapered to a small angle (less than 30 degrees). The maximum angle at which the ramp will work depends on how smoothly the cart gets from the ramp to the table. Students could be asked to design a means to make the transition smooth. For example, thin poster board could be taped in place to make the change more gradual. This will not affect measurement of height, or speed on the table.

Procedure

If time permits, multiple trials could be conducted for each situation, and the average recorded. Height as shown in the diagram does not take into account centre of gravity. For the purpose of this investigation, the approximation is acceptable. However, the concept could be used for enrichment or extension. Time on the ramp can be determined with a stopwatch, ticker timer, or sonic ranger. Data should be adequate to show that the gain in kinetic energy matches the loss in gravitational potential energy on the ramp. Work can be confusing to students in this situation. The active force (*Fg*) acts through a vertical distance (*h*). The product (work) is equal to the change in gravitational potential energy. In the direction of motion, *Fg* cos acts through a horizontal distance that is more than *h*, and the product is the same. Power calculations in situations of this scale are small. The kilowatt is a more practical unit than the watt. One horsepower is 550 ft-lb/s, or 746 watts. An interesting activity for students is to determine their power in kilowatts and horsepower when running up a flight of stairs as fast as possible. It can be done as a take-home lab.

Energy: Another Look at In-Line Explosions and Collisions

Name: ____________________

Group Members: ____________________

Question

What happens to kinetic energy during explosions and collisions?

Background

Previously, you have conducted trials involving explosions and collisions between dynamics carts. Whether a stationary pair of carts separates explosively, two carts collide and stick together, or two carts collide and separate after impact, momentum is conserved. In this investigation, you will re-examine the data from those trials to see what has happened in energy terms. Kinetic energy is not a vector quantity like momentum, but scalar. Determining total energy before and after for your trials is a matter of simple arithmetic.

Materials

- data collected during "Momentum: In-Line Explosions and Collisions"

Procedure

The explosion trials you conducted are all cases where kinetic energy seemed to appear out of nowhere. Two carts at once standing still (kinetic energy = 0) are suddenly moving quickly in opposite directions. Calculate the total kinetic energy after impact for each of the trials. Record your answers in a neat table.

Analysis

Is there any pattern in the answers? For the explosions, where do you think the kinetic energy came from? For the collisions, is the total kinetic energy after impact equal to the total kinetic energy before impact? Is there a different pattern for the collisions where carts stick together compared with the trials where the carts separate after impact?

Conclusion

Summarize what you have learned about how kinetic energy is conserved in explosions and collisions.

Scientific Vocabulary

kinetic energy, in-line explosion, in-line collision, vector quantity, scalar quantity, impact, conservation of energy, conservation of kinetic energy

Energy: Another Look at In-Line Explosions and Collisions

Teacher Notes

Outcome

Students will be expected to

- determine which laws of conservation, momentum, and energy are best used to analyse and solve particular real-life problems in elastic and inelastic interactions (326-4)

Background

Since this is a secondary analysis of data, it may be useful to supply good data, or pick the best set of student data.

Previously, you have conducted trials involving explosions and collisions between dynamics carts. Whether a stationary pair of carts separates explosively, two carts collide and stick together, or two carts collide and separate after impact, momentum is conserved. In this investigation, you will re-examine the data from those trials to see what has happened in energy terms. Kinetic energy is not a vector quantity like momentum, but scalar. Determining total energy before and after for your trials is a matter of simple arithmetic.

Procedure

In the collisions, both the incident cart and the target cart end up with different velocities.

Conclusion

Students will find that some energy is lost during a collision. Energy is lost in the form of heat resulting from friction.

Spring Energy

Name: ______________________________

Group Members: ______________________________

Questions

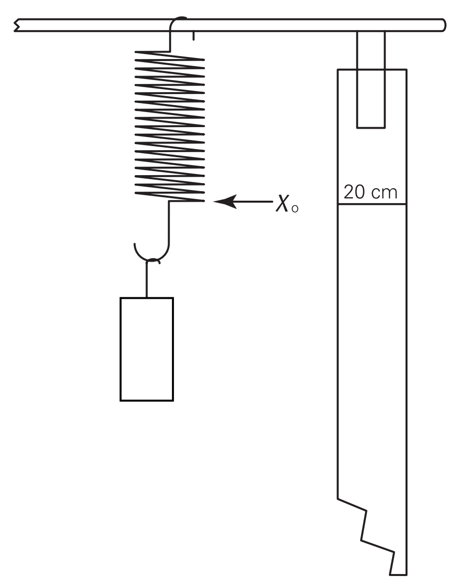
- What is the relationship between the force exerted on a spring and the resulting stretch?
- What are the changes in kinetic energy, gravitational potential energy, and spring potential energy as a mass on the end of a spring moves up and down?
- Develop hypotheses from the two questions.

Materials

- spring about 20 cm long
- retort stand with horizontal bar
- masking tape
- metre stick
- masses with hooks (1-100 g, 2-200 g, 1-500 g)
- motion sensor
- recording device

Background

Most of the situations you have studied so far in physics have been cases in which a constant force is applied to an object for a period of time. In this case, you already know that the more you stretch a spring, the more force you need to apply to it.



Procedure

Using the apparatus shown above, you can put increasingly larger masses on the end of the spring and measure the resulting stretch for each mass. One way to do this is to mount a metre stick vertically so that a certain point (perhaps 20 cm) is exactly in line with the bottom loop of the unstretched spring. When you line it up and measure later positions, be sure to look straight at the scale and not down at an angle to minimize error.

Do not include the length of the hook at the bottom of the spring.

Performing trials at obvious multiples of the manipulated variable will make relationships easier to see. For example, you might add masses to the end of the spring in 100-g increments. Draw a graph of force vs. position. *Although this is not the usual practice of putting the manipulated variable on the horizontal axis, it is useful in this case*. Draw a line of best fit and determine the slope of the line.

Analysis

After you have answered the following questions, write a well-organized summary of the results and additional comments or observations.

What are the units for the slope? What does the slope tell you about the spring? What does the area under the graph represent? How much energy is stored in your spring when it is stretched out to its lowest position? Where did that stored energy come from? What work was done on the "hung" mass? Can you write an expression for *Es*, the energy in the spring, in terms of force constant k and stretch x? Calculate the energy stored in the spring at six positions between zero and maximum stretch.

Draw a graph of *Es* vs. position. Is it a straight line? On the same coordinates, plot a graph of gravitational potential energy vs. position. (Assume the lowest spring position is the zero point for gravitational potential energy.) Determine the sum of the two potential energies at a variety of positions. On the same coordinates, plot a graph of total potential energy. How can you account for its shape? Determine the kinetic energy of the mass at the midpoint of its fall to maximum stretch. What is the velocity of the mass at the midpoint of the drop? Describe a method that could be used to verify this velocity? What can you say about the total energy of the system during the fall of the mass to the maximum stretch position?

Data

Mass (kg)	Force (N)	Stretch (m)	Spring energy (J)	Gravitational potential energy (J)	Total potential energy (J)	Total energy (J)	Kinetic energy (J)

Conclusion

Read the questions of this investigation again. In a few lines, summarize what you have learned about the two questions.

Scientific Vocabulary

kinetic energy, gravitational potential energy, spring potential energy, force, manipulated variable, responding variable

Spring Energy

Teacher Notes

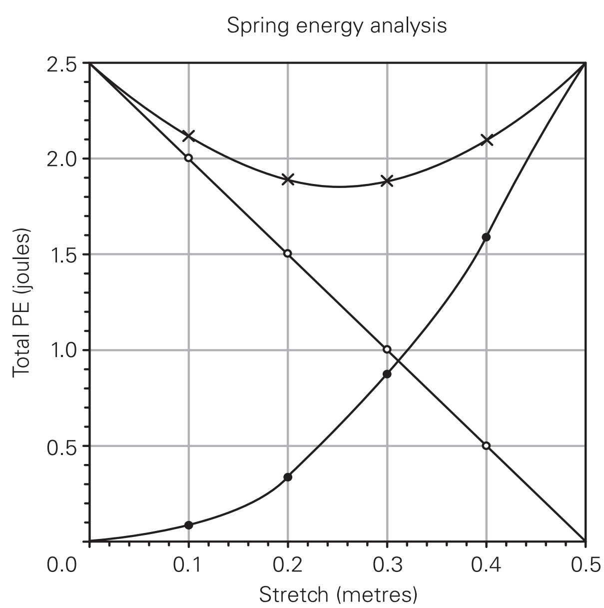
Outcomes

Students will be expected to

- analyse quantitatively the relationships among mass, speed, and thermal energy, using the law of conservation of energy (326-1)
- describe quantitatively mechanical energy as the sum of kinetic and potential energies (326-5)
- analyse common energy transformation situations using the closed system work-energy theorem (326-7)

Questions

- What do you think will be the mathematical relationship between force and stretch? Is the relationship linear or exponential?
- Is it direct or inverse?



Analysis

Students should end up with a graph like this, showing spring potential energy, gravitational potential energy, and total potential energy. They can also draw a horizontal line at the top of the graph representing total energy. At any stretch position, the kinetic energy of the mass is given by the difference between total energy and total potential energy.

Waves on a Spring

Name: ____

Group Members: ___________________________________

Question

What are some of the fundamental properties of waves?

Materials

- long spring (large-diameter coils)
- long helix (small-diameter coils)
- timer with tenths of a second of motion sensor
- force spring scale or force sensor
- retort stands and clamps
- string
- masking tape
- paper clips

Background

Long springs make an ideal elastic medium in which to study the movement of waves because pulses travel as large, slow-moving events. Transverse waves can be produced by moving one end of the spring sharply out and back at a right angle to the stretched-out spring. This results in a cone-shaped disturbance that moves along the spring. It is also possible to create longitudinal pulses by collecting a group of coils, pulling them toward you, and releasing them. This will create a compression that moves lengthwise along the spring without causing any sideways movement.

Caution

When using the large-diameter spring that is similar to a Slinky toy, be careful not to overstretch the coils. When extended, all springs tend to unwind. If you are holding the spring tightly at both ends, this cannot happen, and the result is a twisting force in the spring. When you attempt to create a pulse, the result can be a knot in the spring. This can be prevented by letting the spring twist as it stretches, and before any trials are attempted. When using the small-diameter spring (helix), there is a greater risk of injury. It takes substantially more force to stretch out the helix compared with the spring.

If one end is released when it is stretched out, the person at the other end could get hurt. When holding the ends of both springs, wrap your hand around the coils. **Do not stick a single finger through a loop at the end.**

Note: *In this investigation, you will sometimes have difficulty deciding what is meaningful. Always refer to the question you are trying to answer. You may see things that are interesting but not relevant to the question. In science, it is often necessary to decide when an observation is significant. For example, all pulses you create will not be identical. Will this affect your ability to reach conclusions? Scientists often have to deal with approximations and idealizations when making general statements.*

Procedure

This investigation consists of a series of questions. You will have to design an experiment to test some of them.

Again, **be careful not to stretch the spring or helix coils out of shape** when working with them. You may do this activity by holding the ends of the spring with your hand or by securing the ends to retort stands as follows. When setting up your spring/helix, attach each end to the upright of a retort stand that has been attached firmly to a table. The stands should be 3–4 m apart. If you have ceiling rafters directly above the spring, then suspend the spring horizontally using string tied to the rafters and a paper clip tied to the bottom to support one coil of the Slinky. For small-amplitude impulses, the string/paper clip will not interfere with the impulse. If you do not have rafters, you may need to find another way to suspend the spring in the middle. The force sensor can be used to measure tension in the spring and the motion sensor can be used to help time the impulse as it passes back and forth on the spring. You may need to move the sensor to record the two different kinds of impulse.

You should try the rest of this activity using either a transverse wave or a longitudinal wave or both depending upon time available.

Begin by stretching out the Slinky so that a pulse will travel back and forth at least three times. Hook the spring scale or force sensor to one end and record the force.

1. Does a pulse maintain its size (height, number of coils) and shape as it travels along the spring? Draw a sketch to show how the pulse looks soon after it is created, and another showing its appearance just as it reaches the other end.
2. What happens to the size and shape when the pulse is reflected?

3. What happens to the speed of the pulse as it continues to reflect back and forth? Make measurements of the time and distance and calculate the speeds. Draw a data table.
4. Does the speed of the pulse depend on the size or shape? Collect and record data.
5. Double the tension in the spring and repeat part 3. Collect and record data. How is the speed related to the tension? Be careful not to overstretch the spring.
6. Set up the helix as you did in part 3 under the same tension. How does the speed in this elastic medium compare to the speed in the other? Can you determine what tension would result in this spring carrying waves at the same speed as the spring? Collect and record data.
7. What happens when a pulse reaches a boundary? Securely fasten the two springs end to end. What happens when you make pulses on the helix? What happens when the pulse originates in the spring? Notice that there is a transmitted wave and a "reflected" wave. Draw sketches below showing the pulse before and after reaching the boundary, in both directions.
8. What happens when two pulses travelling in opposite directions meet? This investigation will take some co-ordination and practice. Do not record any observations until you and your partner at the other end of the spring can produce roughly identical pulses at the same time. First make pulses that are on the same side of the spring. What happens when they meet? Try making one pulse twice the size of the other. Use a sketch of before, during, and after meeting to record your observations.

Second, create identical pulses on opposite sides of the spring. What happens when they meet? Try one larger pulse to confirm your observation. Draw a sketch of before, during, and after contact to record your observations. This is called wave superposition, a form of interference.

Conclusion

On a separate piece of paper, write a well-organized summary of your observations and the conclusions about wave behaviour that you can draw from them.

Scientific Vocabulary

wave, longitudinal wave, transverse wave, pulse, reflection, refraction, speed, wave interference, superposition, destructive interference, constructive interference, boundary between media, elastic medium, nodal point

Waves on a Spring

Teacher Notes

Outcomes

Students will be expected to

- describe the production, characteristics, and behaviours of longitudinal and transverse mechanical waves (327-1)
- formulate operational definitions of major variables (212-7)
- implement appropriate sampling procedures and evaluate the relevance, reliability, and adequacy of data and data collection methods in wave experiments (213-1, 214-8)
- apply the laws of reflection and the laws of refraction to predict wave behaviour (327-7)
- state a prediction and a hypothesis about wave behaviour based on available evidence and background information (212-4)

Procedure

If this experiment is done on the floor or several smooth tables placed end to end, friction will result in a gradual loss in amplitude but not speed. Good observations are possible, and friction can be taken into account when interpreting them.

1. Students should see that both amplitude and length are lost over time. Since friction with the floor robs energy, the amplitude diminishes, but not the speed, which is governed by the properties of the medium.
2. The pulse is flipped to the other side of the spring, but size and shape are unchanged.
3. Even though it reflects and loses amplitude, the speed should remain the same.
4. No significant difference in speed should occur based on size and shape.
5. The observed speed should be greater, but not in any specific relation to force. The main point is that speed is controlled by the medium conditions, not the pulse characteristics.
6. At the same tension as the spring, the helix carries waves at a different speed. By trial and error, it may be possible to find the tension that will give the same speed.

