Virtual Physics
Lab Record Sheets

Brian F. Woodfield
Heather J. McKnight

Steven Haderlie
Bradley D. Moser
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Overview

Welcome to Virtual Physics, a set of realistic and sophisticated simulations covering many of the fundamental experiments in physics and planetary motion. In these laboratories, students are put into a virtual environment where they are free to make the choices and decisions that they would confront in an actual laboratory setting and, in turn, experience the resulting consequences. These laboratories include simulations of fundamental experiments in quantum chemistry, gas properties, calorimetry, mechanics and planetary motion, density, circuits, and optics. This overview and the installation instructions are for the single user/student version\(^1\) of Virtual Physics v3.0.

After installing the Virtual Physics simulations, the software is configured to access the laboratories either through an electronic workbook or by clicking on the Physics Laboratory door. The electronic workbook is designed to be used in conjunction with worksheets that are provided with the software and will most likely be the principal method for gaining access to the various laboratory simulations. However, students can also be given electronic assignments through the Web Connectivity Option that they accept inside the various laboratories and report their results back through the electronic lab book. These types of assignments are accessed by entering through the Virtual Physics door and providing a user name, password, and the URL address for the Y Science server. Details on receiving and submitting electronic assignments are given in the various laboratory user guides. It is strongly suggested that the user guides be reviewed before running the software. See the Getting Started section for more information on using Virtual Physics with the accompanying workbook. A brief description of the seven chemistry and physics laboratories found in Virtual Physics is given below.

The Mechanics Laboratory provides students with the flexibility to perform many fundamental experiments to teach the basic concepts of Newton’s laws and planetary motion that are easier to model in a simulated situation rather than a real laboratory. The ability to control the frictions, forces, and physical parameters of motion allows students the ability to easily use equipment that can be found in most instructional laboratories and some equipment that would be less readily available. Students are able to measure speeds and distances, describe the motion of objects using graphs, interpret data, understand our solar system, and gain a foundation for concepts in physics. These results can then be used to validate Newton’s laws, demonstrate the interplay between force and motion, calculate conservation of momentum, and study the intricacies of the solar system under variable initial conditions and parameters. A partial list of the experiments performed in the mechanics laboratory include projectile motion in uniform or radial gravity, ramp motion in uniform or radial gravity, the collision of multiple balls with elastic or inelastic collisions, a falling rod, and the motion of the planets and their moons in the solar system viewed from various perspectives. The difficulty level of these experiments ranges from basic to sophisticated, depending on the level of the class and the purpose for performing the experiments.

\(^1\) Basic installation for site license users is the same as for the single user/student version CD-ROM explained herein. For other installation options for site license users, consult the Installation and Overview guide found on the CD-ROM.
The purpose of the *Quantum Laboratory* is to allow students to explore and better understand the foundational experiments that led to the development of quantum mechanics. Because of the very sophisticated nature of most of these experiments, the *Quantum Laboratory* is the most “virtual” of the *Virtual Physics* laboratory simulations. In general, the laboratory consists of an optics table where a source, sample, modifier, and detector combination can be placed to perform different experiments. These devices are located in the stockroom and can be taken out of the stockroom and placed in various locations on the optics table. The emphasis here is to teach students to probe a sample (e.g., a gas, metal foil, two-slit screen, etc.) with a source (e.g., a laser, electron gun, alpha-particle source, etc.) and detect the outcome with a specific detector (e.g., a phosphor screen, spectrometer, etc.). Heat, electric fields, or magnetic fields can also be applied to modify an aspect of the experiment. As in all *Virtual Physics* laboratories, the focus is to allow students the ability to explore and discover, in a safe and level-appropriate setting, the concepts that are important in the various areas of physics.

The gas experiments included in the *Virtual Physics* simulated laboratory allow students to explore and better understand the behavior of ideal gases, real gases, and van der Waals gases (a model real gas). The *Gases Laboratory* contains four experiments, each of which includes the four variables used to describe a gas: pressure \((P)\), temperature \((T)\), volume \((V)\), and the number of moles \((n)\). The four experiments differ by allowing one of these variables to be the dependent variable while the others are independent. The four experiments include (1) \(V\) as a function of \(P, T,\) and \(n\) using a balloon to reflect the volume changes; (2) \(P\) as a function of \(V, T,\) and \(n\) using a motor driven piston; (3) \(T\) as a function of \(P, V,\) and \(n\) again using a motor driven piston; and (4) \(V\) as a function of \(P, T,\) and \(n\) but this time using a frictionless, massless piston to reflect volume changes and using weights to apply pressure. The gases that can be used in these experiments include an ideal gas; a van der Waals gas whose parameters can be changed to represent any real gas; real gases including \(N_2\), \(CO_2\), \(CH_4\), \(H_2O\), \(NH_3\), and \(He\); and eight ideal gases with different molecular weights that can be added to the experiments to form gas mixtures.

The *Calorimetry Laboratory* provides students with three different calorimeters that allow them to measure various thermodynamic processes, including heats of combustion, heats of solution, heats of reaction, the heat capacity, and the heat of fusion of ice. The calorimeters provided in the simulations are a classic “coffee cup” calorimeter, a dewar flask (a better version of a coffee cup), and a bomb calorimeter. The calorimetric method used in each calorimeter is based on measuring the temperature change associated with the different thermodynamic processes. Students can choose from a wide selection of organic materials to measure the heats of combustion; salts to measure the heats of solution; acids, bases, oxidants, and reductants for heats of reaction; metals and alloys for heat capacity measurements; and ice for a melting process. Temperature versus time data can be graphed during the measurements and saved to the electronic lab book for later analysis. Systematic and random errors in the mass and volume measurements have been included in the simulation by introducing buoyancy errors in measuring mass, volumetric errors in the glassware, and characteristic systematic and random errors in the thermometer measurements.
The Density Laboratory allows students the ability to measure the mass and volume of a large set of liquids and solids which, in turn, will allow them to explore the fundamental concepts governing density and buoyancy. The laboratory has a set of graduated cylinders that can be filled with various liquids such as water, corn syrup, mercury, jet fuel, tar, plus many others. These cylinders can be filled with one or two liquids to study the miscibility, or relative density, of the liquids. The laboratory also contains a large selection of solids that can be dropped into these cylinders, and the students can then observe whether the solids float or sink in the selected liquids. The density of the solids can be calculated by measuring the mass of the solids and the volume of liquid displaced in the cylinders after the solids have been dropped into the liquid. The density of the liquids can be determined by measuring the mass and volume of the liquid.

The Circuit Laboratory gives students the freedom to discover and learn the principles associated with simple electrical circuits involving resistors, capacitors, and inductors. The laboratory allows students to build circuits using either a breadboard or schematic representation. Using the breadboard, students will connect components as they would in an ordinary circuit laboratory by adding resistors, light bulbs, capacitors, or inductors of any combination and a battery or function generator. When using the schematic, the students can “draw” a circuit schematic on paper as they would to plan a circuit. The breadboard and schematic are linked together so they automatically populate when the other one is changed. Using the digital multimeter and oscilloscope, students can then analyze their circuits and learn principles like Ohm’s Law, the power-voltage relationship, AC/DC sources, and much more.

The Optics Laboratory gives students the freedom to discover and learn the principles associated with simple optical experiments involving light sources, objects, mirrors, lenses, prisms, and filters. The laboratory allows students to set up optical experiments on a standard optics table by placing components on the table and moving the viewing detector or virtual eye to different locations to observe the resulting image characteristics. When setting up experiments with mirrors and lenses in different combinations, students can analyze their layouts to test image characteristics depending on object locations. They can also verify the lensmaker equations. Principles of light addition and subtraction can be studied with filters and prism light recombination. Snell’s Law and the law of reflection can also be investigated.
System Requirements

The minimum system requirements are as follows:

**PC**

Pentium 1 GHz (Pentium III or better recommended)
256 Mb RAM (512+ Mb Recommended)
CD-ROM drive (for installation only)
830 Mb of free disk space
Display capable of **and** set to millions of colors (24-bit color)
Recommended minimum resolution 1024 x 768
Windows 2000 Professional or Windows XP
QuickTime 6.x/7.x

**Macintosh**

PowerPC (G3 or better recommended)
256 Mb RAM (512+ Mb recommended)
CD-ROM drive (for installation only)
830 Mb of free disk space
Display capable of **and** set to millions of colors (24-bit color)
Recommended minimum resolution 1024 x 768
OS X (any version)
QuickTime 6.x/7.x

**Note:** The above requirements are the recommended minimum hardware and system software requirements for reasonable execution speeds and reliability. However, it should be noted that the software has been successfully installed and used on computers with significantly lower capabilities than the recommendations given above with corresponding reductions in execution speed and media access time.
Installing Virtual Physics

Locate and run the program “Setup Virtual Physics” on the CD-ROM drive then follow the prompts. There is only one install option available for the single user version, which installs the complete software package to the hard drive. The CD is not needed to run the program after performing the installation.

Important Installation Notes and Issues

1. The graphics used in the simulations require the monitor to be set to 24-bit true color (millions of colors). Lower color resolutions can be used, but the graphics will not be as sharp.

2. When installing Virtual Physics, you must be logged in as an Administrative User in order for all files and folders to be installed correctly and to have correctly configured file permissions; otherwise, unpredictable results such as hard crashes and other errors can occur during installation and running Virtual Physics.

3. The inorganic simulation will not run on some Macintosh Macbooks using an Intel-based processor. This is a known issue affecting all Adobe (formerly Macromedia) Director products, however there is some disagreement whether the fault is in Director or OS X. This problem does not appear on Macbook Pros and only on some regular Macbooks. The current solution to this issue is to install the software on Windows running in a virtual machine such as VMware or Parallels.

4. Occasionally when installing on the OS X operating system, the system fails to copy over the VPL icon for aliases created on the desktop. There is no known cause for this. Aliases with the correct icon can be created manually inside the installation directory or by copying a VPL icon on to an already existing alias.

5. When installing on the OS X operating system v10.4 (or Tiger), selecting the option to place an alias on the dock causes the dock to be reset to its initial installed state and any dock customization is lost.

6. In the directory where Virtual Physics is installed, the user must always have read/write privileges to that directory and all directories underneath. This is the default state for all Administrative Users (both Mac and PC), and this condition has been set by the installer for Standard Users in OS X as well. However, if users will be logged in as Restricted Users in Windows (such as in a computer lab), then the privileges for the Virtual Physics directory must be set manually to “Full Access” for Everyone. The installer attempts to set these permissions for Windows installations, but for unknown reasons it is not always successful. In addition, if the system crashes hard while running Virtual Physics (either on Windows or OS X), these permissions may have to be reset to read/write for everyone.

7. The installer does not allow installation and other directory paths to be typed in directly, but all installation paths must be identified or select by browsing to the desired location. When installing on the OS X operating
Installing Virtual Physics

system, browsing to a folder using aliases occasionally causes the installer to spontaneously shutdown. Consequently, it is recommend that aliases be avoided when browsing. There is no known cause for this.

8. When installing Virtual Physics on to the OS X operating system, the user must have read/write permission for the folder into which Virtual Physics will be installed. In the vast majority of cases, Virtual Physics will be installed into the Applications folder, but in order for this to be successful the user must be an administrative user. In some cases, however, the permissions for the Applications folder have been modified by other software installed on the machine, which will prevent Virtual Physics from being installed in the Applications folder. These permissions can be reset back to their default state using the Repair Disk Permissions function in the Disk Utility program located in the Applications folder.

9. QuickTime 6.0 or later is required for the software to run properly. The most recent version of QuickTime can be obtained at http://www.apple.com/quicktime/

10. For unknown reasons, on some machines the QuickTime videos will not play properly if the system QuickTime settings are in their default state. This can be corrected by changing the Video Settings in QuickTime to Normal Mode.

x   Installing Virtual Physics
Getting Started

After Virtual Physics has been successfully installed, the VPL icon used to launch the program will be located on the desktop, in a Program Group on PC machines, and on the Dock for Macintosh machines. Clicking on the VPL icon will start the simulation where you will be brought to a hallway containing two doors and a workbook sitting on a table. Clicking on the electronic workbook opens and zooms into the workbook pages, where you can select preset assignments that correspond to the assignments in the student workbook. The Previous and Next buttons are used to page through the set of assignments, and the different assignments can also be accessed by clicking on the section titles located on the left page of the workbook. Clicking on the Enter Laboratory button will allow you to enter the physics laboratory (see below), and the Exit button is used to return to the hallway.