7. Partial reflection at a boundary is an important observation which can be compared to light behaviour later.
8. Students must see that pulses can pass through each other unaffected, yet at the point when they are in the same place in the medium, superposition results. This becomes a critical point later when they evaluate the wave model as applicable to light.

The term **nodal point** should be introduced at this time.

Closed Tube Resonance/Speed of Sound

Name: ______________________________

Group Members: ______________________________

Question

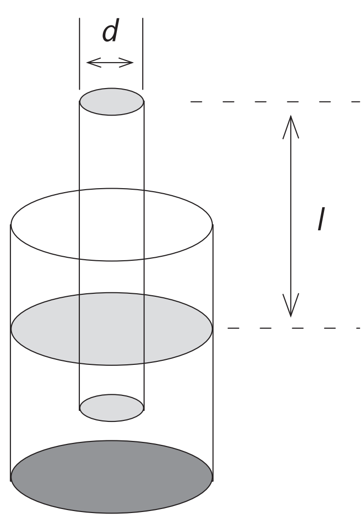
What is the speed of sound in air using a closed tube?

Materials

- plastic graduated cylinder or plastic bucket
- open tube about 40 cm long
- tuning fork of known frequency
- thermometer
- rubber hammer
- water

Background

Resonance occurs when the vibration rates of two objects are the same. A column of air has a natural vibrating frequency. If a plastic tube is held with one end in a container of water, it can be moved up and down until the length of the air column is just right to resonate with a tuning fork held at the open end. The length of the closed tube must be equal to one quarter of the wavelength of the sound produced by the tuning fork. To be precise, the relationship must be slightly corrected for the diameter of the tube according to the following expression: $\lambda = 4(l + 0.4d)$, where l is the length of the air column and d is the inside diameter of the tube. The vibrating frequency of the tuning fork is stamped on it. The wave formula $v = f\lambda$ can be used to calculate the wave speed. The speed is affected by the air temperature. The corrected speed can be calculated using



$$v = 331 \text{ m/s} + \frac{0.59 \text{ m/s}}{\text{C}^\circ} \times T_{(c)}$$

Safety

Do not use tuning forks near any glass objects, eyes, or ears.

Procedure

Read the room temperature on the thermometer. Measure the inside diameter of the open tube. Put the open tube in the cylinder and fill it to the top with water. Strike the tuning fork and hold it near the top of the tube as you raise it out of the water slowly until you find a place where the sound is much louder. Have a partner measure the length of the tube above the water surface.

Data and Analysis

Create a table and record your values for temperature, diameter, fork frequency, and tube length. Calculate the wavelength and speed of the sound before temperature correction. The speed of sound in air at 0°C is 331.5 m/s. Determine the percentage difference of your calculated speed from this accepted value. Calculate the speed of sound corrected for temperature.

Conclusion

What is the speed of sound in your classroom?

Scientific Vocabulary

speed of sound in air, wavelength, vibration, resonance, frequency, air column, tuning fork, closed tube

Closed Tube Resonance/Speed of Sound

Teacher Notes

Outcomes

Students will be expected to

- compare and describe the properties of electromagnetic radiation and sound (327-5)
- describe how sound and electromagnetic radiation, as forms of energy transfer, are produced and transmitted (327-6)

Materials

- A 1.5 inch plastic drain pipe makes a good tube.
- A 512-Hz tuning fork works well.
- The cylinder/bucket should be about the same height as the tube so that the tube starts out full of water.

Safety

Some students may find louder points at harmonic frequencies. The loudest reinforcement should occur for the fundamental. They may have to go past it several times and "zero in" on the best spot. Higher-frequency forks (smaller wavelength) create sharper readings.

Procedure

If you are in a location where two groups of students can be separated by more than 340 m, then you can have one group bang on a metal plate at one end of the field. The other group watches with binoculars and measures the time difference between seeing the metal plate hit and the time sound arrives. Speed may be calculated using $v = \frac{d}{t}$.

Refraction of Waves in a Ripple Tank

Name: ____

Group Members: ______________________________________

Question

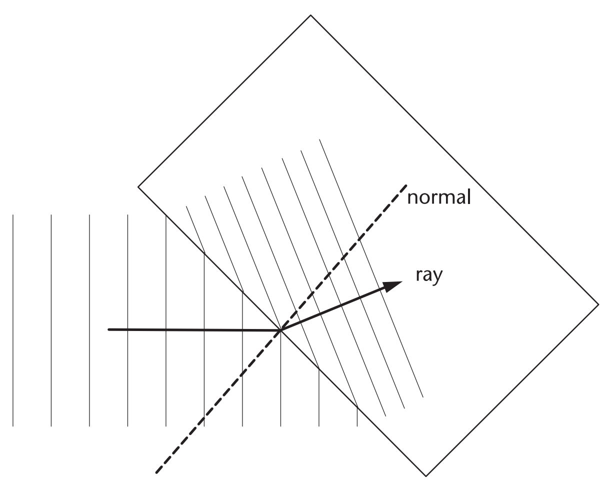
Is there a mathematical relationship governing the refraction of waves?

Materials

- ripple tank
- metre stick
- timer
- rectangular plexiglass plate
- carpenter's level

Background

Refraction is the change in a wave when it passes from one medium to another. In a ripple tank, refraction can be accomplished by placing a sheet of plastic in the tank to create a shallow section. Waves can then be observed passing from deep to shallow. Long straight wave fronts can be produced by rolling a dowel back and forth in the water or using the straight paddle on a wave generator. The wave front is travelling in a direction that is perpendicular to the front line. You can observe the wave front lines directly, or place a metre stick at right angles to the shadow image below the tank to indicate a ray. When you studied waves on springs, you learned that waves sometimes change speed when they go from one medium to another.



Procedure

Set up the ripple tank so that you can make pulses that travel through a section of deep water and then into a section of shallow water. Level the tank. Adjust the depth of water so that the shallow section produces a measurably smaller wavelength. Complete the following data table.

Wave Tank Data

Angle	λ_{deep}	$\lambda_{shallow}$	$\frac{\lambda_{deep}}{\lambda_{shallow}}$	θ_{deep}	$\theta_{shallow}$	$\frac{\theta_{deep}}{\theta_{shallow}}$	$\sin\theta_{deep}$	$\sin\theta_{shallow}$	$\frac{\sin\theta_{deep}}{\sin\theta_{shallow}}$
0°									
20°									
30°									
45°									
60°									
70°									

Analysis

What does the ratio of wavelengths tell you about the relationship of refraction to incident angle? What would the ratio of speeds (deep over shallow) be compared to the ratio of wavelengths? Repeat several trials from the table, and determine the speed in deep and shallow by measuring distance and time in each. Do your measurements support your hypothesis? Does the ratio of sines give you a comparable result? Plot graphs of λ_{deep} vs. $\lambda_{shallow}$, and $\sin\theta_{deep}$ vs. $\sin\theta_{shallow}$, and determine the best fit slopes of both graphs. How do the slopes compare? Even though there is no bending in the 0° case, does refraction occur?

Conclusion

What mathematical conclusions can you state relating to refraction from deep water to shallow?

Scientific Vocabulary

wave, reflection, refraction, ripple tank, wavelength, incident angle, slope

Refraction of Waves in a Ripple Tank

Teacher Notes

Outcomes

Students will be expected to

- apply the laws of reflection and the laws of refraction to predict wave behaviour (327-7)
- explain qualitatively and quantitatively the phenomena of wave interference, diffraction, reflection and refraction, and the Doppler-Fizeau effect (327-8)

Conclusion

After completing this investigation, students should understand that refraction is a change in speed for water waves the same as it was for spring waves. Secondarily, they should see that the ratio of wavelengths and ratio of sines are equal to the ratio of speeds. It should be shown that Snell's law can be written as $V_{deep} = k(V_{shallow})$ or $\sin\theta_{deep} = k(\sin\theta_{shallow})$, where k is the index of refraction for these two depths of water.

Refraction of Light

Name: ____

Group Members: ______________________________________

Question

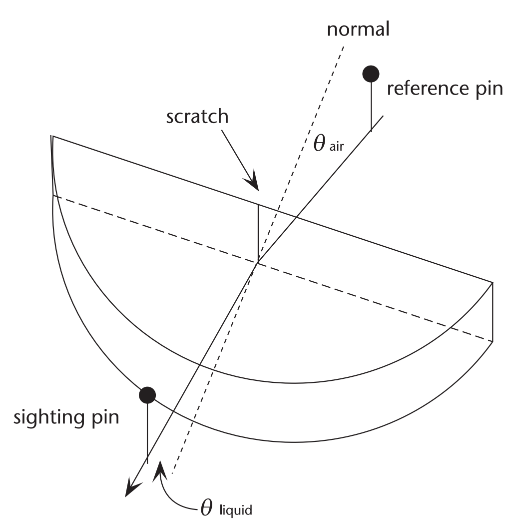
What is the law of refraction for light and how does it apply to liquids and solids?

Materials

- semicircular plastic refraction tank, or other semicircular transparent lens
- water and other liquids such as oil, sugar syrup, alcohol
- cardboard or ½" Styrofoam board larger than 8 ½" × 11"
- six large straight pins or dissecting pins
- 5 cm × 5 cm refraction glass plate
- white paper, 8 ½" × 11" or larger

Background

You have previously seen that refraction is primarily a change in the speed of a wave when it moves into a different medium. The ratio $\frac{v_{deep}}{v_{shallow}}$ is constant for all angles. This ratio is called the index of refraction for the two materials. The ratio $\frac{\sin\theta_{deep}}{\sin\theta_{shallow}}$ was found to be equal to the speed ratio. Since it is difficult to measure the speed of light in a material, in this investigation you will confine your attention to the angle ratio.



Procedure 1

You will be given a semicircular plastic refraction tank that is set up as shown. It should be about three-quarters full of water or other liquid. A vertical scratch is made at the middle of the straight side to serve as a sighting mark. On a sheet of white paper, draw a complete circle the size of the tank. Draw two diameters at right angles to each other and place the tank with its straight side on one of the diameters. The other diameter will serve as the normal to the straight side. Counting the normal as 0°, draw in lines from the scratch outward at 10°, 20°, and so on to 80°. Place a sighting pin about 3 cm away from the scratch at 0°, 10°, and so on in turn. At each position, look with one eye through the curved side of the tank. Move until the scratch on the tank blocks your view of the pin. Place a second pin on the round side of the tank in line with the scratch and first pin. Identify each sight line.

Analysis

For each liquid, complete a data table including angle in air, angle in liquid, sine of the angle in air, sine of the angle in liquid, and ratio $\frac{\sin\theta_{air}}{\sin\theta_{liquid}}$

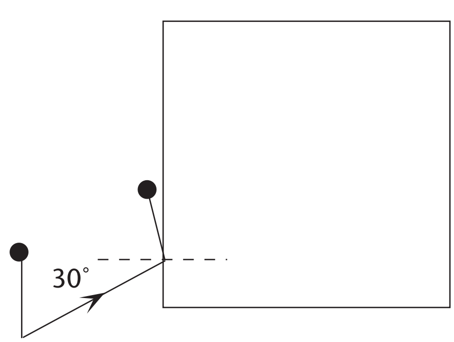
Plot graphs of $\sin\theta_{air}$ vs. $\sin\theta_{liquid}$ and determine the slope. What is the ratio of sines for the 0° trial? How can this be explained? Is the slope value the same for any of the liquids you examined?

Conclusion

What can you conclude about the refraction that occurs when light goes from air to a liquid?

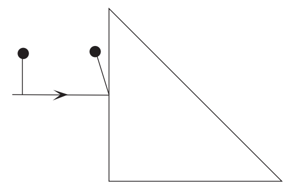
Procedure 2

In this section, you will explore what happens when light goes from air to glass to air. Set up glass plates as shown and follow the directions for each.

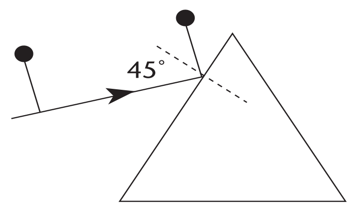


By sighting through the glass plate, locate the ray that emerges on the opposite side. Mark the ray lines on both sides. Remove the plate. Connect the two rays through the plate space. Measure angles from the normal in air and in glass at both sides. What is the average ratio?

$$\frac{\sin\theta_{air}}{\sin\theta_{glass}}$$



Pin-sight the ray through the glass plate. Look at both the bottom and the hypotenuse. Where does it emerge, and at what angle to the normal? What happens at the hypotenuse?



Trace the path by pin-sighting until the ray emerges. Is there only one possibility?

Conclusion

How does the index of refraction for light compare to the indices of the liquids you examined earlier?

Scientific Vocabulary

refraction, normal, angle of incidence, angle of refraction, light ray, incident ray, refracted ray

Refraction of Light

Teacher Notes

Outcome

Students will be expected to

- explain qualitatively and quantitatively the phenomena of wave interference, diffraction, reflection and refraction, and the Doppler-Fizeau effect (327-8)

Conclusion

Rays of light bend toward normal as light velocity decreases.

Index refraction $n = \dfrac{\sin\theta_{air}}{\sin\theta_{liquid}}$.

Procedure 2

Students should see that the ray emerges parallel to its original path.

Students should discover internal reflection on their own. A mathematical discussion of critical angle follows naturally.

If the ray enters the triangle close to the base, internal reflection will occur at the bottom.

Diffraction and Interference

Name: ____

Group Members: ______________________________________

Question

Do water waves exhibit the properties of diffraction and interference?

Materials

- ripple tank kit
- wax blocks

Background

Diffraction and interference are two characteristic behaviours of waves that distinguish wave motion from particle motion. Diffraction is the bending of a wave as it passes by an object or through an opening. Interference is the process by which wave pulses from different sources combine momentarily when they reach the same location. In this investigation, you will study the connection between wavelength and obstacle/opening size. Then you will see how diffraction can be used to create an interference pattern. Finally, you will learn how to make measurements that connect the size of an interference pattern to the wavelength.

Procedure 1

1. Set up the tank with the straight paddle wave generator. Select a moderate speed that creates uniform waves. Use a standing wave to measure the wavelength. Set one of the long blocks about 20 cm in front of the straight paddle, and off to one side so that about half the wave is blocked as it moves out across the tank. Draw a sketch to show what you see. Look closely at the area between the block and the generator. What is happening here? Look at the area on the far side of the block, where no waves can directly enter. What pattern do you see?
2. Set up two long blocks so that the opening between them is approximately as big as one wavelength. What happens if you make the opening larger or smaller? Draw a sketch showing the pattern you observe.
3. Set up the two long blocks with the small block between them so that two openings of wavelength size are created. Draw a sketch.

Conclusion

Summarize what happens to a wave when it passes an obstacle and through an opening.

Procedure 2

Set up the tank with the two round bobbers making identical circular waves. You will create three different patterns by tracing the shadow image on large sheets of paper under the ripple tank. To make the first pattern, set the down shafts of the bobbers parallel to each other. Set the generator at a fairly slow frequency. Measure the wavelength. Where the waves cancel out, a node is created that moves gradually away from the sources.

The path this node takes is a line through all the other nodes following the same path. What shape is any one nodal line? We will only examine the half of the pattern in front of the generator. Mark the images of the two bobbers. Sketch in all the clear nodal lines. Do a second pattern produced by separating the bobbers to about twice the original separation. Do a third pattern for which you increase the frequency and leave the bobbers as before. Measure the wavelength at this new generator setting.

Analysis

Your teacher will review the mathematical principles needed to examine the pattern in detail. Your goal is to find ways of measuring the interference pattern that can be related to the wavelength. If this can be done, then a similar experiment can be conducted for light in order to measure its wavelength.

Conclusion

How does the wavelength of a periodic wave relate to the interference pattern?

Science Vocabulary

diffraction, interference, constructive interference, destructive interference, wavelength, ripple tank, node, nodal lines, interference pattern, periodic wave

Diffraction and Interference

Teacher Notes

Outcome

Students will be expected to

- explain qualitatively and quantitatively the phenomena of wave interference, diffraction, reflection and refraction, and the Doppler-Fizeau effect (327-8)

Procedure 1

1. Waves bend around each end of the barrier and then meet behind the barrier.
2. The waves pass through the opening and spread out in a circular fashion.
3. The waves pass through each opening and a pattern similar to the two-point source wave interference pattern appears.

Analysis

This investigation is important both mathematically and conceptually. The relationship of wavelength to path difference is an excellent example of the role mathematics plays in helping us to explore and express our observations. Most importantly, it gives a more visible example of the technique used later in Young's experiment.

The treatment of light interference in *Physics, Principles and Problems*, Merrill (1992), beginning on page 394 is a minimum treatment of the formation of maxima by interference necessary to understand light interference. The same measurements can be made on a ripple tank. A more complete treatment can be found in sections 8.3 (pp. 354–362) and 8.4 (pp. 367–378) of *McGraw-Hill Ryerson Physics,* in any *PSSC Physics* text, and in section 14.4 of *Fundamentals of Physics*, Combined Edition.

Conclusion

Summarize what happens to a wave when it passes an obstacle or goes through a narrow opening.

The waves will change direction (bend) around the end of an obstacle or will spread out after going through a narrow opening.

The Wavelength of Light: Young's Experiment

Name: ______________________________

Group Members: ______________________________

Question

How can you use interference of light to determine the wavelength of monochromatic light?

Materials

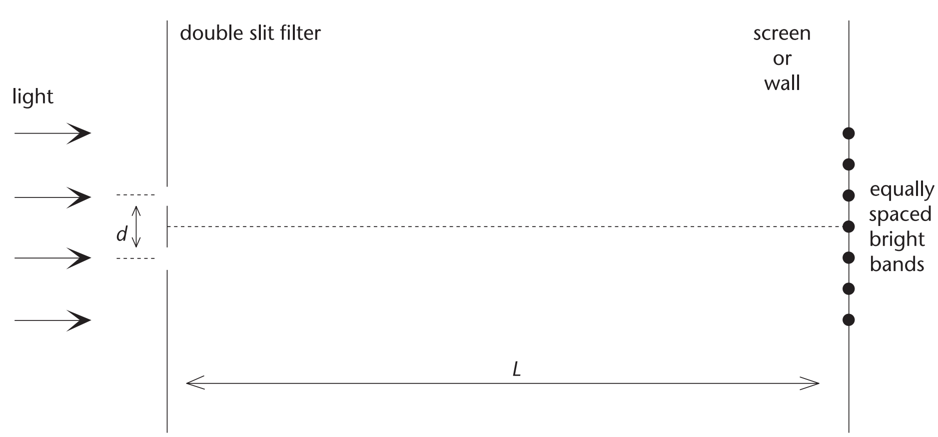
- He-Ne laser
- metre stick
- double slit filter

Background

Many scientists who believed that light was a wave unsuccessfully attempted to demonstrate the interference of light from two sources. Thomas Young first succeeded in 1801 by using a single source of light and two thin slits to produce two perfectly matched point sources of light. As you saw for water waves, when crest meets trough, cancellation occurs momentarily. When two crests or two troughs meet, they combine to give an even larger effect. If light waves cancel, the result should be darkness. If the result is constructive interference, light should be visible.

The wavelength should be given by $\lambda = \frac{xd}{L}$.

The following diagram shows the measurements you will have to make.



Safety

Do not look directly at the laser beam.

Procedure

Set up the laser about five metres from a wall or screen. Hold the filter directly in front of the laser. You should see on the wall a series of bright and dark bands. Locate the brightest, sharpest band. This is the central maximum. The distance from any one band to an adjacent band is x. You must either know or measure d, the distance between the slits in the film, L, the distance from the filter to the wall or screen, and x. To measure x, it is better to measure a number of spaces (six would be good) and divide to get the average value of x.

Results/Data

Record values for x, d, L, and any other observations you make.

Analysis

Use the formula to determine the wavelength of the red light in metres and nanometres. Compare your answer with an accepted value. What is your percentage of error?

Conclusion

Were you able to determine a wavelength for visible light? Is this convincing proof that light has wave properties? Explain.

Scientific Vocabulary

wave, monochromatic light, wavelength, double slit filter, laser, dark band, bright band, diffraction, constructive interference, destructive interference, metres, nanometre, visible light, wave properties

The Wavelength of Light: Young's Experiment

Teacher Notes

Outcome

Students will be expected to

- explain qualitatively and quantitatively the phenomena of wave interference, diffraction, reflection and refraction, and the Doppler-Fizeau effect (327-8)

Purpose

How can you use interference of light to determine the wavelength of monochromatic light?

Background

The laser method presented here has the advantages of large scale and the fact that it is a transmission image that is real, not virtual. Teachers may want to use the light bulb method, which has the advantage of doing more than one colour and comparison to the white light pattern.

Procedure

A similar activity may be done using a diffraction grating instead of double slit. The students will see a full spectrum of visible light and be able to calculate wavelengths of each of the different colours. Chemistry students use a spectroscope to view gases of various elements and determine the spectroscopic characteristics of the elements.

Analysis

Besides the critical importance of this lab in the historical development of our understanding of the nature of light, it also gives students a rare chance to determine a value in the order of 10^{-7}m using a metre stick.

Section 4: Exercises and Investigations for Physics 11

Dynamics: Newton's Laws, Energy Transfer, and Momentum

Name: ____________________

Group Members: ____________________

Question

What are some of the connections between science, technology, society, and environment and dynamics, Newton's laws, energy transfer, and momentum?

Background

There is a close association between the development of technology and the use of scientific knowledge for society's benefit.

Over time technology is improved as new scientific knowledge is gained and society's needs evolve. For example, the first bulletproof vests gave limited protection to the individuals wearing them. As new materials such as Kevlar were developed, vests gave more protection.

Procedure

Two students will work together to conduct their research (two periods), prepare a class presentation of three–four minutes, and submit a one–two page written report about their findings. A cover page with illustrations of the technology should be included with the report. A list of the works cited should be included at the end of the report. The technology chosen should be analysed based on the following topics:

- the motions related to the technology, how the motions fit with Newton's laws, how energy transfer and momentum are involved with the technology
- how society influenced the development of the technology over time
- how scientific principles and knowledge are involved in the technology and helped it improve over time
- environmental issues related to the development and use of the particular technology

Selected technologies for research. With your teacher's approval, you may choose a technology not listed below.

- bulletproof vest
- air bags
- children's swings
- crumple zone in car
- disc brakes
- shock absorber
- baseball bat
- baseball
- golf ball
- golf club driver
- tennis racquet
- splitting mauls and axes
- seat belts
- crash helmets
- swim fins
- excavator
- baseball glove
- CD antiskip device
- bicycle tires
- car tires
- bicycle gears
- yo-yos
- hammers
- gym floors
- hockey sticks
- goalie masks
- can openers
- food mixers
- running shoes

Scientific Vocabulary

dynamics, motion, acceleration, negative acceleration, Newton's laws, mass, force, inertia, momentum, energy transfer, materials research, technology

Dynamics: Newton's Laws, Energy Transfer, and Momentum

Teacher Notes

Outcomes

Students will be expected to

- analyse the influence of society on scientific and technological endeavours in dynamics (117-2)
- describe and evaluate the design of technological solutions and the way they function, using scientific principles (116-6)
- analyse and describe examples where knowledge of the dynamics of bodies was enhanced or revised as a result of the invention of a technology (116-2)
- describe the functioning of technology devices based on principles of momentum (116-5)
- analyse and describe examples where technological solutions were developed based on scientific understanding (116-4)
- analyse and describe examples where energy- and momentum-related technologies were developed and improved over time (115-5, 116-4)
- describe and evaluate the design of technological solutions and the way they function using principles of energy and momentum (116-6)

Materials

Students will require access to computers and the Internet to complete their research. They may want to create a slide or slides on multimedia or an overhead transparency for the class presentation.

Procedure

The second class spent on research should be several days after the first so that students have an opportunity to think about their research. General search engines on the Internet will provide adequate information for the research along with textbook support for the scientific analysis with respect to dynamics, Newton's laws, energy transfer, and momentum. A student sign-up page can be created using table formatting on the computer. Evaluation/ assessment may be in the following areas:

- Scientific content was accurate.
- The report addressed the topics required.

- Students shared in the work and presentation.
- Students maintained eye contact and were loud enough during presentation.
- Written report was readable and free of grammar and spelling mistakes.

Students should take notes on other presentations. Alternatively, the reports may be printed and handed out to the class.

Efficiency of a Simple Machine

Name: ____

Group Members: ______________________________________

Question

Which simple machine tested has the greatest efficiency?

Materials

- Newton scale or force sensor with recorder
- metre sticks
- fulcrum for metre sticks
- small masses (500 g)
- balance scale
- ramp for inclined plane
- wheeled carts
- single pulleys with string

Background

Percentage efficiency of a machine is defined as ratio of the useful work output (W_{output}) of a machine to total work input (W_{input}) times 100.

Therefore % Efficiency = $\frac{W_{output}}{W_{input}} \times 100$.

For a machine used to lift an object, for example, an inclined plane,

% Efficiency = $\frac{F_w \Delta h}{F_a \Delta d} \times 100$ where F_w is the weight of the object, Dh is the height the object is lifted, F_a is the force applied to move the object, and Dd is the distance the object is moved by the machine. There are six different kinds of simple machines—inclined plane, levers, wheel and axle, pulley, screw, and wedge. During this investigation you will work with one of the following: 1st, 2nd, 3rd class lever, inclined plane, or single or double pulley. Your group should choose one of these and register with your teacher. Use the Experiment Design Worksheet on page 91 to help you organize your experiment.

Hypothesis

Write a hypothesis incorporating the type of simple machine chosen.

Procedure

Fill in the Experiment Design Worksheet and have it checked before you start collecting data. If all groups lift the same mass and the same height, then the machine efficiencies may be compared at the end of the experiment. Some class discussion is needed to set these variables. Pass in a final report by the date set by your teacher.

Results/Data

Use some form of graphic organizer to display your data.

Analysis

Calculate percentage efficiency for your simple machine. Compare the percentage efficiency of your chosen machine with that of other groups in the class.

Conclusion

Was your hypothesis true of false?

Scientific Vocabulary

force, displacement, force applied, weight, change in height, simple machine, percentage efficiency, 1^{st} class lever, 2^{nd} class lever, 3^{rd} class lever, screw, inclined plane, wedge, pulley, wheel and axle, work, consistency, trials, precision

Efficiency of a Simple Machine

Teacher Notes

Outcomes

Students will be expected to

- design and carry out an experiment to determine the efficiency of various machines (212-3, 213-2, 213-3, 214-7)
- design an experiment identifying and controlling major variables (212-3)
- evaluate and select appropriate instruments for collecting evidence and appropriate processes for problem solving, inquiring, and decision making (212-8)
- carry out procedures controlling the major variables and adapting or extending procedures where required (213-2)
- use instruments effectively and accurately for collecting data (213-3)
- compile and display evidence and information, by hand or computer, in a variety of formats, including diagrams, flow charts, tables, graphs, and scatter plots (214-3)

Background

Student groups should investigate one of the simple machines for percentage efficiency. You may wish to have students investigate the inclined plane, single pulley, double pulley, and the three levers, since the wheel and axle, wedge, and the screw are more difficult to deal with in class. The experiment design worksheet has been found to be useful for students beginning to design their own experiments. It gets them to think about measuring and collecting meaningful data during an experiment.

Hypothesis

To change from a question to a hypothesis, students should change the question to a statement. For example, "Which simple machine tested has the greatest efficiency?" would become, "The 1st class lever has the greatest efficiency." You should get students to agree upon how high (0.25 m–0.50 m) to lift an agreed-upon mass (0.5 kg–1.0 kg).

Safety

None other than normal classroom safety.

Procedure

Students should show you their experiment design worksheet before starting their experiment. If you provide student with an electronic version of the worksheet, they can type in the spaces provided and later copy and paste some of their writing to the formal lab report. You can ask them questions to help clarify their procedure. This will also stagger the start for each group so that you are able to oversee events taking place in the lab. Students would do a minimum of three to four trials (as many as ten may be better) for each test of their machine so they could evaluate the consistency of the data. More trials would be needed if the data is not consistent. Three significant figures should be recorded for data where possible. As many variables as possible should be kept constant for all of the trials.

Results/Data

Students should design their own data recording table. This may be printed from the computer if they are using force sensors and computers or entering data into a spreadsheet.

Analysis

Calculate mean values for the forces and distances recorded in the trials.

Use the equation %Efficiency = $\frac{F_w \Delta h}{F_a \Delta d} \times 100$.

Each group should display their results for each of the experiments done. The other groups can then use the percentage efficiency of other machines in their lab report. Some class discussion may ensue once the results are posted.

For example, why is there a difference between machine efficiencies?

Conclusion

This will vary depending upon the machine and the variables set for each machine.

Experiment Design Worksheet

Name: ______________________________

Group Members: ______________________________

If you need more room, write on the back.

Question to be answered.

____

____

Hypothesis:

____

____

____

Prediction:

____

____

____

What are we going to do to prove or disprove our hypothesis?

____

____

____

____

____

____

What do we need for materials?

____

____

____

What variable are we going to change (manipulate)?

What variable will respond to the change?

What things do we need to keep constant over the run of the experiment?

What safety precautions do we need to take?

How many trials should we do?