From the hallway, students can also enter the physics laboratory by clicking on the Physics Laboratory door and entering as a guest. Once in the laboratory, students will find seven laboratory benches that represent the seven different physics laboratories. By moving a cursor over each of these laboratory benches, students can display the name of the selected laboratory. To access a specific laboratory, click on the appropriate laboratory bench. While in the physics laboratory, the full functionality of the simulation is available, and students are free to explore and perform experiments as directed by their instructors or by their own curiosity. The Exit signs in the physics laboratory are used to return to the hallway.

Detailed instructions on how to use each of the seven laboratory simulations can be found in the User Guides folder located on the Virtual Physics CD. These same user guides can also be accessed inside each laboratory by clicking on the Pull-Down TV and clicking on the Help button. For those students who will be given electronic assignments from their instructor through the web, they should enter the laboratory through the door and provide their user name, password, and the URL address of the Y Science server at the card reader. A few labs require students to right click on an on-screen object. Students using a mouse without a right-click function should instead press the control key while clicking on the object with their mouse. Details on accessing Virtual Physics can be found in the Accessing Virtual Physics user guide found on the CD.
Lab 1: Forces

Purpose
To understand the effects that balanced and unbalanced forces in many directions have on an object

Background
Have you ever played tug of war or arm wrestled with a friend? To win, you must use a force greater than that of your opponent. If the force you use is equal to the force of your opponent, the opposing forces are balanced and the net force is zero. Nobody wins. When the net force, or sum of the forces, is not equal to zero, the forces are unbalanced. Unbalanced forces cause objects to move, stop moving, or change direction. You can predict the motion of objects by looking at the net forces acting on them. By examining the forces acting on an object in many directions, it is possible to determine when equilibrium is reached.

Skills Focus
Observing, controlling variables, comparing and contrasting, predicting, applying concepts

Procedure
1. Start Virtual Physics and select Forces from the list of assignments. The lab will open in the Mechanics laboratory.

2. The laboratory will be set up with a ball near the top of the experiment window. Attached to the bottom of the ball is a rocket to push (force) the ball up. In this experiment, gravity has been turned on. Gravity will tend to pull the ball down. The object of this experiment is to apply just the right amount of force with the rocket to keep the ball from going up or from falling.

3. Start the experiment by clicking on the Start button. Observe what happens. To turn on the rocket, click on the Force button. When you are done with your observations, click the Pause button to stop the experiment.

   Observing  What did you observe when you turned on the rocket?

4. Now experiment to determine the amount of force needed to balance the ball. Reset the experiment. Use the Parameters Palette to change the rocket force and repeat Step 3. Observe whether the ball falls or goes up. Record each force you try and your observations in Data Table 1. Continue until you can keep the ball from either falling or going up.

   Why do you need to change the rocket’s force?
5. The mass of the ball is 20 kg. What would be another way to calculate the force required to balance the pull of gravity on the ball?
__________________________________________________________________
__________________________________________________________________
__________________________________________________________________
__________________________________________________________________

6. **Controlling Variables** Now find out what happens to the motion of the ball when the rocket is attached to the ball at a different position. Reset the experiment to the beginning by clicking on the Reset button. Using the Forces tab in the Parameters Palette, set the force to 200 N and set the angle of the rocket to $270^\circ$. Record your observations in Data Table 2. Now repeat the experiment using angles of $0^\circ$, $180^\circ$, and an angle of your choice. Record your results in Table 2.

**Data Table 2**

<table>
<thead>
<tr>
<th>Angle</th>
<th>Force (N)</th>
<th>Effect on the ball</th>
<th>Balanced/Unbalanced</th>
</tr>
</thead>
<tbody>
<tr>
<td>$270^\circ$</td>
<td>200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$0^\circ$</td>
<td>200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$180^\circ$</td>
<td>200</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>200</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Analyze and Conclude**

1. **Comparing and Contrasting** What is the difference between the forces used in Data Table 1 and those in Data Table 2? Explain how the combinations of forces created the motion you observed.
__________________________________________________________________
__________________________________________________________________
__________________________________________________________________
__________________________________________________________________

2. Forces
To answer questions 2 and 3, click Return on the red gravity arrow on the table to return it to the tray. Click the green Zoom Out button and click inside the Stockroom. Return the downward gravity to the shelves by double clicking on it, or dragging it to the shelf. Double click on the Right Gravity arrows to select them. Click the green Return to Lab arrow, then click on the work table to zoom down to the Experiment View. Pull the gravity arrows down onto the work bench.

2. Predicting  What direction and size of force would be needed to balance the gravity in the experiment just set up?
__________________________________________________________________
__________________________________________________________________
__________________________________________________________________
__________________________________________________________________

3. Observing  Adjust the rocket as you predicted you would need to and record your observations of the motion.
__________________________________________________________________
__________________________________________________________________
__________________________________________________________________
__________________________________________________________________

4. We are accustomed to the force of gravity pulling down, but theoretically it could pull in any direction, depending on your frame of reference, as it is just another force. It is important to keep track of the directions and magnitudes of all forces when predicting the motion of objects. Change the magnitude of the gravitational force in the Gravity tab in the Palette and observe the resultant motion. Describe how a balancing force would need to change under those conditions.
__________________________________________________________________
__________________________________________________________________
__________________________________________________________________
__________________________________________________________________

5. Applying Concepts  Why would it be important to understand the concept of balancing forces when trying to build a rocket to travel to the moon?
__________________________________________________________________
__________________________________________________________________
__________________________________________________________________
__________________________________________________________________
Lab 2: Newton’s First Law

Purpose
To discover how mass and inertia are related and to learn about the effects of different types of forces on inertial motion

Background
Motion surrounds you in everyday life. Scientists have been fascinated with it for thousands of years. Sir Isaac Newton proposed three basic laws of motion. Newton’s first law of motion states that an object at rest will remain at rest, and an object moving at a constant velocity will continue moving at a constant velocity, unless it is acted on by an outside force. This principle is called inertia and it can be used to explain much of the motion observed throughout the universe.

Skills Focus
Controlling variables, graphing, interpreting data, predicting, making generalizations, comparing and contrasting

Procedure
1. Start Virtual Physics and select Newton’s First Law from the list of assignments. The lab will open in the Mechanics laboratory.

2. The laboratory is set up with a ball on a table. Attached to the 2-kg ball is a rocket used to push the ball in the direction opposite to the motion of the ball. The ball will have an initial velocity. There is no friction. The only thing stopping the ball is the force you turn on. Click on the Lab Book to open it and then click on the red Recording button to start recording data. Start the ball rolling across the table by clicking on the Start button.

3. After a couple of seconds, press the Force button to turn on the rocket. The Force is set to 10 N. Click the Pause button when the ball slows down and starts to reverse direction. You will see a link appear in the Lab Book. This contains the position and velocity versus time data of the ball rolling across the table.

4. Use the data collected to fill out the table on the next page with (1) the magnitude of the force, (2) the distance the ball traveled from when the force was turned on to when it stopped and reversed direction, and (3) the amount of time the force was on. Find these points by looking in the data for the time when the velocity is slowing down, but is still positive, showing that the ball is still traveling to the right.
5. **Controlling Variables**  Repeat the experiment with one more ball of different mass. Remember to click the *Reset* button. Use the *Parameter Palette* to change the mass of the ball. Keep the force the same for the new experiment. The time the rocket is on will be different for each ball, because each ball will stop in different amounts of time.

### Data Table

<table>
<thead>
<tr>
<th>Mass of the ball (kg)</th>
<th>Force applied to ball (N)</th>
<th>Distance traveled after rocket was turned on (m)</th>
<th>Time rocket is on (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

### Analyze and Conclude

1. **Graphing**  On the grid below, graph the distance versus time for each of the experiments. Use the data in the data links saved in your *Lab Book*. Label the horizontal axis as *Time* (s) and the vertical axis as *Distance* (m). Decide on the proper scaling for the axes. Use a different color for each graph. Label the point at which the rocket was turned on in each experiment.
2. **Interpreting Data**  Which mass was easiest to stop? Which was the hardest? How do you know?

________________________________________________________________________________________

3. **Predicting**  What would happen if you had a smaller force pushing on these same balls? Would they still stop? *Hint: The balls have initial velocity but what is actually making the balls stop?*

________________________________________________________________________________________

4. **Drawing Conclusions**  What would happen if you increased the mass of the ball but didn’t apply any forces?

________________________________________________________________________________________

5. **Making Generalizations**  You have worked with rocket forces so far, but what other types of forces do you think would change the motion of the ball?

________________________________________________________________________________________

6. **Comparing and Contrasting**  Now observe the motion with air resistance on the table. The *Air Friction* icon is on the shelf at the top of the screen. Pull the icon down onto the work bench. Reset the experiment and turn on the recording. Repeat the experiment by clicking *Start* and watching the ball move with just air resistance as an externally applied force. Stop after about the same amount of time that you observed in the previous experiments.

Graph the data from this experiment. Indicate on the graph the data from the run with air resistance. How is the motion different with air resistance? Is this motion solely the result of the ball’s inertia? Why or why not? How does the distance traveled compare to the distance covered in the previous experiments?

________________________________________________________________________________________

________________________________________________________________________________________
Lab 3: Measuring Speed

Purpose
To calculate the speed of an object from measurements of distance and time and to compare instantaneous and average speeds

Background
How long does it take you to get to school in the morning? How long would it take you to run a mile? These times depend on the speed you can travel. Speed is calculated from measurements of distance and time. The relationship between distance and time for moving objects is often expressed as average speed, which is calculated by dividing the distance traveled by the time elapsed. Over the course of time, average speed can be calculated to show the general trends in an object’s motion. This value can be quite different from the speed that an object is traveling at from moment to moment, which is called instantaneous speed.

Skills Focus
Graphing, applying concepts, predicting, interpreting data

Procedure
1. Start Virtual Physics and select Measuring Speed from the list of assignments. The lab will open in the Mechanics laboratory.

2. The laboratory will be set up with a block on a frictionless table. Attached to the block is a plunger used to hit the block. You will measure the length of the table and the time it takes the block to slide across this distance. You will also record the force you used to hit the block and get it sliding.

   One block slides across the full length of a table in a short time. Another block takes a long time to slide across the same table. How do the speeds of the two blocks compare?

3. The plunger is initially set to hit the block with a force of 78 N. Start the block sliding by clicking the Force button. When the block gets to the end of the table the experiment will stop automatically. Observe the final position of the block recorded next to r in the data display. Record this distance in Data Table 1. Also record the time it took the block to slide across the table. You will find this time in the Time display in the Detector area. Reset the experiment by clicking the blue Reset button. Repeat the experiment two more times using different force settings for the plunger. Change the plunger force using the Forces tab in the Parameters Palette. Use a weaker hit and a harder hit. Record your data in Data Table 1.
Data Table 1

<table>
<thead>
<tr>
<th>Force (N)</th>
<th>Distance of slide (cm)</th>
<th>Time of slide (s)</th>
<th>Average speed (cm/s)</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
</tbody>
</table>

Analyze and Conclude

1. Graphing  Plot the time and distance for the initial experiment on the graph. Label the horizontal axis Time (s). Label the vertical axis Distance (cm). You have two data points. The first data point will be (0 s, 0 cm). This is the time and place the slide began. The second data point is the time and total distance you measured. You will need to scale the graph to fit your data.

2. On the same graph, draw a different line starting at point (0 s, 0 cm) for each of the forces you used. Use different colors for each line. The lines you draw show that the block started in the same place and traveled the measured distance over a different amount of time.
3. **Applying Concepts** Each line on the graph you just completed should have a different slope. What does the slope of each line tell you about the block as it slid across the table? Think back to what you observed in the different experiments.