How will we know we are getting "good" data?

What data do we need to collect? How will we record the data?

How will we display the data?

How will we analyse the data?

What do the data mean? (Do the next sections after you have completed your experiment.)

How do the findings relate to the hypothesis? (support/not support)

Interpret other findings.

Are there any changes that needed to be made to the procedure? Explain why.

Questions arising from the experiment that may be further investigated.

Waves

Name: ______________________________

Group Members: ______________________________

Question

What are the connections between waves and science, technology, society, and environment?

Background

Mechanical waves, such as vibrations, sound, and electromagnetic waves such as visible light, have a surprisingly great influence on our lives. In fact, modern societies would not exist without wave technologies. Some of these technologies include:

- musical instruments
- ship sonar
- ultrasound
- microwave oven
- hearing aid
- X-ray imaging
- hearing protection
- soundproofing
- speakers
- night vision
- radar
- bat cane for blind
- cell phones
- lasers
- fiber optic transmission
- FM/AM radio
- wave-generated power
- seismograph survey for oil
- laser surgery
- GPS
- CD technology
- stabilizing bridges against resonance
- stabilizing shorelines against waves
- laproscope
- earthquake seismology

Procedure

Working in pairs, research one of the technologies related to waves. Register your choice with your teacher. Use the topics listed on the following page to guide your research.

- description of the technology
- how it works
- historical developments in the technology
- improvements that have been made
- future challenges for the technology
- influence on society and vice versa
- environmental impact of the technology

Prepare a one-page fact sheet, including works cited, for a student handout. Present your findings to the class using both oral and visual means (posters, multimedia, overheads). A “date to present” sign-up list will be posted. Be prepared to answer questions about your research.

Scientific Vocabulary

waves, mechanical waves, sound waves, electromagnetic waves, reflection, refraction, Doppler shift, wavelength, amplitude, diffraction, interference, frequency, resonance

Waves

Teacher Notes

Outcomes

Students will be expected to

- select and integrate information from various print and electronic sources (213-7)
- analyse, from a variety of perspectives, the risks and benefits to society and to the environment when applying scientific knowledge or introducing a particular technology (118-2)
- analyse natural and technological systems to interpret their structure and dynamics (116-7)
- analyse society's influence on scientific and technological endeavours (117-2)
- analyse why and how a particular technology was developed and improved over time (115-5)

Materials

Students will require access to computers and the Internet for their research and perhaps to use multimedia presentation software.

Background

To do this research project, students will rely on wave technology, e.g., fiber optics used for Internet, light, and sound for presentations. They will soon realize their dependency upon wave-related technology.

Procedure

A search for a particular technology through a search engine will provide students with most of the material needed to do their research. The website <www.howstuffworks.com> may be a suitable place to start a search as well. By requiring students to keep the same sequence of topics, students are forced to edit and reconstruct information found on the Internet.

Alternative approaches to this project may be to research wave-related technologies found in a particular complex technology such as the automobile, aircraft, submarine, hospital, or space craft. Students need about two periods for research and one for writing. Two 50-minute sessions will provide enough time for most of the presentations.

Designing and Conducting Your Own Friction Experiment

Name: ______________________________

Group Members: ______________________________

Problem

Design and conduct an experiment related to physics phenomena.

Question

What is the effect of materials on the force used to pull objects across a surface?

Materials

- wooden blocks with hooks
- a variety of surfaces (e.g., carpet, concrete, linoleum, wood, sand paper)
- a variety of flat objects to pull over a surface (e.g., book, sneaker, car tire piece)
- Newton spring scale
- balance scale (force sensor/computer if available)

Background

When an object is pulled over another, the surfaces rubbing together result in friction. To make an object move, the force applied must be greater than the force of friction holding the object back. The relationship between the materials, the force of friction, and the normal force is $F_f = \mathrm{F}F_N$ (force of friction(F_f) = coefficient of friction (F) × normal force (F_N)), also $F_A = \mathrm{F}F_g$ (force applied (F_A) to move the object = coefficient of friction (F) × the weight of the object (F_g)). You may be surprised by some of your observations.

Use the Experiment Design Worksheet (p. 91) to help you plan an experiment to test the effect of materials on the force needed to pull the object. You may work together in groups of three for the experiment.

Hypothesis to Conclusion

See the Experiment Design Worksheet. Have your teacher check your worksheet before starting your experiment.

Scientific Vocabulary

force of friction, coefficient of friction, force applied, weight, hypothesis, manipulated variable, responding variable, controlled variables, precision, data consistency, trials, data table, graphic display

Designing and Conducting Your Own Friction Experiment

Teacher Notes

Outcomes

Students will be expected to

- design an experiment identifying and controlling major variables (212-3)
- evaluate and select appropriate instruments for collecting evidence and appropriate processes for problem solving, inquiring, and decision making (212-8)
- carry out procedures controlling the major variables and adapting or extending procedures where required (213-2)
- use instruments effectively and accurately for collecting data (213-3)
- compile and display evidence and information, by hand or computer, in a variety of formats, including diagrams, flow charts, tables, graphs, and scatter plots (214-3)
- interpret patterns and trends in data and infer or calculate linear and non-linear relationships among variables (214-5)

Materials

Each group could test different surfaces and objects.

Background

There are two ways friction is involved in objects being moved over surfaces. Static friction results from attraction of materials needed to be overcome when starting to move an object, and kinetic friction results from surfaces attracting each other while the object is moving. For any two surfaces in contact with each other, there are coefficients of friction (μ) related to force applied (F_A) to move the object ÷ the weight of the object (F_g).

Force applied is equal in magnitude but opposite in direction to the force of friction (F_f). Weight of the object is equal in magnitude but opposite in direction to normal force (F_N). Therefore $F = \frac{F_f}{F_N}$. To calculate coefficients of friction, you need to find the force applied and the weight of the object being pulled.

Hypothesis

The kind of materials rubbing together affects the force required to move them.

Prediction

The stickier the materials, the more force is required to move them against each other.

Safety

If doing this at desk height, make sure heavy objects don't fall on feet.

Procedure

Using the Experiment Design Worksheet (p. 91) will help students organize their experiment.

The manipulated variable will be the types of material. The responding variable will be force applied, which, opposite in direction, will be equal in magnitude to force of friction.

Calculating the coefficient of friction allows us to compare the materials used even if the object pulled does not have the same mass each time. Students should notice there is a difference between static friction (greater) and kinetic friction (smaller). This is very evident if a force sensor and computer graphically records data. Most groups will measure how much force it takes to pull something over a surface, but then not be able to find the coefficient of friction. Showing an example on the board should help. Each type of material combination should be tested a minimum of four times and the static friction and kinetic friction averaged separately before any calculations are done.

Results/Data

Each type of material combination should be tested a minimum of four times and the static friction and kinetic friction averaged separately before any calculations are done.

Analysis/Conclusion

A bar graph of the different coefficients may be one way to display the analysed results.

The class's final results could be collated for display. Some discussion of applying the results could ensue from the display.

Students can then decide if their hypothesis was true or false. Some discussion about the variety of uses of friction in society and technology could take place after the lab.

Section 5: Experiments and Activities for Physics 12

Hanging Mass Demonstration

Name: ______________________________

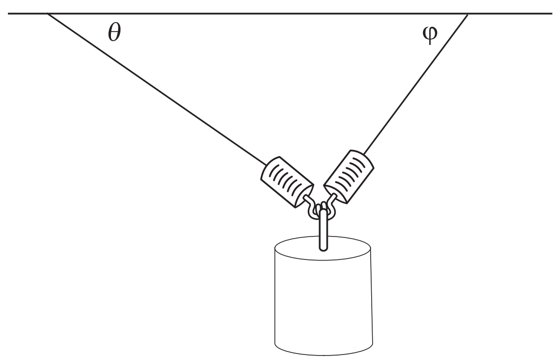
Group Members: ______________________________

Purpose

The purpose of this activity is to use vector analysis to determine the unknown hanging mass.

Materials

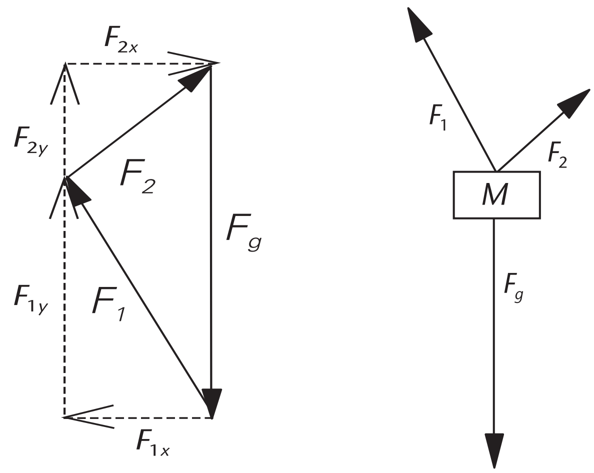
- two spring scales
- selection of masses
- plastic bag
- string
- chalkboard protractor



Procedure

Place a variety of masses (around 1 or 2 kg) in a plastic bag or other type of container. Attach two spring scales (using two strings of unequal length so that there is no symmetry) to a horizontal support rod as shown above. The two spring scales can then be used to support the bag containing the unknown masses.

The free body diagram should consist of 3 force vectors (shown to the left on the following page). The diagram on the right shows the vector diagram indicating that the two forces exerted by the strings must add to the vertical force of gravity to give a net force of zero.



By reading the spring scales, you can know the magnitude of the two force vectors supporting the bag. By measuring the angle that each string makes with the support rod, you can do a vector analysis (using a scaled diagram, vector resolution, or law of sines/cosines) that will allow you to determine the unknown mass.

The horizontal components can be calculated here as well and they should, of course, turn out to be equal (as can be seen in the diagram above). They are not, however, required to find the hanging mass. Only the vertical components of F_1 and F_2 add together to balance the force of gravity.

You may also want to look at the case where the strings are of equal length so that there is symmetry in the problem.

Hanging Mass Demonstration

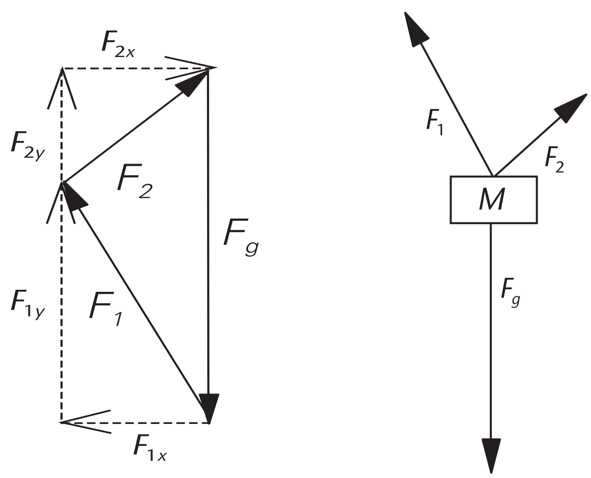
Teacher Notes

Outcome

Students will be expected to

- use vector analysis in two dimensions for systems involving two or more masses, relative motions, static equilibrium, and static torques (ACP-1)

Procedure



The horizontal components can be calculated here as well and they should, of course, turn out to be equal (as can be seen in the diagram above). They are not, however, required to find the hanging mass. Only the vertical components of F_1 and F_2 add together to balance the force of gravity.

Teachers may also want to look at the case where the strings are of equal length so that there is symmetry in the problem.

Acceleration on a Ramp

Name: ____

Group Members: ______________________________________

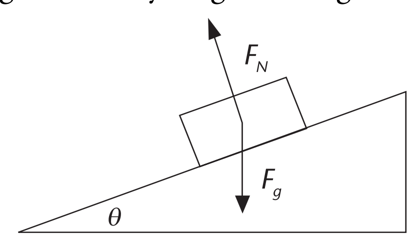
Purpose

To investigate the relationships

- between the acceleration of a cart on a ramp and the angle of the ramp
- between the acceleration of the cart and mass of the cart

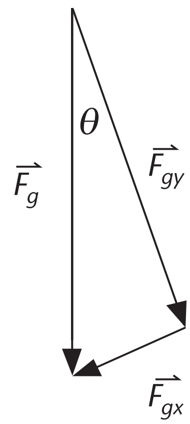
Background

If a cart is placed on a ramp, as in the following diagram, it can be observed (ignoring friction for now) that there are only two forces acting on the box—the normal force F_N (which is perpendicular to the surface) and the force of gravity F_g. Drawing a free body diagram, we get:



In order to apply Newton's second law, it is necessary to analyse the forces one dimension at a time. Instead of using the common coordinate system containing horizontal and vertical axes, it makes more sense in this situation to rotate the axes so that they are perpendicular and parallel to the surface of the inclined plane (in this way, one of our axes is in the same direction as the acceleration). In other words, the x-direction will be parallel to the plane and the y-direction will be perpendicular to the plane.

Since the normal force is already perpendicular to the plane, only the force of gravity must be broken up into components. This can be done as shown in the following diagram (where the F_g from the previous diagram has been enlarged).



The angle θ in the top of the triangle is the same angle as the slope of the inclined plane (try showing this using geometry). It can now be seen that, as long as we ignore friction, the acceleration of the cart should depend only on the component of F_g that is parallel to the ramp (F_{gx} in the diagram below).

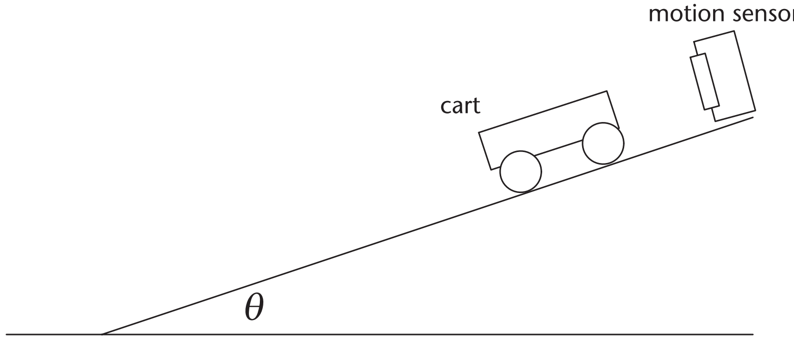
Hypothesis

What do you think will happen to the acceleration of the cart if the angle of the ramp is increased? What do you think the relationship might be? Will the acceleration stay the same? Will acceleration increase (or decrease) linearly with the angle, or as a function of $\sin\theta$ or $\cos\theta$?

What do you think will happen to the acceleration of the cart if mass is added to the cart? Will the acceleration stay the same? Will the acceleration increase or decrease with the mass?

Materials

- cart
- ramp
- motion sensor and appropriate data collection hardware/software
- chalkboard protractor
- selection of masses



Procedure–Part 1

Set the ramp up as shown in the diagram above. Measure the angle that the ramp makes with the floor using the protractor and record this in your data table. Position the empty cart near the top of the ramp in front of the motion sensor. Start the motion sensor and allow the cart to go down the ramp. Record the acceleration of the cart as determined by the motion sensor. Multiple trials can be performed, recorded, and averaged for each angle.

Repeat the above procedure for different angles of the ramp. The angles should probably vary from about 5° to about 35° or 40°, with approximately 5° intervals. Record the angle and the accelerations in the table.

Procedure–Part 2

Set the ramp to a moderate angle (between 15° and 25°). The ramp will remain at this angle for this part of the lab. Position the empty cart near the top of the ramp in front of the motion sensor. Start the motion sensor and allow the cart to go down the ramp. Record the acceleration of the cart as determined by the motion sensor. Again, multiple trials can be performed, recorded, and averaged for each mass.

Repeat the above procedure seven or eight times, adding mass to the cart each time. Mass increments should be either 100 or 200 grams, up to a maximum of about 2 kg. Record the mass and accelerations in the table.

Observations

Acceleration vs. Angle

Angle (θ)	Acceleration (m/s^2)			
	Trial 1	**Trial 2**	**Trial 3**	**Average**

Acceleration vs. Mass

Mass (kg)	Acceleration (m/s^2)			
	Trial 1	Trial 2	Trial 3	Average

Analysis

Look at your data tables. Do you notice any numerical patterns to the data?

Graph 1: Based on the vector analysis done previously, create a graph of acceleration vs. the appropriate function of θ. Is there a relationship evident from your graph? Are the data linear? If so, calculate the slope of the graph. Is the value that you obtained for the slope significant? Write a relationship for the acceleration of the cart as a function of the angle based on your graph. Is this supported by the vector analysis at the beginning of the lab?

Graph 2: Create a graph of acceleration as a function of mass. Is there a relationship? Can you spot any trend to the data, or are any deviations due to experimental uncertainty? Are your results consistent with the vector analysis done at the beginning of the lab? Explain.

Conclusion

What relationship did you find between acceleration and the angle of the ramp? What relationship did you find between acceleration and the mass of the cart? How do these compare with your hypotheses?

Acceleration on a Ramp

Teacher Notes

Outcomes

Students will be expected to

- state a prediction and a hypothesis about wave behaviour based on available evidence and background information (212-4)
- use vector analysis in two dimensions for systems involving two or more masses, relative motions, static equilibrium, and static torques (ACP-1)

Background

The component of the force due to gravity that is parallel to the ramp can be shown to be $F_x = mg\sin\theta$. Therefore, using Newton's second law ($\Sigma F = ma$), it can be shown that $a = g\sin\theta$. This is the relationship that students should find from their analysis of the data. Notice that mass cancels out, indicating that it should not be a factor.

Teachers may also want to discuss the role of friction in this vector analysis. If the friction is modelled as sliding friction (using $F_f = \mu F_N$, since this is what students are familiar with), it can be seen that the mass still cancels out. It must be remembered, however, that *rolling friction* is present here.

Hypothesis

Students should be expected to make a hypothesis based on the analysis above.

Materials

If a motion sensor is not available, you can also find the acceleration by using a stopwatch and measuring the distance down the ramp.

Procedure–Part 1

A low-friction cart will probably give better results for this. In the analysis above, the force of friction was ignored. If a cart with significant friction is used, this should be factored into the analysis and discussion.

When using the motion sensor, the acceleration can be found directly using an acceleration graph of the motion. Fitting a line to, and calculating the slope of, a velocity-time graph of the motion is another method of determining the acceleration. The acceleration graphs in the DataStudio program can sometimes be a bit choppy, so better results may be obtained by determining the slope of the velocity-time graph.

Procedure–Part 2

Again, the amount of friction present in the cart will probably affect the results obtained here. With a totally frictionless cart, the mass should not have an effect. In reality, friction with the axles and wheels may allow the mass to have an effect on the acceleration.

Analysis

Graph 1: Depending on the level of ability of the students, teachers may want to specifically tell them to plot acceleration vs. $\sin\theta$ instead of requiring the students to decide what to plot. Since $a = g\sin\theta$, the slope of the graph should be (ignoring friction) 9.8 m/s^2.

Graph 2: Based on the vector analysis, it can be seen that mass should not have an effect on the acceleration of the cart; however, the rolling friction present in the cart may be affected by an increase in mass. This change in friction would produce a change in the acceleration that is being measured by the students.

Conclusion

Students should find from their graph that $a = g\sin\theta$. The slope of the graph can be compared with the value of g on earth.

Based on the vector analysis, it can be seen that mass should not have any effect on the acceleration but students may in fact find a trend in their data (as was discussed earlier). This is a good opportunity to discuss how labs do not always give the ideal results that we may expect or predict. It is important that students interpret the data that are collected, and not try to slant their interpretation to match what they think "should" happen.

Collisions in Two Dimensions

Name: ____________________

Group Members: ____________________

Purpose

To determine if momentum is conserved in two-dimensional collisions.

Background

When you analysed one-dimensional collisions, you could show that in an isolated system the momentum of each object before the collision added up to equal the total momentum after the collision. This still applies in two-dimensional collisions, but remember that momentum is a vector, so it must be added as a vector! For a collision between two objects, conservation of momentum can be expressed as

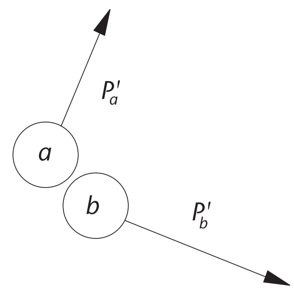
$$p_a + p_b = p_a' + p_b'$$

where primed quantities (') mean after the collision and unprimed mean before the collision. In a one-dimensional situation, the vector nature of the momentum could be addressed using positive or negative values for the velocities.

In two dimensions, the vector nature of momentum does not allow simple algebraic operations. Although you can still express the conservation of momentum, special attention must be paid to the vector nature of momentum. To add momentum vectors in two dimensions, you need to draw a vector diagram.

In this lab, we will launch a moving incident ball *a* that will collide with a stationary target ball *b*, as shown below.

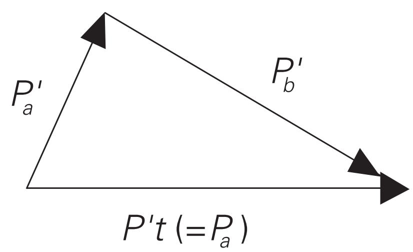
If the collision is not head on, the two balls will go in different directions after the collision.



If momentum is being conserved, then when we add the two momentum vectors after the collision (p_a' and p_b'), they should give the same vector as the initial momentum vector (p_a).

$$p_a = p_a' + p_b'$$

The vector diagram in this situation would look like this:



The initial velocity of the incident ball is horizontal; therefore, the momentum that we are concerned with is also horizontal. This means that it is only the horizontal velocities that will be included in any calculations of the momentum.

$$mv_a = mv_a' + mv_b'$$

In this lab, the actual collision will occur at a certain height above the floor. Since each ball has the same initial vertical velocity (0 m/s) and falls the same height, the balls will be in the air for the same amount of time. It is only during this time that they will be travelling horizontally. Since the horizontal velocity is constant and can be expressed in terms of the displacement using $v = \frac{d}{t}$, the conservation of momentum can be expressed as $md_a = md_a' + md_b'$ where d_a is the displacement of the incident ball if no collision had occurred, and d_a' and d_b' are the displacements of the two balls after the collisions.

Notice that the time is not a factor since it is the same for all of the displacements.

If all of the masses are the same, it is clear that the displacement vectors can be used in place of the actual momentum vectors to show that momentum is being conserved. If the masses are different, then some scaling of the displacement vectors must be performed first before they can be used to represent the momentum vectors.

Hypothesis

What do you think will happen? Why?

Materials

- rolling ball two-dimensional collision apparatus
- carbon paper
- metre sticks
- balls
- masking tape
- paper

Procedure

Set up your apparatus so that the ball bearing that rolls from the launcher is rolling horizontally off the edge of the table and landing on the floor. Let the ball roll down a couple of times from a specific height to determine the general area where it lands. *Remember to always launch the ball from the same height*. Tape a piece of paper on the floor where the ball landed. Place a piece of carbon paper over the taped paper (carbon side down). Launch the ball ten times so that it lands on the carbon paper. Lift the carbon paper and circle these dots.

Before collecting any more data, it is necessary to ensure that the screw holding the target ball is at the proper height. Place the target ball (of equal mass to the incident ball) on the screw directly in front of the launcher so that there will be a head-on collision. Adjust the screw so that the target ball is at the same height as the incident ball at the time of collision. Carry out several head-on collisions (releasing the incident ball from the same height as before). If the screw is set to the proper height, the target ball should land in the same spot as the original group of dots. If it does not, adjust the height of the screw until the target ball does land in the same area as the original incident ball by itself.

Equal Mass Collision: Set up the target ball (of equal mass) on the screw to one side of the launcher so that when the ball rolling down the apparatus strikes the one at rest there will be a glancing collision. Hang a plumb mass (such as a screw) directly under the point where the collision will take place. Mark the spot on the floor directly under this collision point. This is the point from which the vectors will be drawn.

Run a couple of trials of the glancing collision (without carbon paper), using the same launch height (of the incident ball) as the other trials. Tape two pieces of paper to the floor where the two balls are landing. Next place two pieces of carbon paper at these locations so that the balls will leave a mark when they hit the paper. Carry out ten trials of this glancing collision. Remove the paper and label the dots.

Draw a vector (chalk lines can be used) from the mark representing the point underneath the launch position to the centre of each of the three groups of dots created.

Measure and record the length of these displacement vectors and the angles (using 0° as the direction of the original displacement of the incident ball).

Unequal Mass Collision: This part of the procedure is carried out the same way as the equal mass collision, but the target ball is changed so that it does not have the same mass as the incident ball.

Observations

Mass Collisions

	Incident ball before collision		**Incident ball after collision**		**Target ball after collision**	
	length (m)	angle (θ)	length (m)	angle (θ)	length (m)	angle (θ)
Equal mass collision		0°				
Unequal mass collision		0°				

Analysis

For the collision of equal masses, draw a scaled vector diagram that will show if the momentum vectors after the collision are equal to the momentum vectors before the collision. Remember that the displacement vectors are actually proportional to the momentum vectors, so you can use the displacement vectors to show this conservation.

Notice the angle between the two momentum vectors after the collision. Does this angle have any significance? Is it what you expect?

For the collision of unequal masses, you need to know the ratio of the masses. If one mass is half the mass of the other, its displacement vector must be cut in half to represent a momentum vector. Again, draw a scaled vector diagram that will indicate if the momentum before the collision is equal to the momentum after the collision.

Conclusion

Does your evidence indicate that momentum was conserved in these collisions? What errors may have been introduced into this experiment? How might these errors be reduced?

Collisions in Two Dimensions

Teacher Notes

Outcome

Students will be expected to

- apply quantitatively the laws of conservation of momentum to two-dimensional collisions and explosions (326-3)

Background

The apparatus for this experiment is available from several suppliers such as Boreal.

Teachers may want to discuss the special case of an elastic collision where the two objects are the same mass and one of the masses is originally at rest, which results in a 90° separation after the collision. Students should be able to observe this during this experiment.

Hypothesis

Since momentum conservation is written as a vector equation, students will probably predict that the momentum will be conserved; however, they may not be able to explain why.

Materials

Instead of a rolling ball two-dimensional collision apparatus, other devices can also be used such as a ballistic pendulum collision apparatus or an air table.

Procedure

When using the rolling ball collision apparatus, it must be emphasized that it is crucial that the ball be dropped from the same height all the time so that the initial momentum will be constant for every trial.

If the rolling ball apparatus is used, it may be possible to use a single piece of paper that is large enough (flip chart paper) to cover the entire area of the floor being used for the experiment. In this way, all of the lines representing the vectors can be drawn directly on the paper. Otherwise, it is possible to use chalk to mark the vectors directly on the floor.

Instead of using the displacement vectors to represent the scaled momentum vectors, teachers may want to measure the mass of the balls and calculate the time in the air so that the actual momentum vectors can be used in drawing the scale vector diagrams. In either case, it should be emphasized that the vectors being drawn actually represent momentum vectors.

Observations

When recording the angles measured, students should probably measure all angles from the path that the incident ball travelled with no collision.

Analysis

Students should find that the angle between the vectors after the collision of equal masses is close to 90°, signifying an elastic collision. It is assumed that this has either been discussed in class previously or will be brought up during the discussion of the lab.

Conclusion

Students should be expected to make some judgment call on whether or not their data support their hypothesis.

Projectile Lab

Name: ____________________

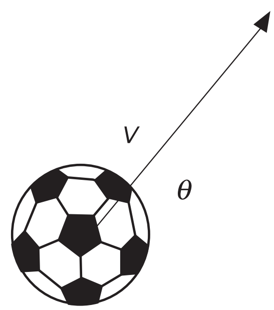
Group Members: ____________________

Purpose

The purpose of this lab is to determine the horizontal distance that a projectile will travel.

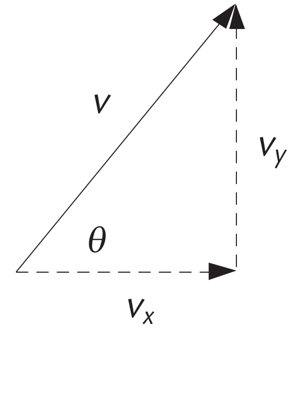
Background

Consider a soccer ball that is launched at an angle, as shown below.



It is important to remember that the arrow in the diagram above represents the velocity vector for the soccer ball, not the ball's actual path! The direction of the arrow indicates the ball's initial direction, and the length of the vector (if drawn to scale) indicates its magnitude. Remember, the ball follows a parabolic path; it does not follow a straight line!

Your first step with an object launched at an angle should be to resolve the object's velocity into its components, as shown in the diagram below. We can then analyse the motion in each dimension (horizontal and vertical).



Looking at the horizontal motion, there is no acceleration since there are no horizontal forces acting after the launch of the projectile (as long as we are ignoring air resistance).

All horizontal motion can then be described using the equation $d_x = v_x t$ where d_x is the horizontal distance travelled by the projectile and v_x is the horizontal component of the projectile's velocity. If we know the initial velocity, only the time is needed to calculate the horizontal distance travelled. This can be found by analysing the vertical motion.

Looking at the vertical motion, the only force acting is gravity; the acceleration will then be –9.8 m/s^2 (with up as the positive direction).

If we know the vertical displacement of the motion and the initial velocity, we can then use the equation $d_y = v_{yi}t + \frac{1}{2}a_y t^2$ to find the time that the projectile was actually in the air.

Hypothesis

None required.

Materials

- elastic band
- projectile
- chalkboard protractor
- metre stick
- target

If a projectile launcher is available, this can be used in place of the elastic band, projectile, and metre stick apparatus.