4. **Predicting** What would you predict for the slope of the line if another block took an even shorter amount of time to cross the table?

5. **Interpreting Data** You can calculate the slope of a line by using the following equation.

\[
\text{slope} = \frac{\text{rise}}{\text{run}}
\]

In this experiment the rise is the distance the block traveled. The run is the time it took on the x-axis. From the data on the graph or in Data Table 1, calculate the average speed of the blocks and record the value in Data Table 1. Was the speed constant, or did it change throughout the experiment?

### Data Table 2

<table>
<thead>
<tr>
<th>Distance (cm)</th>
<th>Time (s)</th>
<th>Speed (cm/s)</th>
</tr>
</thead>
<tbody>
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</tbody>
</table>

6. **Predicting** Reset the experiment again and under Friction in the Palette, change the object material to plastic. This will turn on the table friction, to a value as if the table and object were made of plastic. How will having friction on the table affect the speed of the block?

7. **Interpreting Data** Open the Lab Book and click on the red Recording button to save the experimental data. Repeat the experiment and record the distance traveled, the time it took, and your calculation of the average speed below. A link will appear in the Lab Book with the position and speed data.
8. **Graphing**  Plot the time and speed for the experiment with friction on the graph below. Label the horizontal axis *Time (s)*. Label the vertical axis *Speed (cm/s)*. Use the data from the data link in the *v_tot* column. Plot several data points to get the general shape of the curve. This graph shows how the speed of the object changed over time. Now draw a line to show the average speed you calculated in question 7. You will need to scale the graph to fit your data.

9. **Interpreting Data**  Why are the two lines on the graph different? What is the difference between the average speed you calculated and the instantaneous speed that you used actual data to graph? How did the average speed in this last experiment compare with the previously calculated speeds?

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10  Measuring Speed
Lab 4: Graphing Motion

Purpose
To learn how different types of graphs describe the motion of objects

Background
Line graphs are used to describe the motion of objects such as a rolling ball, a moving automobile, or an airplane in flight. There are different types of motion graphs that each express different properties of motion. Displacement graphs, x vs. y graphs, and velocity graphs may all be used to graph the exact same motion, but they each use different data and are used to communicate varying information. Newspapers and other media reports use many different graphs but these are commonly misunderstood. Careful examination can reveal information that would fill many data tables. A picture really is worth a thousand words!

Skills
Graphing, interpreting data, drawing conclusions

Procedure
1. Start Virtual Physics and select Graphing Motion from the list of assignments. The lab will open in the Mechanics laboratory.

2. The laboratory will be set up with a 10-kg ball on a table. Attached to the ball is a plunger to be used to hit the ball. You will hit the ball and observe it as it rolls across the table. You will record the position and velocity of the ball over a period of time in your electronic lab book and then use your data to make several graphs of the motion.

3. Click on the Lab Book to open it. Click on the red Recording button to start recording data. Start the ball rolling by clicking on the Force button and wait until the ball hits the end wall. Click the Pause button to stop the experiment. You should see a link appear in the Lab Book. This contains the position and velocity versus time data for the ball as it rolls across the table.

4. Click the Reset button. Repeat the experiment with a smaller mass. Change the mass to 8 kg using the Parameters Palette. Under the Forces Tab, change the angle to 90 degrees. This will move the plunger to hit the ball straight up. Double click in the Lab Book next to each link to label each with the corresponding mass and direction.

5. Reset the experiment and in the Palette change the Elasticity to 1. This will allow the ball to bounce off the wall. Repeat the experiment, this time stopping the experiment after the ball bounces and returns to x = 0. Label the link in the Lab Book Bounce.

6. Reset the experiment again and in the Palette change the Elasticity to 1 and under the Forces Tab, change the angle to 30 degrees. This will move the plunger to hit the ball at an angle. Repeat the experiment, stopping after 2 bounces off the wall. Label the link in the Lab Book 2D Bounce.
Analyze and Conclude

1. Graphing  Click on the first data link in your lab book to view the data from the first experiment. Use the $x(m)$ position data to graph the motion of the first ball over time. Your graph should show the distance the ball traveled versus time, with *Time* shown on the *x*-axis and *Distance* on the *y*-axis. Also graph the position data of the second (lighter) ball on the same graph. Use the $y(m)$ data to find the distance of the ball from the origin over time. Label the axes with the proper variables and their units. Use a different color to connect the points for each ball. Scale the graph to fit your data. Just plot a few of the points from each line, enough to be able to draw the whole graph accurately. Remember that you are just plotting distance, not direction.

2. Interpreting Data  What does each point on the graph represent?

3. What is the difference between the two lines you graphed?  What do the slopes of the lines tell you about each ball?

4. Graphing  Click on the third data link in your lab book to view the data from the first bouncing experiment. Use the $x(m)$ position data to graph the motion of the first ball over time on the left grid on the next page. Your graph should show the distance the ball traveled versus the *Time*, with time shown on the *x*-axis and *Distance* on the *y*-axis. Label the axes with the proper variables and their units. Scale the graph to fit the data. Then graph velocity versus time on the right grid on the next page using the $v_{tot}$ data in the link. Remember to label your axes with time on the *x*-axis and velocity on the *y*-axis.
5. **Interpreting Data**  When the ball got back to $x = 0$, what was the total displacement? How did the velocity of the ball change when it bounced?

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6. **Graphing**  Use the 2D Bounce data to make another graph below. Click on the fourth data link in your lab book to view the data and use the $x(m)$ and $y(m)$ data to make a graph of the physical position of the ball on the table. Your graph should show the $x$- and $y$- positions that the ball traveled, with the $x$ data shown on the $x$-axis and the $y$ data on the $y$-axis. Label the axes with the proper variable and its units. You will need to scale the graph to fit your data. Remember that this is not a position versus time graph, it is just a graph of the physical location. Have your first point in the bottom left hand corner of the graph be $x = 0$, $y = 0$.

7. **Drawing Conclusions**  You have drawn several different types of graphs. How did each graph communicate different information?

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Lab 5: Inclined to Roll

Purpose
To create and interpret the graphs of several objects that are accelerating

Background
A car traveling along a highway usually moves at a nearly constant speed. But when the car first enters the freeway, it must speed up to get to highway speed. When you ride a bike on a flat road, you usually move at a constant speed. However, you may slow down as you are pedaling up a hill and you speed up when you start to ride down it. These are all examples of different types of acceleration. Position, velocity, and acceleration graphs each can represent acceleration in different ways and understanding what they show is important to understanding motion of all types.

Skills Focus
Graphing, interpreting data, calculating, drawing conclusions, applying concepts

Procedure
1. Start Virtual Physics and select Inclined to Roll from the list of assignments. The lab will open in the Mechanics laboratory.

2. The laboratory will be set up with a ball on a ramp. The ramp has an angle of 30°. Click on the Lab Book to open it. Click the Record button to start recording data. Start the ball rolling down the ramp by clicking the Start button. Observe what happens as the ball hits the end of the ramp. You will see a link appear in the lab book that contains the position, velocity, and acceleration versus time data for the ball rolling down the ramp.

3. Click the Reset button to move the ball back to the top of the ramp. Set the angle of the ramp to 45° using the Ramp tab under the Parameters Palette. Repeat Step 2. Repeat the experiment once more with the ramp at 60°. You should now have three data links in your lab book. Double click beside each link to label the link with the angle of the ramp. If you click on any of the data links, the Data Viewer window will open with four columns of data. The first column, t (sec), is Time. The second column, r (m), gives the Position. The third column, v_tot (m/s), gives the Velocity. The fourth column, a_tot (m/s²), gives the Acceleration.
Analyze and Conclude

1. **Graphing**  Use the $r(m)$ data in each of the data links in your lab book to draw three position versus time graphs on the grid below. Label the horizontal axis *Time (s)* and the vertical axis *Position (m)*. You will need to scale the graph to fit your data. Use a different color for each ramp angle.

2. **Graphing**  Now you will graph velocity versus time on the grid below. Label the horizontal axis *Time (s)* and the vertical axis *Velocity (m/s)*. The velocity data is in the $v_{tot}$ column. Use the same colors for the graphs of the same ramp angle as you did in the previous graph. Label each line with the angle of the ramp.
3. **Interpreting Data**  What is the relationship between the slope of the lines and the ramp angles?

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4. **Calculating**  You can use the slopes of the velocity graphs to compare the speeds of the ball as it rolled down the ramp. To calculate the slope of a line, use the equation \( \text{Slope} = \frac{\text{Rise}}{\text{Run}} \) or, for this experiment, \( \text{Slope} = \frac{\text{change in velocity}}{\text{elapsed time}} \). From the data on the velocity graph or from the data in your data links, calculate the slope of each line by filling in the following table.

<table>
<thead>
<tr>
<th>Rise (velocity (m/s)) (Change in velocity from the top to the bottom of the ramp)</th>
<th>Run (time (s)) (Time elapsed from the top to the bottom of the ramp)</th>
<th>Slope of line (m/s/s) (Divide rise by run.)</th>
</tr>
</thead>
<tbody>
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</tbody>
</table>

5. **Drawing Conclusions**  If the slope of the line on the velocity versus time graph tells us the amount the velocity is changing over time, what do we call this quantity?

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6. What do the units of the change in velocity tell you about the velocity of the ball as it rolls down the ramp?

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7. **Graphing**  Use the \( a_{tot} \) data in each of the data links in your lab book to draw three acceleration versus time graphs on the grid below. Label the horizontal axis \( Time (s) \) and the vertical axis Acceleration (m/s\(^2\)). Use the same colors for the graphs of the same ramp angle as you did in the previous graphs. Label each line with the angle of the ramp.

16  Inclined to Roll
8. **Interpreting Data** What does the shape of each of the acceleration graphs tell you about the motion?

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**Going Further**

9. **Applying Concepts** Describe the motion (both position and velocity) that you would observe if the acceleration graph sloped down to 0, showing decreasing positive acceleration.

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Lab 6: Acceleration of Gravity

Problem
To study the acceleration of a ball when it is thrown into the air, both with and without air resistance

Background
You experience acceleration when you walk faster to get somewhere on time, or slow down to talk to a friend, or turn a corner as you walk down the hall. What do these movements have in common? They are examples of a change in speed or a change in direction. A change in the speed or direction of a moving object is acceleration. Acceleration can be positive (speeding up) or negative (slowing down).

When an object falls through the air, two forces act on it. The force of gravity pulls the object down causing the object to speed up as it falls. At the same time, the force of air resistance tends to slow the object’s fall by opposing its motion. When you put your hand out the window of a moving car, you can feel the air resistance against your hand. As the car goes faster, the air resistance increases. With a falling object, the force of air resistance increases until it eventually equals the pull of gravity. At this point, the object reaches its highest velocity, called terminal velocity.

Skills Focus
Predicting, observing, graphing, interpreting data, comparing and contrasting, applying concepts

Procedure
1. Start Virtual Physics and select Acceleration of Gravity from the list of assignments. The lab will open in the Mechanics laboratory.

2. The laboratory is set up with a 0.25 kg ball near the bottom of the experiment window. A plunger is attached to the bottom of the ball. The ball will be shot straight up into the air by the plunger, but there will be gravity to pull it back down. You will observe the acceleration of the ball as it rises in the air and then falls back to the bottom of the screen.

Predicting How do you think the speed of the ball will change as it moves up in the air? How will the speed change as the ball falls back down?
3. Click on the Lab Book to open it. Click on the red Recording button to start recording data. Hit the ball into the air by clicking on the Force button. Observe the trajectory of the ball. The force of the plunger is initially set to hit the ball with a force of 75 newtons (N). When the ball reaches the bottom of the screen, the experiment will stop. You should see a link appear in the lab book. This contains the position, velocity and acceleration versus time data for the motion. In the table below write the time it took the ball to drop and its final velocity just as it reaches the ground.

4. Try the experiment again with a different force on the plunger. Click the Reset button to reset the experiment. Change the force in the Parameters Palette to a different value and repeat Step 3.

5. Click the Reset button to reset the experiment. Now place the air resistance graphic in the work area from the tray. Repeat Step 3 to record the velocity of the ball as it falls.

6. The air resistance slowed down that last ball a lot so it wasn’t able to rise as far in the air. Now you can adjust the force so the ball will shoot up higher, and observe the velocity as it drops. Click the Reset button to reset the experiment. Use the Parameters Palette to adjust the force to a larger value. Remember to bring down the air resistance graphic again. Repeat Step 3.

<table>
<thead>
<tr>
<th>Force (N)</th>
<th>Air Resistance (on or off?)</th>
<th>Time to reach ground (s)</th>
<th>Velocity at the ground (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>off</td>
<td></td>
<td></td>
</tr>
<tr>
<td>75</td>
<td>on</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7. Observing In each of these experiments where, along its path, does the ball accelerate?

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Analyze and Conclude

1. Graphing Use the data in each of the data links in your Lab Book to draw the position versus time graphs on the grid on the next page. Label the horizontal axis Time (s) and the vertical axis Distance (m). You will need to scale the graph to fit your data. Use about 10 points from each data link to plot the trajectory of the ball. The first data point in each graph is (0 s, 0 m). This is the time and place where the ball was hit. Plot the height of the ball (the y data) over the whole trajectory of rising and falling. Use a different color for each ball. Connect the data points with lines. Label each line with the force on the ball and indicate if there was air resistance.
2. After you have made your graphs of position versus time, graph velocity \( (v_y) \) versus time on the grid below. Label the horizontal axis \( Time \ (s) \) and the vertical axis \( Velocity \ (m/s) \). Use about 10 data points to plot the trajectory of the balls. Connect the points. Use the same colors as you did in the first graph. Label each line again. Identify the parts of the trajectory where the speed is increasing, where the speed is decreasing, and where the ball is changing direction.
3. **Interpreting Data**  Describe any differences you see in the graphs. Explain why the graphs are different. Is there a difference in the motion of the objects with or without air resistance?

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4. **Interpreting Data**  How do the velocity versus time graphs show that the balls are accelerating?

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5. **Comparing and Contrasting**  How does the acceleration compare in the different experiments without air resistance? Compare the slopes of the velocity lines. How does this acceleration compare to the acceleration when there is air resistance?

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6. **Interpreting Data**  Do the graphs of the experiments with air resistance have any regions that show constant acceleration? Do they have any regions with constant velocity, or no acceleration? Why wouldn’t the balls accelerate even with gravity still pulling them down? What is stopping them?

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7. **Applying Concepts**  Is there a relationship between the slopes of the lines and the plunger forces? *Hint:* Does the size of the force used to hit the ball have anything to do with the velocity when the ball was falling? What about the velocity when the ball was rising?

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Lab 7: Gravity and Projectile Motion

Purpose
To study projectile motion with different launch angles and with and without air resistance

Background
On the basketball court, the baseball field, and at the football game, balls are thrown or hit. These balls follow a path through the air that depends on the initial velocity and angle of the ball’s path. Surprisingly, if air resistance is ignored, the horizontal velocity of a thrown ball is constant. Only the vertical velocity changes as the ball flies through the air. What forces accelerate the ball? Just gravity! Gravity slows the ball down as it rises and speeds it up on its way down.

Skills Focus
Predicting, interpreting data, graphing, drawing conclusions, applying concepts

Procedure
1. Start Virtual Physics and select Gravity and Projectile Motion from the list of assignments. The lab will open in the Mechanics laboratory.

2. The laboratory will be set up with a 200-g ball (the approximate weight of a baseball) at the bottom of the experiment window. Attached to the bottom of the ball is a plunger used to hit the ball up into the air. Gravity will pull the ball down. There is no air resistance. Observe how far the ball travels when hit at different angles. The plunger is initially set to hit the ball with a force of 100 N at an angle of 45°.

   Predicting What would happen if the ball were hit into the air and there was no gravity or air resistance? How far would it go?

3. Click on the Lab Book to open it. Click the red Recording button to start recording data. Start the experiment by clicking on the Force button and observe the path of the ball. The experiment will stop when the ball falls to the bottom of the screen. You will see a link appear in the lab book. Double click next to the link to label it as 45 degrees. It contains the position versus time data for the ball flying through the air. Record the horizontal distance (the maximum x-distance) the ball traveled in the table on the next page. You will need to look in the link for the x-distance closest to when y = 0.
4. Click the Reset button to reset the experiment to the beginning. Change the angle of the plunger to 15° using the Forces tab in the Parameters Palette and repeat Step 3. Repeat the experiment two more times using the angles shown in the table.

Data Table

<table>
<thead>
<tr>
<th>Angle</th>
<th>Force (N)</th>
<th>Mass of Ball (kg)</th>
<th>Air Resistance?</th>
<th>Distance Traveled (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>45°</td>
<td>100</td>
<td>0.2</td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>15°</td>
<td>100</td>
<td>0.2</td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>30°</td>
<td>100</td>
<td>0.2</td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>75°</td>
<td>100</td>
<td>0.2</td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>45°</td>
<td>100</td>
<td>0.2</td>
<td>yes</td>
<td></td>
</tr>
</tbody>
</table>

5. To see how the mass of the ball affects its motion, hit another ball of a different mass from the angle you think will make the ball go farther. Reset the experiment with the Reset button. Use the Forces tab in the Parameters Palette to change the angle of the plunger to your chosen angle. Change the mass to either a larger or smaller mass, whatever you think will make the ball go farther. Repeat Step 3 to collect your data.

6. Now you can test to see how air resistance would affect the motion. Reset the experiment with the Reset button. Drag the air resistance icon down into the work area, and repeat Step 3 to collect your data.

Analyze and Conclude

1. Interpreting Data Which ball traveled the farthest?

How does the angle affect how far the ball goes? Explain.

2. Graphing On the grid on the next page, graph the x-position versus y-position for each of the five different experiments. Use the data found in the data links saved in your Lab Book. Plot Distance (m) on the horizontal axis and Height (m) on the vertical axis. Decide on the proper scales for the axes. Use a different color for each angle. Label which line corresponds to each angle. Identify the graph of the ball that has a different mass and also which graph has air resistance.
3. **Interpreting Data**  Do any of the angles make the ball travel the same horizontal distance?

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Explain why two different angles cause the ball to travel the same horizontal distance.

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4. **Drawing Conclusions**  What effect does the mass of the ball have on the distance the ball traveled?

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5. **Interpreting Data**  How did the distance the ball traveled change with air resistance?

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6. **Applying Concepts**  Which do you think would travel farther with air resistance: a ball shot up at 75° or out at an angle of 15°? Explain your prediction, then test it.

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Lab 8: Newton’s Second Law

Purpose
To investigate through graphing and data analysis how force, mass, and acceleration are related

Background
Newton’s second law of motion states that the acceleration of an object depends on the object’s mass and the net force applied to the object. The law can be written mathematically as \( Force = Mass \times Acceleration \) or \( F = m \times a \). This equation can also be rearranged.

\[
\text{Acceleration} = \frac{\text{Force}}{\text{Mass}}
\]

The relationship between these variables can be used to explain the mechanics involved in many collisions, from football tackles to car crashes. It is also useful to keep in mind when figuring out how to accelerate quickly or how to create the greatest force with the least amount of effort!

Skills Focus
Graphing, predicting, interpreting graphs, controlling variables, drawing conclusions

Procedure
1. Start Virtual Physics and select Newton’s Second Law from the list of assignments. The lab will open in the Mechanics laboratory.

2. The laboratory will be set up with a ball on a table. Attached to the ball is a rocket used to push the ball across the table. There is no friction. In this experiment, you will collect position and velocity data as the ball moves across the table. Then you will make position and velocity graphs.

   Predicting What do you think your velocity versus time graphs will look like if the ball is accelerating?

3. Click on the Lab Book to open it. Click on the red Recording button to start recording data. Start the ball rolling by clicking on the Force button. Observe what happens as the ball rolls across the table. The force is set to 10 N and the mass of the ball is 2 kg. Does the ball speed up? The experiment will stop automatically when the ball has reached the end of the table. You will see a link appear in the lab book containing the position and velocity versus time data of the ball rolling across the table. Double click next to the link to label the line with the force and mass.

4. Click the Reset button to reset the experiment back to the beginning. Use the Parameters Palette to change the rocket force and repeat Step 3 for two different forces. Record the forces in the table on the next page.
Newton’s Second Law

5. Now observe what happens to the ball’s speed and acceleration when you change the mass. Click the Reset button to reset the experiment back to the beginning. Use the Parameters Palette to change the mass of the ball. Make sure the force is set to 10 N, and repeat Step 3 for two different masses. Don’t change the force for these experiments. Record the masses in the table.

Table

<table>
<thead>
<tr>
<th>Force (N)</th>
<th>Mass of ball (kg)</th>
<th>Final Velocity (m/s)</th>
<th>Time to reach end of ramp (s)</th>
<th>Acceleration (m/s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>10</td>
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<tr>
<td>10</td>
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</tbody>
</table>

Analyze and Conclude

1. Graphing Using the data in each of the data links in your Lab Book, draw the velocity versus time graphs on the grid below. You will be plotting the velocity of the ball versus the time as the ball crossed the table. Label the horizontal axis as Time (s) and the vertical axis as Velocity (m/s). Choose a scale for your graph that fits your data. The first data point will be (0 s, 0 m/s). This is the time and speed of the ball when it started rolling. Plot ten points for each ball. Connect the data points using a different color for each experiment. Label each line with the force and mass of the ball.
2. Open each of the links and record the final velocity and the time it took to reach that velocity in the table. Note: record the time when the ball first reaches the end of the ramp—there may be another data point after that, but just take the time when it reaches the end.

3. **Interpreting Graphs**  How do the velocity versus time graphs show that the balls are accelerating?

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Which ball accelerated the most?

4. Acceleration is a measure of how much the velocity is changing over time. This is expressed in an equation like this: Acceleration = Change in speed/time interval. Calculate the acceleration of each of the balls using this equation. Each ball started at 0 m/s. Record your calculations in the table on the previous page.

5. Another way to calculate acceleration is to use Newton’s Second Law, solved for the acceleration. Do your calculations for acceleration in #4 above match what you would calculate using Newton’s Second Law?

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6. **Graphing**  Using the calculated data from your data table, draw a force versus acceleration graph on the grid below. You will be plotting the applied force on the ball versus the observed acceleration as the ball crossed the table. Label the horizontal axis Acceleration (m/s\(^2\)) and the vertical axis Force (N). Just use your first three data points, collected in procedure step 4, which were all performed on the same ball. Choose a scale for your graph that fits your data.
7. **Interpreting Graphs**  What does the slope of the force-acceleration graph tell you?

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8. **Controlling Variables**  Explain how you could produce a large acceleration using a very small force.

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9. **Drawing Conclusions**  What are two ways in which you can increase acceleration?

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Lab 9: Acceleration and Friction

Purpose
To investigate the effect that friction has on the acceleration of an object

Background
Have you ever tried to ride a bike with flat tires, or push a heavy crate across a rough floor? Chances are you couldn’t get the bike or the crate to move very fast. What makes these activities so hard is the large amount of friction involved. Friction affects motion just as all other forces affect acceleration. But when multiple forces act on an object together, the result can be unpredictable. All motion is due to a complex interplay of different balanced and unbalanced forces, and often the effects are only visible by examining the resulting accelerations.

Skills Focus
Graphing, interpreting data, applying concepts

Procedure
1. Start Virtual Physics and select Acceleration and Friction from the list of assignments. The lab will open in the Mechanics laboratory.

2. The laboratory will be set up with a sled on a table. The surface of the table can be changed to be made of different materials. Attached to the sled is a small rocket that will be used to push the sled. Click on the Lab Book to open it.