Procedure

Each group will be assigned an angle to use for this experiment. Upon receiving your angle, you will be required to calculate the horizontal distance that your projectile will travel.

You will use the metre stick as a launcher. You will need to determine the launch velocity of your "launcher" when the elastic is stretched to a certain length. The only permitted trials to determine the launch speed are straight up with a certain stretch or horizontally with a certain stretch.

After you have determined the initial launch velocity of the launcher, you must use this velocity along with the angle that you were assigned to calculate the horizontal distance that will be travelled by your projectile. You are required to make any other measurements of the apparatus required to perform these calculations.

Once you have calculated the horizontal distance that will be travelled by the projectile (and everyone in your group agrees with your result) you can proceed to actually launching your projectile. To do this, draw a straight line on a piece of paper. This line will be your target. Tape the paper to the floor so that the line is exactly the proper distance away from your launcher. Place a piece of carbon paper over the target (carbon side down). Use the chalkboard protractor to set up your launch apparatus at the appropriate angle. Launch your projectile. Make sure that you are using the same stretch of the elastic as you did to determine the initial velocity. If the projectile does not hit the target paper, go back and check your calculations. Perform four or five more trials.

Observations

Record all data that you have collected in trying to determine the launch velocity of your projectile, as well as any data that you have recorded in order to calculate the horizontal distance of the projectile.

There should be five hits recorded on your target paper. Since you know how far away your target was, you can measure the actual distance travelled for each of the five trials. Record and average the five trials; these can then be compared with the calculated horizontal distance.

Analysis

Show all calculations that were used to find the launch velocity and horizontal distance travelled by the projectile. Explain the methods used and the reasons for performing these calculations. Comment on your success, or lack thereof, in hitting the target. What errors were present in this lab? Have they been controlled? If not, why not? In what ways could the success of this lab be improved upon?

Conclusion

Is the mathematical model of projectile motion supported by your results?

Projectile Lab

Teacher Notes

Outcomes

Students will be expected to

- design an experiment identifying and controlling major variables (212-3)
- apply and assess alternative theoretical models for interpreting knowledge in a given field (214-6)
- analyse quantitatively the horizontal and vertical motion of a projectile (325-6)

Safety

For safety, have students stand well away from the area in front of the launcher when the projectile is being launched. Students should wear eye protection whenever a projectile is being launched. If using a spring-loaded projectile launcher, make sure students only load the projectile when they are ready to launch. They should not be working around a loaded projectile launcher.

Procedure

Teachers may have a projectile launcher that they want to use with this lab. The lab can then follow the same procedure, but the results will probably be much more accurate.

If the projectile is not being launched at the same level as the target, make sure that students realize that they have to measure the vertical displacement and include this in their calculations.

It may be helpful to have one of the group stand behind the target to make sure that the launcher is being aimed at the target, to ensure that they are not shooting to the left or the right of the target.

When assigning angles to the class, it is a good idea to assign a range of angles, perhaps between 25° and 65°. Upon completion of the lab, the class can compare their results. Students can see that the greatest horizontal displacement should have been at a 45° launch.

Circular Motion

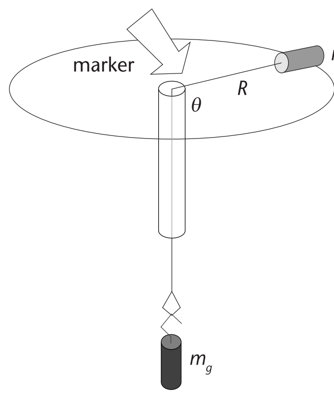
Name: ______________________________

Group Members: ______________________________

Purpose

The purpose of this activity is to determine the relationships among centripetal force, mass, and circular speed.

Materials



The diagram below shows an apparatus that can be used to study circular motion.

The apparatus consists of a piece of fire-polished glass tubing inserted into a section of rubber hose to form a protective grip. Alternatively, it can be wrapped heavily with duct tape. Strong fly-fishing line can be cut to a length sufficient to allow trials to a maximum radius of 50 cm. If loops are tied at both ends, hooked weights can be used for the swung mass and the hung mass. A small alligator clip or paper clip should be attached as a marker just outside the top of the tube. A large timer visible throughout the classroom is useful for visualizing the timing of rotations.

Background

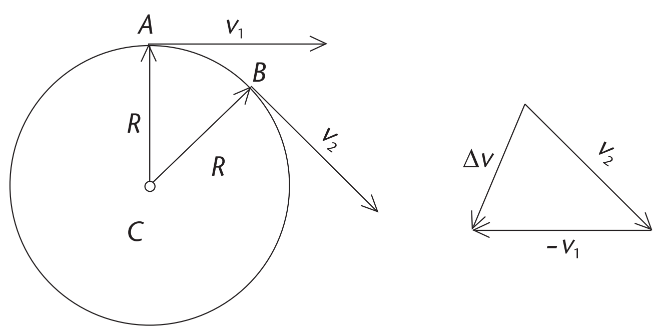
You have learned that Newton's second law can be summarized algebraically as $F_{NET} = ma$ for linear motions. In such cases, the net force acts in the same line as the motion, and either increases or decreases speed, depending on the direction in which the force is applied. Circular motion presents a unique case in which the force acts continuously at right angles to the direction of motion. The result is that only the direction of the motion is affected, and not the speed.

In this demonstration, you will explore the application of Newton's second law to this circular case. Since acceleration is defined as $\frac{\Delta v}{\Delta t}$, we must be careful how we conduct circular trials.

Both the magnitude of the radius and the time per revolution (period) affect circular speed (v_c). It is easy to determine the radius and circumference of a particular circular motion. It is NOT easy to determine acceleration.

Since speed is distance divided by time, circular speed is circumference divided by time for one revolution.

$$v = \frac{2\pi R}{T}$$



In the diagram above, the position triangle is similar (equiangular, not congruent) to the velocity vector diagram. This means that ratios of corresponding sides are equal. The arc distance *AB* can be considered approximately straight for small angles. (You will hear more about these sorts of idealizations later in math.) Since we want to find acceleration, the velocity vector diagram is a subtraction diagram. To determine the vector difference between v_2 and v_1, $(v_2 - v_1)$, a negative v_1 vector is added to v_2.

$$\frac{\Delta v}{v(either)} = \frac{AB}{R} = \frac{v_c \Delta t}{R}$$

$$\Delta v = \frac{v(v\Delta t)}{R} = \frac{v^2 \Delta t}{R}$$

$$a_c = \frac{\Delta v}{\Delta t} = \frac{v^2 \Delta t}{R} \div \Delta t = \frac{v^2}{R}$$

$$\therefore F_c = \frac{mv^2}{R}$$

Procedure

To conduct a trial, a person must attach a known swung mass at the top of the line and swing it at a steady speed above the head. The string below the tube must be held with the free hand as the trial begins. When a mass (m) is attached at the top and swung in a circle at a steady speed, another mass (m_g) can be hung on the bottom end of the line to provide the centripetal force. If too much mass is hung at the bottom, the swung mass will be pulled toward the top of the tube. If too little is used, the swung mass will pull away. Only when the weight of the hung mass is equal to the centripetal force required by the swung mass does the radius remain constant. At this point the operator should be able to release the line below the tube and no motion should be observed in the marker.

You will observe at least three trials when only the mass is varied, three when only the radius is varied, and three when only the speed is varied, as in the following data table.

Circular Motion Data

	Trial	Swung mass (kg)	Radius (m)	Frequency (Hz)	Speed (m/s)	Hung mass (kg)	Centripetal force (N)
$F \propto m$	1						
	2						
	3						
$F \propto R$	4						
	5						
	6						
$F \propto v$	7						
	8						
	9						

The first three trials are easy to conduct since radius and speed are unchanged. To do trials 4–6, in which the radius is to change, presents a problem. How can the speed be maintained if the circumference of the circle is changed? For the last three trials, will there be any difficulty collecting data?

Analysis

First, examine the relevant columns of data to see if there is a mathematical pattern. Consider the first three trials in which swung mass is the manipulated variable. When swung mass doubles, how does the centripetal force change? (Increase or decrease, arithmetic factor or exponential?) Sketch a graph of F_c vs. swung mass for the first three trials. Does the magnitude or the unit of the slope tell you anything useful?

Conclusion

What are the relationships among centripetal force, mass, and circular speed?

Circular Motion

Teacher Notes

Outcomes

Students will be expected to

- describe uniform circular motion using algebraic and vector analysis (325-12)
- explain quantitatively circular motion using Newton's laws (325-13)

Background

There can be substantial friction in this apparatus. The longer the radius, the more sag in the line. This does not affect distance significantly, but it does cause more friction between the line and the tube. For this reason the condition of the string must be monitored constantly, or else it will become a demonstration of Newton's first law!

When setting up a trial, you must hold the string below the tube. It is not practical to add incremental weights to provide the centripetal force. You may want to show the result of too little or too much force at the beginning. To keep the data easy to manipulate, it is better to add the correct weight and demonstrate the balance that results by releasing your grip on the line below the tube.

Students could examine the effect of depression angle. Even at a depression angle of 20°, the cosine component is still .940 times the line distance.

Students need to see how frequency and velocity are related. Good results depend on the experimenter being able to synchronize revolutions with a clock. A large-face, 10-second timer with a sweep hand is easy for students to see. Counting out the revolutions orally will help students focus on the general pattern rather than slight variations from swing to swing. The marker at the top of the tube is bound to move slightly. Students should see that this is not significant over an interval of 10 seconds.

Doing the velocity trials can be challenging. Frequencies of 1 or 2 Hz are easy to maintain, but 3 Hz is difficult. A suggestion might be to try 2.5 Hz, or five revolutions every two seconds.

Sample data are included in the table. Note that trials 1, 4, and 7 are identical. Three trials for each variable is an adequate number to identify the relationship.

Sample Circular Motion Data

	Trial	Swung mass (kg)	Radius (m)	Frequency (Hz)	Speed (m/s)	Hung mass (kg)	Centripetal force (N)
$F \propto m$	1	0.050	0.500	1.00	3.14	0.100	0.98~1
	2	0.100	0.500	1.00	3.14	0.200	1.97~2
	3	0.200	0.500	1.00	3.14	0.300	3.94~4
$F \propto R$	4	0.050	0.500	1.00	3.14	0.100	0.98~1
	5	0.050	0.250	2.00	3.14	0.200	1.97~2
	6	0.050	0.125	3.00	3.14	0.300	3.94~4
$F \propto v$	7	0.050	0.500	1.00	3.14	0.100	0.98~1
	8	0.050	0.500	2.00	6.28	0.400	3.94~4
	9	0.050	0.500	3.00	9.42	0.900	8.87~9

Analysis

This is a good opportunity to encourage students to examine the data table for patterns before they draw a graph. Direct, inverse, and square data patterns stand out clearly.

The graphs for each of the proportions work out well for only three points because the data are "idealized" by the method used to collect them.

Kepler's Laws

Name: ____

Group Members: ______________________________________

Materials

- polar graph paper (2 sheets)
- sharp pencil
- metric ruler

Background

In the 1600s Johannes Kepler, using data collected by Tycho Brahe, postulated three empirical relationships that describe the motion of the planets. Today, these relationships are known as Kepler's laws.

- **Kepler's first law**: Planets move in elliptical orbits, with the Sun at one focus of the ellipse.
- **Kepler's second law**: An imaginary line between the Sun and a planet sweeps out equal areas in equal time intervals.
- **Kepler's third law**: The quotient of the square of the period of a planet's revolution around the Sun and the cube of the average distance from the Sun is constant and the same for all planets.

Procedure

Place your polar graph paper on the table so that the zero degree point is on your right as you view the graph paper. The sun is at the centre of your graph paper. Label the location of the sun without covering up the centre mark on the graph paper.

Choose an appropriate scale to represent the value for the radius vectors of Mercury's position.

Table 1 shows the heliocentric position of Mercury over a period of three months in 2003. Select the data point for January 1, 2003, and locate the given longitude on the polar graph paper. Mark the radius vector at this longitude on your graph paper.

Mark all the data points provided in Table 1 on your polar graph paper. After all the data points have been plotted, carefully connect the points of Mercury's position and sketch the orbit of Mercury.

Prepare a graph of Earth's orbit using the data given in Table 2.

Results/Data

Heliocentric Ecliptic Positions for Mercury (2003)

Table 1

Date	Longitude (degrees)	Radius vector (AU)	Date	Longitude (degrees) (AU)	Radius vector
Jan 1	44	0.316	Feb 18	254	0.466
Jan 5	69	0.308	Feb 22	265	0.466
Jan 9	94	0.310	Feb 26	276	0.461
Jan 13	118	0.321	Mar 2	287	0.451
Jan 17	140	0.339	Mar 6	299	0.437
Jan 21	160	0.361	Mar 10	313	0.420
Jan 25	178	0.384	Mar 14	327	0.400
Jan 29	193	0.406	Mar 18	343	0.377
Feb 2	206	0.426	Mar 22	1	0.354
Feb 6	219	0.442	Mar 26	21	0.333
Feb 10	231	0.455	Mar 30	44	0.316
Feb 14	242	0.463	Apr 3	69	0.308

From the United States Naval Observatory Astronomical Applications Department <http://aa.usno.navy.mil/>

Heliocentric Ecliptic Positions for Earth (2002)

Table 2

Date	Longitude (degrees)	Radius vector (AU)	Date	Longitude (degrees)	Radius vector (AU)
Jan 1	100	0.983	Jul 15	292	1.017
Jan 16	116	0.984	Jul 30	307	1.015
Jan 31	131	0.985	Aug 14	321	1.013
Feb 15	146	0.988	Aug 29	335	1.010
Mar 2	161	0.991	Sep 13	350	1.006
Mar 17	176	0.995	Sep 28	5	1.002
Apr 1	191	0.999	Oct 13	19	0.998
Apr 16	206	1.003	Oct 28	34	0.994
May 1	220	1.007	Nov 12	49	0.990
May 16	235	1.011	Nov 27	64	0.987
May 31	249	1.014	Dec 12	80	0.985
Jun 15	264	1.016	Dec 27	95	0.983
Jun 30	278	1.017	Jan 11	110	0.983

From the United States Naval Observatory Astronomical Applications Department <http://aa.usno.navy.mil/>

Analysis

Do your graphs for Mercury's orbit and Earth's orbit support Kepler's first law?

Draw a line from the Sun to Mercury's position on February 2. Draw a second line from the Sun to Mercury's position on February 14. Determine the area contained by these two lines and Mercury's orbit.