3. Click on the red Recording button to save the position versus time data. Click on the Force button to start moving the sled. The rocket will turn off automatically after two seconds. When the sled has stopped moving, click on the Pause button to stop the experiment and stop recording data. A new data link should appear in your lab book. Record what happens to the sled in the table on the next page.

4. You will try other types of materials for the sled and the table to see how long it takes the sleds in each case to stop. Remember to click the Reset button before trying new materials. In the Parameters Palette choose the materials under the Frictions tab. Choose a variety of different types. For each trial, record the materials of the sled and table, the distance the sled travels until it stops, and the time it takes the sled to stop in the table below. If the sled reaches the end of the table, the experiment will stop automatically. Double click next to each link in the lab book to label the link with the materials.
Analyze and Conclude

1. **Graphing**  On the grid below, graph the position versus time for each of the five different experiments. Use the data found in the data links saved in your lab book. Label the horizontal axis *Time (s)*. Label the vertical axis *Distance (m)*. Use a different color for each graph. You will need to scale the graphs to fit your data. Identify on the graphs the place where the rocket finished firing.

```
<table>
<thead>
<tr>
<th>Material of the Sled</th>
<th>Material of the Table</th>
<th>Sliding Distance (m)</th>
<th>Sliding Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood</td>
<td>Plastic</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
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2. **Interpreting Data**  As the friction increases, what happens to the shape of the position versus time graphs during the firing interval? Explain why.

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__________________________________________________________________
__________________________________________________________________
3. What happens to the shapes of the position versus time graphs after the rockets turn off? Recall that the slope of a position vs. time graph is the velocity of the object.

__________________________________________________________________
__________________________________________________________________
__________________________________________________________________

4. **Applying Concepts** What forces are acting on the sled throughout the experiment? List the forces that are acting on it in the different stages of motion.

__________________________________________________________________
__________________________________________________________________
__________________________________________________________________

5. **Graphing** Now graph velocity versus time for each of the five different experiments. Use the v_tot data found in the data links saved in your lab book. Label the horizontal axis *Time (s)* and the vertical axis *Velocity (m/s)*. Use the same colors that you used in the position graphs. Identify on the graphs the place where the rocket finished firing.
6. Interpreting Graphs  What do the shapes of the velocity-time graphs tell you about the acceleration throughout the experiment? Is the acceleration constant or does it change? Where do you see positive acceleration and where do you see deceleration?
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________

7. Applying Concepts  What do you think would happen if you repeated the same lab with a more massive sled?
___________________________________________________________________
Lab 10: Newton’s Third Law

Purpose
To study action and reaction by observing collisions between moving balls of different masses

Background
In the past, cannons were an important weapon for reaching the enemy at a distance. However, soldiers had to be careful not to stand behind a cannon when it was fired. The heavy cannon would “kick” back or roll backward with each shot. This “kick” back is an example of Newton’s third law of motion: For every action (the cannon ball firing forward at high speed) there is an equal and opposite reaction (the cannon moving backwards at low speed).

Skills Focus
Predicting, interpreting data, applying concepts, drawing conclusions

Procedure
1. Start Virtual Physics and select Newton’s Third Law from the list of assignments. The lab will open in the Mechanics laboratory.
2. The laboratory will be set up with two balls of the same mass on a table. The balls will move towards each other. As they collide, they will exert forces on each other which are equal and opposite.
   Predicting When a heavier ball hits a lighter ball, how do the forces they exert on each other compare? What is the resulting motion of the balls?

3. The initial velocity of all of the balls will be the same for the first three trials, but the masses of the balls will change. You will observe what happens in the collisions and record the final velocities of each ball.
4. Click the Start button to start the balls in motion. After the balls bounce off each other and move a short distance away from each other, click the Pause button to stop the experiment. Note the velocity of each ball in the display panel below the table. You can display the velocity of the second ball by clicking on the ball, or by clicking on the Tracking arrows located in the lower right corner of the display to change the display. Record the velocities in the table on the next page. Describe what happened to each ball in the reaction box.
5. Click the Reset button to reset the experiment before trying new masses. Use the table to keep track of what mass to use for each trial. Use the Parameters Palette to change the masses of the balls. Uncheck the Balls Same Mass and Diameter box to be able to change each mass separately.
6. Now change the masses and initial velocities of the balls so you can get one ball to totally stop after a collision when they both start out moving (Trial 4). Also conduct a trial (Trial 5) where one of the balls starts at rest and is still at rest after the other ball collides into it.

Table

<table>
<thead>
<tr>
<th>Trial 1</th>
<th>Mass (kg)</th>
<th>Velocity Before</th>
<th>Velocity After</th>
<th>Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ball 1</td>
<td>10</td>
<td>−10</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Ball 2</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ball 1</td>
<td>20</td>
<td>−10</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Ball 2</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ball 1</td>
<td>50</td>
<td>−10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ball 2</td>
<td>1</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ball 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ball 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ball 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ball 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Analyze and Conclude

1. Interpreting Data  Describe what happened when the masses of the balls were the same, and when they were very different.

2. Applying Concepts  Explain why a lighter ball has more velocity after a collision with a heavy ball than it had before. Where did that velocity come from? Hint: Think about Newton’s second law of motion.
3. **Drawing Conclusions**  Does the data prove your earlier prediction? Explain.

__________________________________________________________________

4. If forces are acting on each object in every collision, how can a ball stop or not even move, as you observed in Step 6?

__________________________________________________________________

__________________________________________________________________

__________________________________________________________________

5. **Drawing Conclusions**  Why don’t the forces of action and reaction cancel each other? Why isn’t the net force zero if the forces are the same in each direction?

__________________________________________________________________

__________________________________________________________________
Lab 11: Conservation of Momentum

Purpose
To discover what happens to total momentum when objects collide

Background
You might think of conservation as relating to how much water or gas you use. But conservation also means that conditions before and after an event do not change. Conservation of momentum means that the total momentum of any group of objects before an event is the same as it is afterwards. No momentum has been lost and none has been gained. Although collisions may be elastic or inelastic, and even if some balls bounce off at greater velocity than they started with, energy really is conserved and total momentum remains constant.

Skills Focus
Graphing, interpreting data, drawing conclusions, making generalizations

Procedure
1. Start Virtual Physics and select Conservation of Momentum from the list of assignments. The lab will open in the Mechanics laboratory.
2. The laboratory will be set up with two balls of the same mass on a table. You will perform three experiments to look at the momentum of the system by looking at the momentum of each ball within the system.
3. **Trial 1: Two balls moving** The masses of the balls are the same. The velocities of the balls are the same in magnitude but opposite in direction, toward each other. The balls start out separated by 10 meters. Click the Start button to watch the balls collide. Click the Pause button a few seconds after they bounce off each other. Record the final velocity of each ball in Data Table 1 using data from the display panel. You can display the velocity of the second ball by clicking on the ball, or clicking on the Tracking arrows in the lower right corner of the display to change the display.

<table>
<thead>
<tr>
<th>Trial 1</th>
<th>Mass (kg)</th>
<th>Velocity Before (m/s)</th>
<th>Velocity After (m/s)</th>
<th>Momentum Before (mass 3 velocity before)</th>
<th>Momentum After (mass 3 velocity after)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ball 1</td>
<td>10</td>
<td>-10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ball 2</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. **Trial 2: One ball moving initially** Click the Reset button to reset the experiment. Using the Parameters Palette, change the mass of Ball 1 to 15 kg, and the mass of Ball 2 to 5 kg. Uncheck the Balls Same Mass and Diameter box to be able to change each mass separately. Set the velocity of Ball 1 to
10 m/s and the velocity of Ball 2 to 0 m/s. Click the Start button to watch the balls collide. Click the Pause button a few seconds after the balls bounce off each other. Record the final velocity of each ball in Data Table 2.

**Data Table 2**

<table>
<thead>
<tr>
<th>Trial 2</th>
<th>Mass (kg)</th>
<th>Velocity Before (m/s)</th>
<th>Velocity After (m/s)</th>
<th>Momentum Before (\text{mass} \times \text{velocity})</th>
<th>Momentum After (\text{mass} \times \text{velocity})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ball 1</td>
<td>15</td>
<td>–10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ball 2</td>
<td>5</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Total Momentum =**

5. **Trial 3: Two connected balls.** Click the Reset button to reset the experiment. Set the velocity of Ball 2 to 0 m/s, and change the Elasticity to 0 to make the balls inelastic. Click the Start button to watch the balls collide. Click the Pause button a few seconds after they collide. Record the final velocity of each ball in Data Table 3.

**Data Table 3**

<table>
<thead>
<tr>
<th>Trial 2</th>
<th>Mass (kg)</th>
<th>Velocity Before (m/s)</th>
<th>Velocity After (m/s)</th>
<th>Momentum Before (\text{mass} \times \text{velocity})</th>
<th>Momentum After (\text{mass} \times \text{velocity})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ball 1</td>
<td>10</td>
<td>–10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ball 2</td>
<td>10</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Total Momentum =**

6. **Trial 4: Choose your own variables**  Click the Reset button to reset the experiment. Click on the Lab Book to open it. Click on the red Recording button to start recording data. Choose your own masses and velocities for each ball. Try it with the balls initially traveling in the same direction, but with one of the balls traveling faster than the other. Switch the elasticity to 0 again to observe an inelastic collision. Predict what you think the resulting velocities might be. Test your prediction. Record the data in Data Table 4.

**Data Table 4**

<table>
<thead>
<tr>
<th>Trial 3</th>
<th>Mass (kg)</th>
<th>Velocity Before (m/s)</th>
<th>Prediction: Velocity After (m/s)</th>
<th>Actual: Velocity After (m/s)</th>
<th>Momentum Before (\text{mass} \times \text{velocity})</th>
<th>Momentum After (\text{mass} \times \text{velocity})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ball 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ball 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Total Momentum =**
7. **Graphing**  On the following grid, graph the momentum of each ball over the course of the experiment. When you pause the trial after your observations, a data link will appear in the lab book. Click on that link to display the momentum over time for each ball. Use the #1 $p_x$ data to graph the momentum of the first ball over time. Your graph should have Time on the $x$-axis and Momentum on the $y$-axis. Also graph the momentum data of the second ball on the same graph. Label the axes with the variable and its units. Use a different color for each ball. You will need to scale the graph to fit your data.

**Analyze and Conclude**

1. **Interpreting Data**  Is the momentum of the system conserved in each trial? Explain.

2. **Interpreting Data**  How did the graph help to show the conservation of momentum?

3. **Drawing Conclusions**  How can a ball with a small mass have the same momentum as a ball with a large mass?

4. **Making Generalizations**  Describe momentum in your own words.
Lab 12: Energy Conversions

Purpose
To measure the conversion of energy between potential and kinetic using an inclined plane

Background
Knowing how energy behaves is even more important than knowing what it is. The law of energy conservation states that energy cannot be either created or destroyed. So the energy of a system must remain the same before and after things happen to it. A person walking to the top of a burning building has to work to climb the stairs. The energy from the work is then stored in potential form because of the force of gravity pulling her down. If she were to jump from the burning building onto a fire fighters’ trampoline, her potential energy would be converted into kinetic energy as she was falling. As she speeds up while falling, her potential energy decreases because she is closer to the ground and her kinetic energy increases as her speed increases. When she hits the trampoline she will slow down and her energy will convert into vibrations (elastic potential energy), heat and noise.

Skills Focus
Making generalizations, interpreting data, applying concepts, drawing conclusions

Procedure
1. Start Virtual Physics and select Energy Conversions from the list of assignments. The lab will open in the Mechanics laboratory.

2. The laboratory will be set up with a ramp, a ball on the ramp, and a plunger on the ball. Using the Force button to hit the plunger, you will push the ball up the ramp. The ball will stop at some point and come rolling back down the ramp.

3. You will need to record and use the data from the experiment. Click on the Lab Book to open it. The click the red Recording button. When the Force button is clicked, the data selected with the check marks will be automatically recorded.

4. Click the Force button to hit the ball up the ramp. Then watch the ball fall back to the bottom.