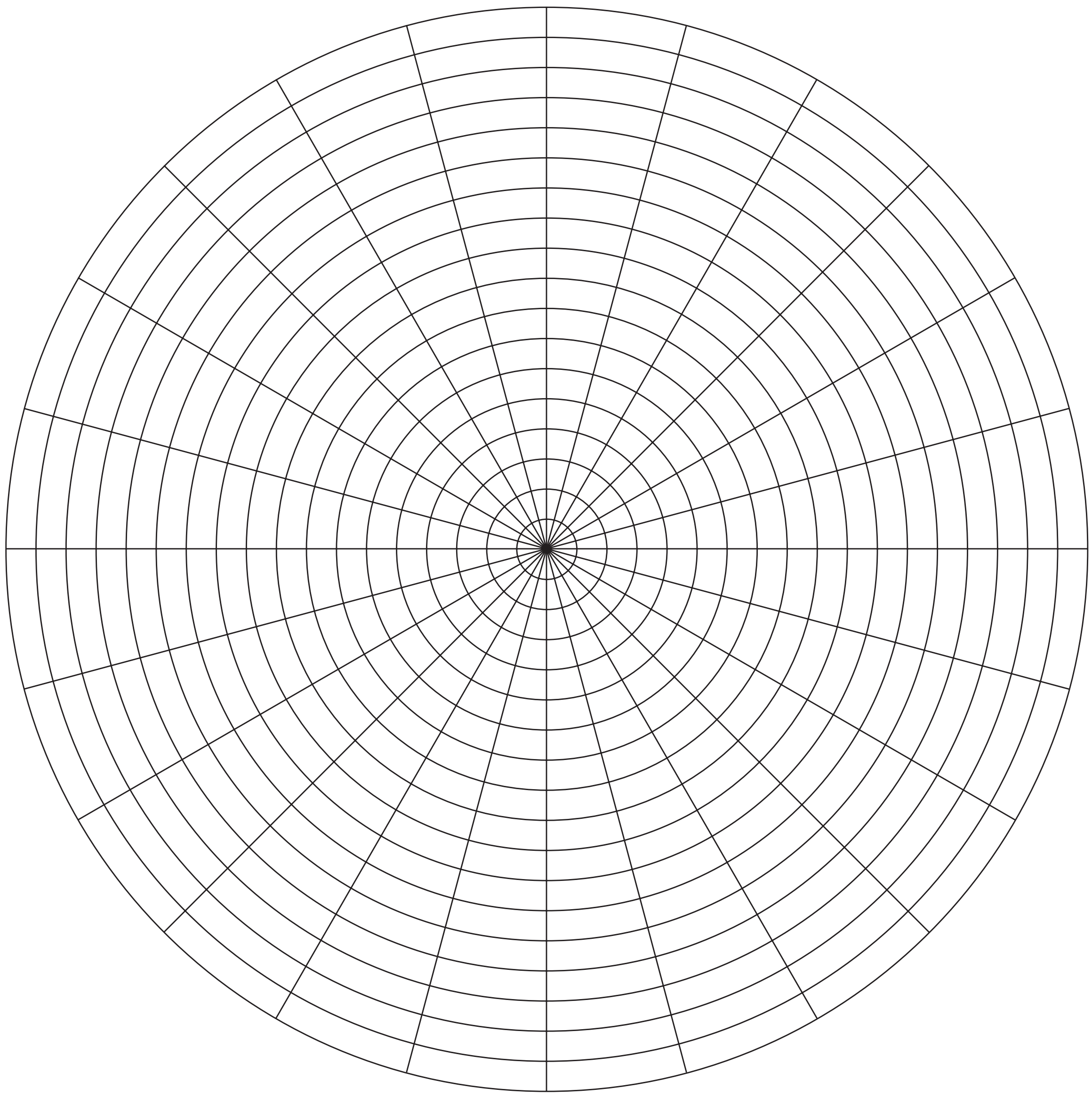
Select two additional twelve-day periods (one in January and one in March) and determine the areas for each of those twelve-day periods.

Do these areas support Kepler's second law?

Determine the area for three separate 30-day periods from the graph of Earth's orbit. Do these areas support Kepler's second law?

From Table 1 and Table 2, determine the period of Mars and of Earth. Determine the average radius vector for Mars and for Earth. Use your values for period and average radius vector for Mars and for Earth along with Kepler's third law to determine the Kepler constant for Mars and for Earth. Does your data support Kepler's third law?

Polar Coordinate Graph Paper



Kepler's Laws

Teacher Notes

Outcomes

Students will be expected to

- explain qualitatively Kepler's first and second laws and apply quantitatively Kepler's third law (ACP-2)
- compile and organize data, using data tables and graphs, to facilitate interpretation of the data (213-5)
- to compile and display evidence and information, by hand or computer, in a variety of formats, including diagrams, flow charts, tables, graphs, and scatter plots (214-3)

Materials

- polar graph paper (2 sheets)
- sharp pencil
- metric ruler

Procedure

It is very important that students choose an appropriate scale before they begin to plot points. Often, students will start plotting data only to have to start over when they realize that the scale they have chosen is not appropriate.

This will most likely be the students' first experience with polar graph paper. They may need instruction in how to plot points on polar graph paper.

Results/Data

Students should see that the orbits for both Mercury and Earth are elliptical, thus supporting Kepler's first law.

If students are careful when measuring the area of their twelve-day periods for Mercury, they should find data that supports Kepler's second law.

Again, students should have little problem showing that the ratio of the square of the period to the cube of the average radius is consistent for both Mercury and Earth.

Coulomb's Law

Name: ______________________________

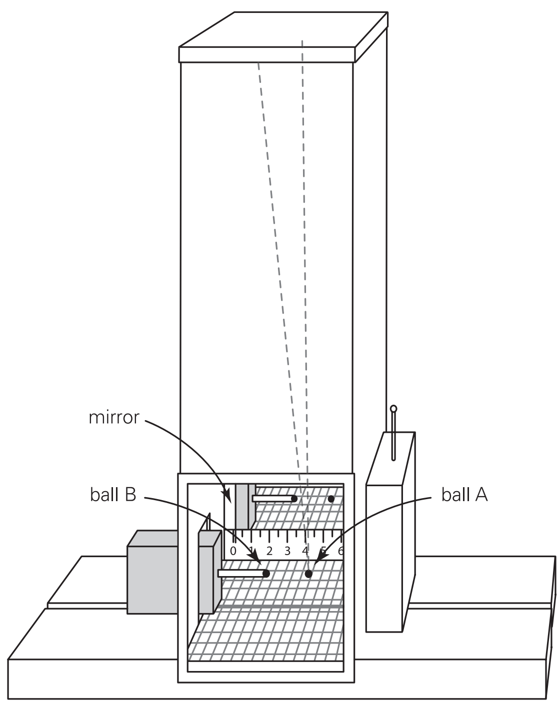
Group Members: ______________________________

Purpose

The purpose of this activity is to measure the effect of separation on the electric force between two charged spheres

Background

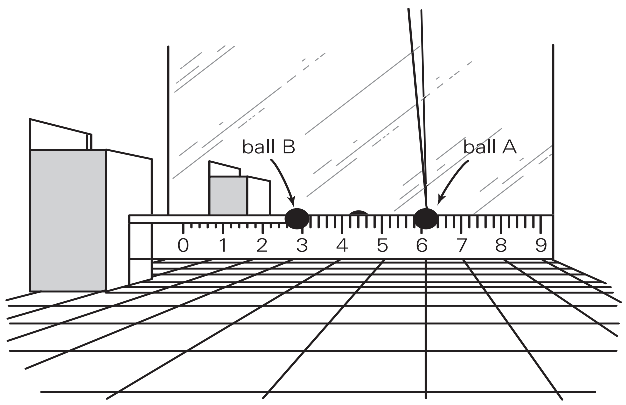
The apparatus used in this experiment requires careful attention to detail. Although Coulomb's law includes the effect of magnitude of charge on electric force, it is not part of this experiment. You will be concerned only with the effect of separation. However, you must understand how force will be dealt with.



The apparatus consists of a cardboard chimney in which a small conducting charged sphere is hung by a vee of fine nylon thread. This limits movement horizontally. On the back of the chimney is a mirror and centimetre scale. When you look with one eye straight in through the window along the plane of the table, you can change your position slightly so that the actual suspended sphere completely blocks your view of its image in the mirror.

When this happens, you can read the position of the right-hand edge of the sphere on the scale. This guarantees that you are looking straight into the box. Notice that the entrance on the right-hand edge of the chimney is blocked to prevent the influence of air currents.

Before beginning trials, the two balls must be given equal charges. This is done by charging ball B outside the apparatus and carefully placing it in the chimney. Ball A should be attracted to ball B. Briefly touch the balls together to see that the charge is shared equally, and then it is repelled because of their like charges. As long as these charges remain unchanged, the electric force is only affected by separation.



In the picture above, you can see that the viewer is looking straight in at suspended ball A. Its image is hidden behind. The right-hand edge of ball A is at 6.4 cm on the scale. You will need to know the starting position of ball A (when no electric force is present) and its positions under a variety of forces. **Since charge may leak over time, it is important to work quickly**. Move ball B close enough to ball A to cause some movement. Record the positions of ball A and ball B. Move ball B closer in increments and repeat the recording of both positions in a suitable data table.

It is important not to overcharge the balls. One way to avoid this is to use a proof plane. A penny glued to an insulating stick (plastic drinking straw, toothpick) makes a good device.

Rub a plastic strip or sheet of overhead transparency with silk or paper. Place the penny on the plastic and ground it with a finger. This will transfer a small charge to the penny, which in turn can be transferred to ball B. This apparatus is called an **electrophorus**.

All that remains is to find a way to deal with electric force. When suspended, ball A is at rest; it is experiencing a net force of zero. When no electric force is present, the tension *T* in the suspending thread is equal but opposite in direction to the gravitational force, *mg*. When ball B is close enough to ball A to move it, the electric force F_e is equal and opposite to the vector sum of the tension and gravitational force.

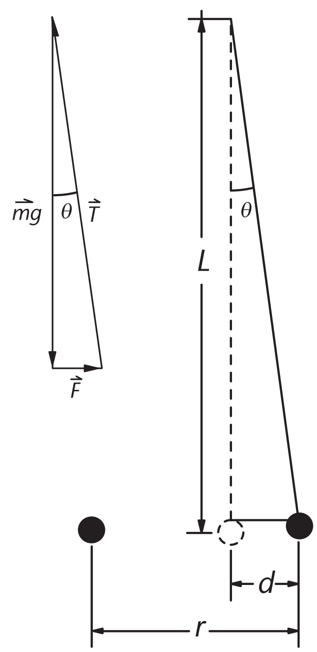
For small angles, $\frac{F_e}{mg} = \frac{d}{L}$, and $F_e = \frac{mg}{L}d$

Therefore $Fe = (k)d$

Analysis

In other words F_e is proportional to *d*. This means that we can determine the nature of the relationship between F_e and separation *r* by plotting a graph of *d* vs. *r*.

Continue manipulating the data until you get a straight line graph.



Conclusion

What is the relationship between electric force and separation?

Coulomb's Law

Teacher Notes

Outcomes

Students will be expected to

- compare Newton's law of universal gravitation with Coulomb's law, and apply both laws quantitatively (328-4)

Background

The apparatus for this experiment is available from several suppliers such as Northwest or Fisher Scientific.

There are several aspects to this experiment that make it valuable for grade 12 students. Precision in measuring position is essential in this lab. It is possible to measure position to the nearest tenth of a millimetre. It is a chance to validate one application of the inverse square relationship. It is also a chance to conduct trials where something can easily go wrong. As in "real" science, refining methodology is an important part of this investigation. It is also a good chance to practice inferring a relation from limited data.

Analysis

As explained in the student notes, a graph of d vs. r will give the same relationship as if we had actually measured F_e to plot against separation. Data will be obviously inverse, and obviously not linear. How well students can identify the exponent (square) in the relation will depend on how much charge leakage occurred. The slope of the final graph is of limited value.

Conclusion

It is important that students realize what they can—and cannot—conclude from this experiment. The proportionality can be stated, but not the equation.

$$F_e \alpha \frac{1}{r^2}$$

The Electric Motor

Name: ______________________________

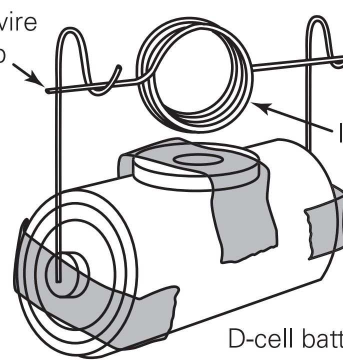
Group Members: ______________________________

Purpose

The purpose of this activity is to construct a working electric motor and experiment with factors controlling its operation.

Materials

- two 1.5-V D-cell batteries
- small disk magnet
- approximately one metre of enamelled armature wire, 28 gauge
- two metal paper clips
- tape
- sandpaper



Procedure A

Tape the magnet to the side of the dry cell as shown in the diagram. Wind the wire into a loop approximately the diameter of a quarter. Leave 4–5 centimetres straight at each end. Remove the enamel coating from one side of the ends of the wire using the sandpaper. This must be done carefully so as to leave the coating intact on the other side of the wire. Bend the two paper clips as shown to act as supports for the coil and tape them in place. Make sure there is enough room for the coil to rotate above the dry cell. You may have to make minor adjustments to get smooth operation. Place the loop in position and give it a little push to start it spinning. *Do not let it run for extended times.*

Analysis

What is the proper name for the loop? the paper clips? Will the loop turn in both directions? What happens if you flip the loop end for end? Why are the ends of the wire left half covered with enamel? Is there a continuous electric current through the loop as it rotates?

Procedure B

What do you think would change if two cells were used to power the motor? The loop should have the same diameter and number of coils. Tape two dry cells in series (end to end) and set the loop in motion. What difference do you notice?

Analysis

What specifically causes the change in behaviour that you noticed?

Procedure C

How does the size of the coil affect the operation of the motor? It is possible to change the number of windings in the coil, and also the diameter of the coil. Design an experiment to test the effects of each of these changes and summarize your observations.

The Electric Motor

Teacher Notes

Outcomes

Students will be expected to

- compare the ways a motor and a generator function, using the principles of electromagnetism (328-9)
- describe and compare direct current and alternating current (ACP-4)
- carry out procedures controlling the major variables and adapting or extending procedures where required (213-2)
- interpret patterns and trends in data, and infer or calculate linear and non-linear relationships among variables (214-5)

Background

Students may have done similar experiments in earlier grades. This is an extension, in that several variables are examined separately. If students are going to do two cells in series, it is wise at the start to make the straight ends of the loop wire long enough to extend over two cells in line. No quantitative analysis is expected.

If a large demonstration motor is available in your school, this would be a good time to discuss the function of commutators. For this simple motor, the electric current flows only when the bare part of the wire is in touch with the paper clip (about half the time). Inertia carries the loop through a complete rotation until current flows again. A split-ring commutator makes it possible for the current to change direction for the second half rotation, and the force will repel the side of the loop that it had just attracted.

APPENDICES

Appendix A: Grade 12 Curriculum/Text Correlation

The following topics are addressed in *McGraw-Hill Ryerson Physics*:

Outcome	Topic	Reference
Force, Motion, Work, and Energy: Dynamic Extension		
Text References		
ACP-1	Vector Components	pp. 90–94 (Chapter 3.2) pp. 168–175 (Chapter 5.2) pp. 454–466 (Chapter 10.1)
ACP-1	Systems Involving Two or More Masses—Horizontal	Not covered as a separate topic in this text (Questions found in chapter 10.2)
ACP-1	Systems Involving Two or More Masses—Incline Plane	pp. 188–194 (Chapter 5.3) pp. 485–489 (Chapter 10.2)
ACP-1	Systems Involving Two or More Masses—Atwood's Machine	pp. 478–485 (Chapter 10.2)
ACP-1	Relative Motion	pp. 104–110 (Chapter 3.3)
ACP-1	Static Equilibrium	pp. 496–501 (Chapter 10.3)
ACP-1	Torques	pp. 490–495 (Chapter 10.3)
Lab References		
ACP-1	Vector Components	p. 171 (Chapter 5.2) p. 174 (Chapter 5.2) p. 192 (Chapter 5.3)
ACP-1	Systems Involving Two or More Masses—Atwood's Machine	pp. 480–481 (Chapter 10.2)
ACP-1	Relative Motion	pp. 111–112 (Chapter 3.3)
ACP-1	Static Equilibrium pp. 502 (Chapter 10.3)	p. 468 (Chapter 10.1)
Force, Motion, Work, and Energy: Collisions in 2 Dimensions		
Text References		
326-3, 326-4	Laws of Conservation of Momentum	pp. 503–508 (Chapter 10.4) pp. 510–513 (Chapter 10.4)
326-3, 326-4	Elastic and Inelastic	pp. 513–515 (Chapter 10.4)
Lab References		
326-3, 326-4	Laws of Conservation of Momentum	p. 516 (Chapter 10.4)
Force, Motion, Work, and Energy: Projectiles		
Text References		
214-14, 214-16, 325-6	Projectiles	pp. 532–549 (Chapter 11.1)
Lab References		
214-14, 214-16, 325-6	Projectiles	p. 531 (Chapter 11) p. 538 (Chapter 11.1) p. 544 (Chapter 11.1)

Outcome	Topic	Reference
Force, Motion, Work, and Energy: Circular Motion		
Text References		
325-12, 325-13	Circular Motion	pp. 551–567 (Chapter 11.2)
Lab References		
325-12, 325-13	Circular Motion	pp. 561–562 (Chapter 11.2)
Force, Motion, Work, and Energy: Simple Harmonic Motion (SHM)		
Text References		
327-2, 327-4	Simple Harmonic Motion	p. 600 (Chapter 13.1) pp. 604–605 (Chapter 13.1) pp. 610–614 (Chapter 13.1)
Lab References		
327-2, 327-4	Simple Harmonic Motion	p. 609 (Chapter 13.1) p. 612 (Chapter 13.1) p. 616 (Chapter 13.1)
Force, Motion, Work, and Energy: Universal Gravitation		
Text References		
ACP-2, 215–2	Kepler's Laws	pp. 572–576 (Chapter 12.1) pp. 580–586 (Chapter 12.1)
ACP-2, 215–2	Universal Law of Gravitation	pp. 577–580 (Chapter 12.1) pp. 587–594 (Chapter 12.2)
Lab References		
ACP-2, 215-2	Kepler's Laws	p. 573 (Chapter 12.1) pp. 581–582 (Chapter 12.1)
Fields: Magnetic, Electric, and Gravitational Fields		
Text References		
114-2, 114-5 115-3, 215-1 328-1, 328-2 328-3	Magnetic Fields	p. 651 (Chapter 14.2) pp. 660–661 (Chapter 14.2)
114-2, 114-5 115-3, 215-1 328-1, 328-2 328-3	Electric Fields	pp. 644–647 (Chapter 14.2) pp. 651–655 (Chapter 14.2) pp. 658–659 (Chapter 14.2)
114-2, 114-5 115-3, 215-1 328-1, 328-2 328-3	Gravitational Fields	pp. 647–649 (Chapter 14.2) pp. 656–658 (Chapter 14.2) p. 659 (Chapter 14.2)
328-4	Coulomb's Law	pp. 632–642 (Chapter 14.1)
Lab References		
328-4	Coulomb's Law	p. 631 (Chapter 14.1) p. 634 (Chapter 14.1) p. 638 (Chapter 14.1)
Fields: Electric Circuits		
Text References		
ACP-3	Current, Resistance, Potential Difference and Power	pp. 667–679 (Chapter 14.3) pp. 686–705 (Chapter 15–15.3) pp. 712–714 (Chapter 15.3) pp. 734–744 (Chapter 15.5)

Outcome	Topic	Reference
ACP-3	Series and Parallel Circuits	pp. 715–728 (Chapter 15.4)
Lab References		
ACP-3	Current, Resistance, Potential Difference and Power	p. 687 (Chapter 15) pp. 709–711 (Chapter 15.3)
Fields: Electromagnetism and Electromagnetic Induction		
Text References		
328-6, 328-5 328-7	Electromagnetism	pp. 750–767 (Chapter 16.1)
328-6, 328-5 328-7	Electromagnetic Induction	pp. 781–782 (Chapter 16.3)
Lab References		
328-6, 328-5 328-7	Electromagnetism	p. 751 (Chapter 16.1) pp. 757–759 (Chapter 16.1) pp. 762–763 (Chapter 16.1)
328-6, 328-5 328-7	Electromagnetic Induction	p. 783 (Chapter 16.3) pp. 784–786 (Chapter 16.3)
Fields: Generators and Motors		
Text References		
328-9, ACP-4	Transformers	Not covered as a separate topic in this text.
328-9, ACP-4	Generators	pp. 787–794 (Chapter 16.3)
328-9, ACP-4	Motors	pp. 768–780 (Chapter 16.2)
Lab References		
328-9, ACP-4	Motors	pp. 771–772 (Chapter 16.2)
Waves and Modern Physics: Quantum Physics		
Text References		
326-9, 327-9 327-10	Quantum Physics	pp. 838–854 (Chapter 18–18.1)
Lab References		
326-9, 327-9 327-10	Quantum Physics	p. 839 (Chapter 18)
Waves and Modern Physics: Compton and de Broglie		
Text References		
329-1	Compton and de Broglie	pp. 854–860 (Chapter 18.2)
Waves and Modern Physics: Particles and Waves		
Text References		
327-11	Particles and Waves	p. 861 (Chapter 18.2)
Waves and Modern Physics: Bohr Atoms and Quantum Atoms		
Text References		
329-2, 329-3 329-7	Bohr Atoms and Quantum Atoms	pp. 864–872 (Chapter 19.1)
Lab References		
329-2, 329-3 329-7	Bohr Atoms and Quantum Atoms	p. 865 (Chapter 19) p. 869 (Chapter 19.1)

Outcome	Topic	Reference
Radioactivity: Natural and Artificial Sources of Radiation		
Text References		
329-5, 326-9	Natural and Artificial Sources of Radiation	pp. 898–904 (Chapter 20.1) pp. 906–907 (Chapter 20.2)
Radioactivity: Radioactive Decay		
Text References		
329-4, 214-2	Radioactive Decay	pp. 907–912 (Chapter 20.2) pp. 915–917 (Chapter 20.2)
Lab References		
329-4, 214-2	Radioactive Decay	p. 897 (Chapter 20)
Radioactivity: Fission and Fusion		
Text References		
329-6	Fission	pp. 922–925 (Chapter 21.1) pp. 926–931 (Chapter 21.2)
329-6	Fusion	pp. 923–925 (Chapter 21.1) pp. 932–933 (Chapter 21.2)

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Appendix B: Physics 12 Labs

The following labs are in *McGraw-Hill Ryerson Physics*:

Outcomes	Title	Page
Students will be expected to • use vector analysis in two dimensions for systems involving two or more masses, relative motions, static equilibrium, and static torques (ACP-1)	QuickLab: Maintaining Equilibrium	468
• use vector analysis in two dimensions for systems involving two or more masses, relative motions, static equilibrium, and static torques (ACP-1) • compile and organize data, using data tables and graphs, to facilitate interpretation of the data (213-5)	Investigation 10-A: Atwood's Machine	480
• use vector analysis in two dimensions for systems involving two or more masses, relative motions, static equilibrium, and static torques (ACP-1) • construct and test a prototype of a device or system and troubleshoot problems as they arise (214-14) • evaluate a personally designed and constructed device on the basis of criteria they have developed themselves (214-16)	QuickLab: Build a Mobile	502
• apply quantitatively the laws of conservation of momentum to two-dimensional collisions and explosions (326-3) • compile and organize data, using data tables and graphs, to facilitate interpretation of the data (213-5)	Investigation 10-B: Collisions in Two Dimensions **Note**: *An alternative version of this lab, which does not require an air table, is included in this resource.*	516

Outcomes	Title	Page
Students will be expected to • analyse quantitatively the horizontal and vertical motion of a projectile (325-6) • compile and organize data, using data tables and graphs, to facilitate interpretation of the data (213-5)	Investigation 11-A: The Components of Projectile Motion	538
• analyse quantitatively the horizontal and vertical motion of a projectile (325-6) • construct and test a prototype of a device or system and troubleshoot problems as they arise (214-14) • evaluate a personally designed and constructed device on the basis of criteria they have developed themselves (214-16) • select and use appropriate numeric, symbolic, graphical, and linguistic modes of representation to communicate ideas, plans, and results (215-2)	QuickLab: Maximum Range of a Projectile	544
• describe uniform circular motion, using algebraic and vector analysis (325-12) • explain quantitatively circular motion, using Newton's laws (325-13) • compile and organize data, using data tables and graphs, to facilitate interpretation of the data (213-5)	Investigation 11-B: Verifying the Circular Motion Equation	561

Outcomes	Title	Page
Students will be expected to • explain qualitatively Kepler's first and second laws and apply quantitatively Kepler's third law (ACP-2)	QuickLab: Kepler's Empirical Equations **Note**: *Another lab for Kepler's laws is included in this resource.*	573
• explain qualitatively Kepler's first and second laws and apply quantitatively Kepler's third law (ACP-2) • explain and apply the law of universal gravitation to orbital notations by using appropriate numeric and graphic analysis (215-2)	Investigation 12-A: Orbital Speed of Planets	581
• analyse quantitatively the horizontal and vertical motion of a projectile (325-6) • explain quantitatively the relationship between potential and kinetic energies of a mass in simple harmonic motion (327-4) • construct and test a prototype of a device or system and troubleshoot problems as they arise (214-14) • evaluate a personally designed and constructed device on the basis of criteria they have developed themselves (214-16)	Investigation 13-A: A Projectile Spring	599
• explain quantitatively the relationship between displacement, velocity, time, and acceleration for simple harmonic motion (327-2) • explain quantitatively the relationship between potential and kinetic energies of a mass in simple harmonic motion (327-4)	Investigation 13-B: The Period of a Mass on a Spring	609

Outcomes	Title	Page
Students will be expected to • explain quantitatively the relationship between displacement, velocity, time, and acceleration for simple harmonic motion (327-2) • design an experiment identifying and controlling major variables (212-3) • evaluate a personally designed and constructed device on the basis of criteria they have developed themselves (214-16)	QuickLab: Measuring the Value of *g*, the Acceleration Due to Gravity	612
• explain quantitatively the relationship between displacement, velocity, time, and acceleration for simple harmonic motion (327-2) • explain quantitatively the relationship between potential and kinetic energies of a mass in simple harmonic motion (327-4) • to compile and organize data, using data tables and graphs, to facilitate interpretation of the data (213-5)	Investigation 13-C: Position, Velocity, and Acceleration and Simple Harmonic Motion	616
• explain quantitatively the relationship between displacement, velocity, time, and acceleration for simple harmonic motion (327-2) • to compile and display evidence and information, by hand or computer, in a variety of formats, including diagrams, flow charts, tables, graphs, and scatter plots (214-3)	QuickLab: Graphing the Motion of a Simple Harmonic Oscillator	620

Outcomes	Title	Page
Students will be expected to • describe gravitational, electric, and magnetic fields as regions of space that affect mass and charge (328-1) • define and delimit problems, estimate quantities, interpret patterns and trends in data, and infer or calculate the relationships among variables (212-2, 213-4, 214-5) • describe the historical development of a technology (115-4)	QuickLab: A Torsion Balance	631
• compare Newton's universal law of gravitation and Coulomb's law, and apply both laws quantitatively (328-4)	Investigation 14-A: The Nature of the Electrostatic Force **Note**: *An alternative procedure is included in this resource.*	634
• compare Newton's universal law of gravitation and Coulomb's law, and apply both laws quantitatively (328-4) • interpret patterns and trends in data, and infer or calculate linear and non-linear relationships among variables (214-5)	QuickLab: Graphical Analysis of Coulomb's Law	638
• describe the magnetic field produced by current in both a solenoid and a long, straight conductor (328-6) • use instruments effectively and accurately for collecting data (213-3) • select and use apparatus and materials safely (213-8)	Investigation 16-A: Magnetic Field around a Straight Conductor	757

Outcomes	Title	Page
Students will be expected to • describe the magnetic field produced by current in both a solenoid and a long, straight conductor (328-6) • use instruments effectively and accurately for collecting data (213-3) • select and use apparatus and materials safely (213-8)	Investigation 16-B: Magnetic Field around a Helix	762
• compare the ways a motor and a generator function, using the principles of electromagnetism (328-9)	Investigation 16-C: The Motor Effect **Note**: *An alternative motor activity is included in this resource*	771
• analyse, qualitatively and quantitatively, the forces acting on a moving charge and on an electric current in a uniform magnetic field (328-5)	Investigation 16-D: Faraday's Discovery	783
• analyse, qualitatively and quantitatively, the forces acting on a moving charge and on an electric current in a uniform magnetic field (328-5)	Investigation 16-E: Induced Currents	784
• describe how the quantum energy concept explains both black-body radiation and the photoelectric effect (327-9)	Investigation 18-A: Discharging an Electroscope	839
• explain the relationship among the energy levels in Bohr's model, the energy difference between levels, and the energy of the emitted photons (329-3)	Investigation 19-A: Identifying Elements by Their Emission Spectra	865

Outcomes	Title	Page
Students will be expected to • develop appropriate sampling procedures (212-9) • select and use apparatus and materials safely (213-8) • demonstrate a knowledge of WHMIS standards by selecting and applying proper techniques for handling and disposing of lab materials (213-9) • describe the products of radioactive decay, and the characteristics of alpha, beta, and gamma radiation (329-4)	Multi-Lab: Radioactive Decay Part A: Penetrating Ability of Radioactive Emissions	897
• analyse data on radioactive decay to predict half-life (214-2)	Part B: Half-Life	

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