5. Click the link in the lab book that contains your data. You may want to copy and paste it into a spreadsheet program. From the data you should find five different locations of the ball and compare the ball’s potential and kinetic energies at those points. First you will find and record the different velocities and the heights at which the ball had those velocities. The beginning was when the ball first got hit. Record the ball’s velocity right after it was hit (the first data point where velocity ≠ 0.) Then find a middle height in the data and record it and the velocity of the ball at that height. Do the same for the top, the middle on the way down, and then the bottom again. Record the information in Data Table 1.

**Data Table 1**

<table>
<thead>
<tr>
<th>Ball Position</th>
<th>Height (m)</th>
<th>Velocity (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beginning bottom</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Middle going up</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Middle coming down</td>
<td></td>
<td></td>
</tr>
<tr>
<td>End bottom</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6. Now you can calculate the gravitational potential energy and the kinetic energy of the ball at the different positions. Recall that gravitational potential energy is due to the work of lifting the ball against gravity. So you only need to know the height of the ball off the ground \( y(m) \). Record your calculations in Data Table 2. Use the equation:

\[
PE = mgh
\]

where \( m \) is mass of ball, \( g \) is the acceleration due to gravity, and \( h \) is height of ball from ground.

7. Recall that the kinetic energy of an object depends on its mass and the speed or velocity that it is moving. Calculate the kinetic energy using the equation:

\[
KE = \frac{1}{2}mv^2
\]

where \( m \) is mass, and \( v \) is the velocity of the ball.

**Data Table 2**

<table>
<thead>
<tr>
<th>Ball Position</th>
<th>Potential Energy</th>
<th>Kinetic Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starting bottom</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Middle going up</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Middle coming down</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ending bottom</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Analyze and Conclude

1. Making Generalizations  What determines potential energy? Kinetic energy?

__________________________________________________________________
__________________________________________________________________

2. Interpreting Data  When did the ball have the most potential energy? Why?

__________________________________________________________________
__________________________________________________________________

3. Interpreting Data  When did the ball have the most kinetic energy?

__________________________________________________________________
__________________________________________________________________

4. Applying Concepts  What is the relationship between the PE at the top of the ramp, and the KE at the bottom of the ramp?

__________________________________________________________________
__________________________________________________________________

5. Drawing Conclusions  Where did the energy go from the top of the ramp to the bottom? Explain the motion of the ball throughout the experiment in terms of potential and kinetic energy.

__________________________________________________________________
__________________________________________________________________
__________________________________________________________________
__________________________________________________________________
__________________________________________________________________
Lab 13: Centripetal Motion

Purpose
To use a rotating rod to study aspects of centripetal motion

Background
Baseball bats being swung, race cars turning a corner, the swing of your arm when you walk, all these things have something in common, centripetal motion. The baseball bat is rigid, which means it can’t bend without breaking. Think about when you swing a bat. The inside, close to your hand, doesn’t move as fast as the tip of the bat. Hence, you could hit a ball farther when you hit it near the end of the bat rather than near your hands. In this activity you will observe and compare two ways to describe speed: tangential speed and rotational speed.

Skills Focus
Predicting, graphing, interpreting data, forming operational definitions, analyzing data, developing hypotheses

Procedure
1. Start Virtual Physics and select Centripetal Motion from the list of assignments. The lab will open in the Mechanics laboratory.

2. The laboratory will be set up with a rod on a table. The only force acting on the rod is gravity. You will record the position, velocity, and angular velocity of different points along the rod.

3. The rod is going to act like a baseball bat. It is 1m in length. It has a radius of .1m and is made of wood. The rod is ready to rotate towards the ground once you click Start. First, you will make some observations, then some predictions, and then you will need to collect and analyze actual data.

4. Click the Start button and observe the rod rotate to the ground. Record your observations below.
   Observations: _______________________________________________________
   _______________________________________________________
   _______________________________________________________
   Predicting: What part of the rod travels the fastest? ____________________
   _______________________________________________________

5. There are two ways to describe the speed of the rod. You may want to know the turning or angular speed. The angular speed is the amount of radians turned in a second. Or you may want to know how fast a part of the rod is traveling in linear motion. When something travels in a circular path, its linear speed is called tangential speed because it is measured tangent to the circle.
6. You will observe the angular speed and tangential speed of the rod at four different locations during the experiment. Since the rod is falling due to gravity, it will be speeding up. So you will examine three different times to compare the angular speeds and tangential speeds of those four locations along the rod. You will need to collect enough data to fill in the data tables below. You will then create a graph comparing the tangential speeds of four different locations along the rod for one of the times.

7. To record the position and angular speed of the rod, you need to open the Lab Book. Click the red Recording button. Then click the Start button to make the rod rotate. A link should appear in the lab book once the rod hits the ground.

8. The four locations along the rod that you need to examine are: .25m, .50m, .75m, and the tip of the rod (1.0m). The link will contain the angular speed of the rod at different times. Since the rod is a rigid body, you can assume that the angular speed is the same for each location.

9. Open the link and fill out the three data tables below. In the fourth column you will need to use the equation for calculating tangential speed, which is:

\[
\text{Tangential speed} = \text{Distance away from pivot point} \times \text{Angular speed} \quad (V_t = D \times \omega / s).
\]

Time: .5 sec

<table>
<thead>
<tr>
<th>Location</th>
<th>Distance from pivot point (m)</th>
<th>Angular speed ((\omega/s))</th>
<th>Tangential speed (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Time: 1 sec

<table>
<thead>
<tr>
<th>Location</th>
<th>Distance from pivot point (m)</th>
<th>Angular speed ((\omega/s))</th>
<th>Tangential speed (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Time: 1.5 sec

<table>
<thead>
<tr>
<th>Location</th>
<th>Distance from pivot point (m)</th>
<th>Angular speed ((\omega/s))</th>
<th>Tangential speed (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
10. **Graphing**  Create a bar graph below for one of the three data tables on the previous page. Include both the tangential speeds and corresponding angular speeds on the graph. Be sure to label your graph properly.

![Graph](image_url)

**Distance from pivot point**

**Speed**

**Analyze and Conclude**

1. **Interpreting Data**  What is similar on the graph for all of the locations?

__________________________________________________________________
__________________________________________________________________

2. **Forming Operational Definitions**  How does tangential speed change as you move further out on the rod?

__________________________________________________________________
__________________________________________________________________

3. **Predicting**  Using the graph for support, predict where you think the next plot would be on the graph.

__________________________________________________________________
__________________________________________________________________

4. **Analyzing Data**  Did your pre-experiment predictions prove correct? Explain.

__________________________________________________________________
__________________________________________________________________

5. **Developing Hypotheses**  If you had to design a rod that could rotate, where would you want the material that the rod is made from to be the strongest? Why?

__________________________________________________________________
__________________________________________________________________

44  Centripetal Motion
Lab 14: Rotational Inertia

Purpose
To study the motion of hollow and solid balls rolling down a ramp and compare the angular acceleration and rotational velocity of each type of ball

Background
Objects are in motion all around you. Often, with just a little added force, those objects begin to rotate. Studying rotating objects has changed the way we do many sports, the way machines are developed, how power is created, and even the way we understand the formation of the universe. The principles of rotational inertia and angular momentum explain much of the motion around us and can be understood through a few basic observations of rotating objects.

Skills Focus
Predicting, interpreting data, observing, controlling variables, drawing conclusions, applying concepts

Procedure
1. Start Virtual Physics and select Rotational Inertia from the list of assignments. The lab will open in the Mechanics laboratory.

2. The laboratory will be set up with a solid ball on a ramp. The ramp has an angle of 30°. You will be observing the ball’s speed and acceleration as it moves down the ramp. Later, you will compare it with the motion of other types of balls. Click on the Lab Book to open it. Click the red button in the Recording area to start recording data. Start the ball rolling down the ramp by clicking the Start button. When the ball hits the end of the ramp, you will see a link appear in the lab book that contains position, velocity and acceleration versus time data for the ball as it rolls down the ramp.

3. Predicting How would the motion of a larger ball down the same ramp compare with the motion of the first ball? Predict how you think its velocity and acceleration would be different.

__________________________________________________________________

__________________________________________________________________

__________________________________________________________________
4. Click the Reset button to move the ball back to the top of the ramp. The diameter of the first ball was 2 meters. Set the diameter of the ball to 3 meters using the Objects section of the Parameters Palette. Repeat Step 2. Then repeat the experiment one more time with a ball with a diameter of 0.5 meters. You should now have three data links in your lab book. Click to the right of the data links until a cursor appears to label each run with the corresponding ball diameter. Click on the blue data link to display the data and record the final velocity and acceleration for each ball in the data table below. Find the final velocity by looking for the velocity when the ball reaches the end of the ramp (r=0). Also record the time when the ball reaches the end of the ramp.

5. **Interpreting Data**  How did the accelerations of the three solid balls compare?

___________________________________________________________________
___________________________________________________________________
___________________________________________________________________

**Data Table**

<table>
<thead>
<tr>
<th>Ball Diameter (m)</th>
<th>Solid or Hollow?</th>
<th>Final Velocity (m/s)</th>
<th>Linear Acceleration (m/s²)</th>
<th>Time (s)</th>
<th>Final Rotational Velocity (rad/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>solid</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>solid</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>solid</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>hollow</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>3</td>
<td>hollow</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>hollow</td>
<td></td>
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</tbody>
</table>

6. **Observing**  As you observed the motion of the three balls, you probably noticed that there are similarities and differences in how the different balls rolled. Small balls and large balls may roll down a ramp with the same acceleration, but that does not mean that they roll with exactly the same motion. What is different about the rotations of the different balls?

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7. Record the final rotational velocities, which can found in the Data Viewer under \( v_{rot} \), in the data table above.
8. **Predicting**  You will now test balls with different properties to see how their motion compares. The balls you have been rolling up to this point have been solid balls. Now you will be rolling hollow balls, with all of their mass in the outer shell of the ball. How do you think the motion will compare? Will the hollow ball or the solid ball roll down the ramp faster? Explain your reasoning.

9. Reset the experiment. In the Parameters Palette, change the Mass Distribution to Ring. Click the red Recording button and Start the experiment. When the ball reaches the end of the ramp, label the new data link to identify the ball, and compare the velocity and acceleration data to the solid ball data. Record the data in the data table. What was different about the motion of the hollow ball?

10. **Controlling Variables**  Repeat the experiment with hollow balls of the same diameters as the previously tested solid balls. Record the data in the data table. Remember to change the mass distribution to Ring every time you reset. Also, try adjusting the mass without changing the radius, and then with a change in radius. What trends do you see with the different variables you have tested?

**Analyze and Conclude**

1. **Drawing Conclusions**  Why do you think that shape, or mass distribution, affects speed, while size and total mass do not?

2. **Applying Concepts**  Apply what you have studied in this lab to explain why you would speed up when spinning on a chair, or on ice skates, when you pull your arms and legs in.
Lab 15: Universal Gravitation

Purpose
To investigate the inverse square law of gravity

Background
Copernicus, Galileo, Newton and other scientists helped formulate our current understanding of planetary orbits. Although familiar today, their ideas were revolutionary at the time. Initially these ideas were widely rejected due to tradition and a lack of scientific understanding. Finally, with data and interpretations that could not be avoided, Newton’s Law of Universal Gravitation was published, revealing the simple concept of a universal force holding each of the planets in orbit around the sun. Gravity can also be used to explain falling objects on Earth and the orbit of the moon around Earth. Indeed, every object in the universe attracts every other object by exerting a gravitational force on it, even if the force is often infinitesimally small. Gravity is an important force that helps to hold everything in our universe together.

Skills Focus
Collecting data, calculating, interpreting data, comparing and contrasting, drawing conclusions, controlling variables

Procedure
1. Start Virtual Physics. Select Universal Gravitation from the list of assignments. The lab will open in the Mechanics laboratory.
2. The laboratory will be set up in the Solar System view with the sun in the middle. Earth is located in its orbit around the sun. You will calculate the force of gravity between Earth and the sun and find the gravitational acceleration of Earth towards the sun. You will also calculate the force of gravity between the sun and Mars, the sun and Jupiter, and Earth and its moon.
3. Collecting Data In Data Table 1 on the following page record the average orbital distance of Earth from the sun. The distance is found in the data display below the viewing area as the value \( r \) in meters. Round the value to a number with 3 significant digits in scientific notation.
4. In the Parameters Palette under the Objects tab, find the mass of Earth and record it in Data Table 1. Record the sun’s mass in the space below.
5. Calculating  Earth is being pulled toward the sun due to the gravitational attraction between the two. You will first calculate the gravitational force that Earth and the sun are exerting on each other. Newton’s Law of Universal Gravitation is given algebraically by the following equation:

\[ F = \frac{G m_1 m_2}{d^2} \]

This shows the force of gravity between two objects of mass \( m_1 \) and mass \( m_2 \) separated by a distance \( d \). \( G \) is a universal constant and has the value \( 6.67 \times 10^{-11} \text{Nm}^2/\text{kg}^2 \). Calculate the value of the force between Earth and the sun and record this value in Data Table 1.

6. In the Objects tab in Parameters, click on the icons for Mars and Jupiter and record the mass of each of the planets in the table. Click the blue Clear button in the Experiment Control panel to return Earth to the tray at the top of the table. Drag the planet Mars down into the work area and record the orbital radius by repeating Step 3. Repeat with Jupiter. Calculate the force of gravity between the sun and each of these planets.

Data Table 1

<table>
<thead>
<tr>
<th>Planet</th>
<th>Radius of Orbit (meters)</th>
<th>Mass of Planet (kg)</th>
<th>( F_g ) (N)</th>
<th>( g ) (m/s(^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mars</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jupiter</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

7. Interpreting Data  How can you explain that Mars has a greater orbital radius than Earth but exerts a smaller gravitational force on the sun, while Jupiter has a greater orbital radius than Earth but exerts a larger gravitational force on the sun?
8. The acceleration due to gravity (g) near Earth’s surface is often reported as 9.8 m/s\(^2\). But this is not the value you just calculated. The value of 9.8 m/s\(^2\) is calculated by finding the gravitational acceleration between an object on Earth and the Earth itself, using the radius of the Earth as the separation of the two objects. The gravitational attraction between planets and the sun that you just calculated is a force, not an acceleration. You can now calculate the acceleration of each of these planets towards the sun and compare them to gravitational acceleration on Earth.

\[
g = \frac{F}{m_{\text{planet}}} = \frac{G m_{\text{sun}} m_{\text{planet}}}{d^2} = \frac{G m_{\text{sun}}}{d^2}
\]

Calculate the acceleration of each planet toward the sun by using the given equation, substituting the average distance from the planet to the sun. Record your answers in the Data Table 1.

9. Confirm these values by dragging each of the planets down into the work area and noting the \(a_{\text{tot}}\) value in the data display area. Observe the value for each of the planets by clicking on the planet in the work area or cycling through the planets in the Tracking control in the bottom right hand side of the screen. Did your values match those displayed?

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10. Clear the on-screen table. You will now calculate the force of gravity between Earth and its moon. Pull Earth down into the work area. Click on the Object View button on the right side of the screen. This zooms you down to the region close to Earth, where you can see just Earth and the moon in the display. Click on the moon or use Tracking to switch the data display to show the moon’s data. Record the distance between the moon and Earth in Data Table 2. Also record the mass of Earth from the Parameters Palette. The mass of the moon is given in the data table. Calculate the gravitational force between Earth and the moon. Remember to use the masses of the moon and Earth, not the mass of the sun. Also calculate the moon’s gravitational acceleration towards the Earth by dividing the calculated force by the moon’s mass.

**Data Table 2**

<table>
<thead>
<tr>
<th>Object</th>
<th>Radius of Orbit (meters)</th>
<th>Mass of object (kg)</th>
<th>Mass of Planet (kg)</th>
<th>(F_g) (N)</th>
<th>(g) (m/s(^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moon</td>
<td></td>
<td>7.35 \times 10^{22}</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
11. **Calculating**  You have calculated the gravitational attraction between planets and other objects in the solar system. Now you will compare the magnitude of these forces to the force of gravity here on Earth. A typical human weighs about 50 kg. What is the gravitational force between the person and Earth, when he or she is standing on the Earth’s surface? (Hint: the radius of Earth is \(6.37 \times 10^6\) m.) Show your work below.

12. **Comparing and Contrasting**  Compare the value of the gravitational force between a person and Earth that you calculated in Step 11 to the force of gravity between Earth and the sun. Why are these values so different?

13. Calculate the gravitational acceleration of this person on Earth, as in Step 8, by dividing the gravitational force by the mass of the person. Compare this acceleration to the acceleration of the moon towards the Earth.

14. **Drawing Conclusions**  You have calculated the acceleration of several planets toward the sun, and of the moon towards Earth. Why don’t these planets crash into the sun and the moon into Earth?

15. **Controlling Variables**  Experiment with what would happen if any of the parameters for Earth’s orbit were altered. Change the mass of the sun or Earth and note how Earth’s orbit changes. You may want to accelerate time with the Time control to speed up the process.
Lab 16: Gravitational Interactions

Problem
To compare the gravitational accelerations on different planets and moons in the solar system

Background
The English scientist Isaac Newton realized that gravity acts everywhere in the universe, not just on Earth. Gravity is the force that makes an apple or any other object fall to the ground. It is the force that holds you firmly on Earth's surface so that you don't float off into space. It is the force that keeps the moon orbiting around Earth and all the planets in our solar system orbiting around the sun. The gravitational acceleration on the surface of each of the planets varies, depending on the mass and radius of the planet. Astronauts on the moon bounded across the surface, due to the weaker gravity, but the strength of gravity on some planets would be so strong that an astronaut couldn’t even walk at all.

Skills Focus
Graphing, interpreting data, applying concepts, predicting, controlling variables

Procedure
1. Start Virtual Physics and select Gravitational Interactions from the list of assignments. The lab opens in the Mechanics laboratory.

2. The laboratory will be set up with a ball at the top of the experiment window, 40 m above the surface. This is about as high as a 12 story building. Gravity, which is set the same as on Earth, will pull the ball downward. You will observe how long it takes the ball to fall to the ground. The mass of the ball is 1 kg.

3. Click on the Lab Book to open it. Click on the $v_{tot}$ square above the data display to select recording of the velocity data. Click on the red Recording button to start recording data. Start the experiment by clicking on the Start button and observe what happens. The experiment will stop when the ball reaches the bottom of the screen. You will see a link appear in the lab book. This contains the velocity versus time data for the falling ball. Double click next to the link and label it as Earth.

4. Click the Reset button to reset the experiment. Use the Gravity tab in the Parameters Palette to select the strength of gravity of a different planet. Repeat Step 3 to record the velocity of the ball as it falls. Do this on four different planets or moons. Try a big planet such as Jupiter and a small body such as Earth’s moon.
Analyze and Conclude

1. Graphing  For each experiment, use the data in the tables to draw a velocity versus time graph on the grid below. Label the horizontal axis Time (s) and the vertical axis Velocity (m/s). Scale the graph to fit your data. The first data point will always be (0 s, 0 m/s). Connect the data points using different color for each planet or moon. Label each line with the name of the planet or moon.

2. You have observed the different speeds at which the ball falls on several planets or moons. Now, for each planet or moon that you observed, calculate the acceleration, or change in velocity, over the course of the whole drop. Find the slope of the velocity line on each of the graphs and record that in the following table. Acceleration = Velocity Slope = Change in velocity/Elapsed time.

<table>
<thead>
<tr>
<th>Planet</th>
<th>Final Velocity (m/s)</th>
<th>Initial Velocity (m/s)</th>
<th>Elapsed Time (s)</th>
<th>Acceleration (m/s²)</th>
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</thead>
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</table>
3. **Interpreting Data**  How does the speed at which the balls fall vary from planet to planet?

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On which planet or moon did the ball fall the fastest? On which planet or moon did the ball fall the slowest?

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4. **Applying Concepts**  What does the constant slope of each of the graphs tell you about the motion of the ball?

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5. **Predicting**  You have performed all of the experiments with different gravities on balls of the same mass. What would happen if you made the ball more massive? Predict how the acceleration on each of the planets would change.

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6. **Controlling Variables**  Now test your prediction by repeating the experiment. But after resetting, change the mass of the ball in the *Parameters Object* section. Test with the different gravities you observed earlier. Report your conclusions. Explain how your observations support the fact that objects of greater mass exert a greater gravitational pull on each other.

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Lab 17: Satellite Motion

Purpose
To investigate the conditions for launching a satellite and maintaining stable orbital motion

Background
Try looking into the night sky in an open field away from city lights. If you look closely enough, you might eventually see what looks like a star moving quickly across the sky. But what you see is not a star. It is one of many satellites that have been launched into orbit around Earth. These satellites move around Earth in much the same way as the moon does. Satellites are carefully put into orbit and their orbit is maintained with just the force of gravity, but other orbiting spacecraft require booster rockets to maintain or change their orbits. The gravitational laws that govern orbiting satellites are simple, but require precise conditions to exactly reach the anticipated elliptical orbits.

Skills Focus
Predicting, controlling variables, drawing conclusions, observing cause and effect

Procedure
1. Start Virtual Physics and select Satellite Motion from the list of assignments. The lab will open in the Mechanics laboratory.

2. The laboratory will be set up with a ball on the screen. The ball’s mass is 100 kg. Attached to the ball is a plunger that you will use to launch the ball into motion. A radial gravitational field, which is the same as Earth’s, has also been set up. You will hit the ball with the plunger and observe its motion as it is pulled by gravity towards Earth’s surface. The goal is to hit the ball with the amount of force that will put it into a stable orbit around the gravity center.

3. The ball is set 100 km away from the center of the radial gravity source.

Predicting What will happen if you let the ball go without applying any force from the plunger?

4. Try your prediction by clicking the Start button. The plunger is not hitting the ball at all. Observe the motion of the ball. The experiment will stop automatically when the ball reaches the source.

5. Click the Reset button to bring the ball back to the starting position. This time you will use the plunger to hit the ball. Use the Forces tab under the Parameters Palette to choose a plunger force. Remember that you want to put the ball into an orbit around the gravitational source. Start the ball by clicking the Force button. The experiment will stop automatically if the ball runs into the origin. Observe whether or not the ball goes into orbit.
6. Reset the experiment and adjust the force if necessary using the *Force* section of the *Parameters Palette*. Record in the table below the force used, the reaction of the ball to that force, and what you think needs to be adjusted to reach a stable orbit.

7. Repeat Step 6 until you have found a force that makes the ball travel in an orbit around the source. Remember to *Reset* the ball after every attempt.

**Data Table**

<table>
<thead>
<tr>
<th>Mass (kg)</th>
<th>Force on Plunger (N)</th>
<th>Initial Distance from Source (km)</th>
<th>Reaction of Ball</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0</td>
<td>100</td>
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<td>100</td>
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<td>100</td>
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</tbody>
</table>

8. What other variables would affect the orbit of a satellite? *Hint:* Think about the variables the lab had already set, those that you didn’t get to choose.

9. **Controlling Variables**  
   Reset the experiment and change one of the variables you just identified in Step 8, either by clicking on the ball and plunger or adjusting variables in the *Parameters Palette*. Using the same force you used earlier to achieve a successful orbit, launch the ball into orbit. What did you observe? Why?
Satellite Motion

Analyze and Conclude

1. Drawing Conclusions  Now you have learned about a few of the variables that NASA engineers think about when they put a satellite into orbit. The mass of the satellite, the orbit’s distance from Earth, and the amount of force in the direction of the orbit (thrust) are important variables for orbital motion. You will now adjust satellite motion with a rocket thruster force. Click on the plunger and drag it to the spotlight on the transfer table at the top of the screen. Click the green Zoom Out button, then click inside the Stockroom window to enter. Double click on the plunger to return it to the shelf, then double click the rocket to select it. Click the green Return to Lab arrow and click on the on-screen table or TV screen to return to the Experiment View.

2. Pull the rocket down and place it on the ball. Click the Force button to fire the rocket. It will only fire for 1 second. Adjust the ignition time, force, and angle until you can make a stable circular orbit. Report the conditions you chose.

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3. Observing Cause and Effect  You can also fire the rocket multiple times while the rocket is moving. Set up an orbit, then fire the rocket at different points of the orbit and record how the ability to add force at different times during the orbit affects the orbit.

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4. Set up an elliptical orbit and then fire the rocket when needed to transform the orbit into a circular orbit. Report on the positions in the orbit where it was best to fire the rocket in order to adjust the orbit.

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Lab 18: Rutherford and the Nucleus

Purpose
To discover how the physical properties of an object, such as size and shape, can be measured by indirect means, and to duplicate the gold foil experiment of Ernest Rutherford.

Background
A key experiment in understanding the nature of atomic structure was performed by Ernest Rutherford in 1911. Rutherford directed a beam of alpha particles (helium nuclei) through a gold foil and then onto a detector screen. According to previous atomic models, scientists thought that electrons floated around inside a cloud of positive charge. Based on this model, Rutherford expected that almost all of the alpha particles in the beam would pass through the gold foil in a straight path. He thought that a few of the alpha particles would be slightly deflected due to their attraction to the negatively charged electrons (alpha particles have a charge of +2). Imagine his surprise when a few alpha particles were deflected at large angles, some even nearly straight backwards!

According to previous models, there was nothing in the atom massive enough to deflect the alpha particles to such a degree. About this he said it was "...almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you." He suggested that the experimental data could only be explained if the majority of the mass of an atom was concentrated in a small, positively charged central nucleus. This experiment provided the evidence needed to prove this nuclear model of the atom. Although this was an indirect way to discover the nucleus, it was the only way to discover something so small that it couldn’t even be seen with a microscope. In this experiment, you will make observations similar to those of Rutherford.

Skills Focus
Interpreting models, comparing and contrasting, interpreting data, drawing conclusions

Procedure
1. Start Virtual Physics and select Rutherford and the Nucleus from the list of assignments. The lab will open in the Quantum laboratory.

2. The experiment will be set up on the lab table. The gray box on the left side is the alpha particle source. The metal sample stand in the center of the table has a sheet of gold foil in it. The detector on the right side of the table is a phosphor screen which detects charged particles.
3. Turn on the detector by clicking on the red/green light switch. What does the signal in the middle of the screen represent?
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What other signals do you see on the phosphor detection screen? What do these signals represent?
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4. **Interpreting Models**  Click the **Persist** button (the dotted arrow) on the detector screen. How would the old atomic models have explained these deflected alpha particles?
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5. **Comparing and Contrasting**  Now, you will make observations at different angles of deflection. Click on the detector screen and move it to the spotlight in the top right corner of the table. The **Persist** button should still be on. Describe the number of hits in this position as compared to the first detector position.
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6. Move the detector to the top center spotlight position at a 90-degree angle to the foil stand. Compare the number of hits in this position to the hits found at the previous detector positions.
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7. Move the detector to the top left spotlight position. Describe the number of hits in this position as compared to the first detector position.
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What causes the alpha particles to deflect backwards? How do these results disprove the old atomic models? Keep in mind that there are 1,000,000 alpha particles passing through the gold foil at any given second.
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8. **Interpreting Data**  Are the gold atoms composed mostly of matter or empty space? How does the Rutherford’s gold foil experiment show that almost all of the mass of an atom is concentrated in a small, positively charged central atom?

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9. **Drawing Conclusions**  Students often ask, “Why did Rutherford use gold foil?” The most common response is that gold is soft and malleable and can be made into very thin sheets of foil. There is another reason, which you can discover for yourself. Double-click the metal foil sample holder. It will move the holder to the stockroom window. Click on the Stockroom to enter. Click on the metal foil sample box on the top shelf. Click on Na to select sodium. Then click the Return to Lab arrow.

10. Move the metal foil sample holder from the stockroom window back to the center spotlight. Observe the number of hits with sodium compared to the number of hits with a gold sample. Move the detector to the different locations and compare the number of hits with what you observed earlier with the gold foil. Repeat Step 9 two more times and try with different metal foil each time. Why would Rutherford choose gold foil instead of sodium foil? Explain using what you observed from your three new experiments.

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Lab 19: Solid Structure Model

Purpose
To study the elasticity of solids by analyzing crystal structure and density

Background
Some solids are made of a crystal lattice of identical atoms, while other solids have complex structures with many different types of atoms mixed together in regular patterns. The physical and chemical properties of substances are determined by the molecular structure and ordering of the substance.

Skills Focus
Predicting, controlling variables, applying concepts, observing, drawing conclusions

Procedure
1. Start Virtual Physics and select Solid Structure Model from the list of assignments. The lab will open in the Mechanics laboratory.
2. The laboratory will be set up with nine balls arranged in a lattice structure. Each ball represents an atom as part of the fundamental structure of the object. These atoms are densely packed and no vibration would be possible. However, depending on how the atoms are bonded together, layers of atoms could shear off.
3. Calculate the density of the balls in this area. Each ball has a mass of 1 kg. Estimate the area taken up by the whole structure by looking in the Parameters Palette for the diameter of the balls and multiplying this by the number of balls on each side. Record below the total mass of the balls and the area they cover.

4. Predicting  How could you increase the density of the given solid?

5. Controlling Variables  Without changing the mass of the balls, increase the density and report how you did it.
6. Reset the experiment by clicking the Reset button. Uncheck the Balls Same Mass and Diameter box in Parameters. Scroll down the list to Ball 10 and change the size of the ball by adjusting the Diameter and set it equal to .8 m. Drag Ball 10 down onto the work area by clicking the yellow basket in the transfer table area and pulling the next ball down to the table. Find room to place it within the lattice. Adjust a few more balls and pack the lattice as tightly as you can. If these atoms were all bonded together, there would be a lot more in the same area, so the substance would be denser. Calculate the total mass of the balls and approximate the total area that the new structure covers.

__________________________________________________________________

7. **Applying Concepts**  How could you have a dense object with very low mass atoms?

__________________________________________________________________

8. **Predicting**  Predict how you think each solid would respond if it were hit. Would the denser object or the less dense object compress or bounce back more?

__________________________________________________________________

9. Reset the experiment. Click Force to hit the ball and note how the atoms move around. Click Pause when you have finished your observations. Reset the experiment again and pack the area as tightly as possible with more balls and then apply the force again. How does the motion of the atoms compare?

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10. **Observing**  So far, all of the balls have been set to be perfectly elastic in every collision, which is not always the case for real atoms. Repeat Step 9 to observe how less elastic objects respond to forces. Each time you reset the experiment, decrease the elasticity of the ball using the Objects tab in the Parameters Palette. Report your findings.

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11. **Drawing Conclusions**  Solid structures are not always completely rigid and may have a bit of bend or elasticity. Explain from what you have observed in this lab what causes this elasticity and how density affects the elasticity.

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Going Further

12. Observe the rebound of multiple collisions happening at the same time with a high coefficient of elasticity. Reset the lab. Remove all the balls except numbers 1, 2, and 3. Uncheck the check box for Balls Same Mass and Diameter. Change the balls to have the following radius and mass.
Ball 1: 1 kg and .5 m diameter, Ball 2: 5 kg and 1 m diameter, and Ball 3: 100 kg and 5 m diameter. Then place Ball 1 on top of Ball 2. Place Ball 3 under Ball 2. Return to the Stockroom to select downward gravity. Double click on the gravity icon to transfer it to the work area. Return to the lab and pull gravity down into the work area. Click the Start button so the balls fall towards the ground. Observe the collisions and the rebound of Ball 1. Report your observations below.

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Lab 20: Density and Buoyancy

Problem
To learn how to predict whether an object will float or sink

Background
Eureka! According to popular legend, in the 3rd century B.C. the Greek mathematician Archimedes discovered that there was a relationship between the amount of water he displaced when getting in a bathtub and the buoyant force that made him feel lighter in the water. This discovery led to the principle named after him, which states that “an immersed object is buoyed up by a force equal to the weight of the fluid it displaces.”

Why do some objects float and others sink? The answer depends partly on the densities of the object itself and the liquid it is placed in. Density is the mass of a material in one unit of volume. The mathematical formula for density is given below.

\[
\text{Density} = \frac{\text{Mass}}{\text{Volume}} \quad \text{or} \quad d = \frac{m}{V}
\]

The answer also depends on the volume of fluid that is displaced by the object. The shape of an object affects how much fluid is displaced—which explains why a solid block of iron will sink, while the same mass of iron when shaped in the form of a boat would float.

Skills Focus
Problem solving, calculating, applying concepts, predicting, drawing conclusions

Procedure
Density of a Solid
1. Start Virtual Physics and select Density and Buoyancy from the list of assignments. The lab will open in the Density laboratory.

2. You will be measuring the density of solid objects and of various liquids to predict whether the solids will float or sink. You will also calculate the buoyant force on the solids in one of the fluids. Find the ice ball on the lab wall. Pick up the ball and drag it to the spotlight on the balance. Record its mass in Data Table 1.

3. Use the Up and Down arrows on the control panel to toggle through the options of fluids to use in the lab. Select Virtual Fluid B. This is a unique Virtual Fluid that is used only in this virtual laboratory. Click the Full button underneath that display to select the amount of fluid to be added to the cylinder. Click the Fill button to release the chosen amount of fluid into the 250 mL graduated cylinder on the laboratory bench. Click on the top of the cylinder to see a zoomed in view of the level of the fluid. Record the volume of the Virtual Fluid in Data Table 1.
Density and Buoyancy

4. Drag the ice ball to the top of the cylinder and drop it in the cylinder of Virtual Fluid. Click the green Drop button to let the ball fall into the fluid. Look at the close-up view window to note the new volume of the cylinder with both the Virtual Fluid and the ball. Record the volume in the table.

5. **Problem Solving**  How can you determine the volume of the ice ball from your measurements?

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Record the volume of the ice sample in Data Table 1. Click the handle at the bottom of the cylinder to empty the contents of the cylinder.

6. Repeat Steps 2–5 for two more samples: aluminum and pine wood. Record your measurements in Data Table 1.

7. Calculate the weight of each of the objects. Remember Weight = mass × force of gravity (g). Use the mass of the objects in kg and use g = 9.8 m/s².

**Data Table 1**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Mass of Sample (g)</th>
<th>Volume of Virtual Fluid (mL)</th>
<th>Volume of Virtual Fluid and Sample (mL)</th>
<th>Volume of Sample (mL)</th>
<th>Weight of solid (N)</th>
<th>Density (g/mL)</th>
<th>Buoyant force in olive oil (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ice</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aluminum</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Pine Wood</td>
<td></td>
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</tbody>
</table>

**Density of a Liquid**

8. Use the Up and Down arrows on the control panel to toggle through the options of fluids to use in the lab. Select Ethanol. Click the Full button underneath that display to select the amount of fluid to be added to the cylinder. Click the Fill button to release the chosen amount of fluid into the cylinder. Click on the cylinder to see a zoomed in view of the level of the fluid. Record the volume in Data Table 2.

9. Drag the empty beaker on the counter to the balance and record its mass in Data Table 2.

10. Pick up the cylinder filled with ethanol and pour it into the empty beaker. Record the mass of the ethanol and beaker in Data Table 2.
11. **Problem Solving**  How can you determine the mass of the ethanol in the beaker?

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Record the mass of the ethanol in Data Table 2. Click the handle at the bottom of the cylinder to empty the contents of the cylinder.

12. Repeat Steps 8–11 to obtain the densities of water and olive oil. Record your measurements in Data Table 2.

**Data Table 2**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Volume of Sample (mL)</th>
<th>Mass of Empty Beaker (g)</th>
<th>Mass of Beaker and Sample (g)</th>
<th>Mass of Sample (g)</th>
<th>Density (g/mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanol</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Water</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Olive oil</td>
<td></td>
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</tr>
</tbody>
</table>

**Analyze and Conclude**

1. **Calculating**  Use the formula for density to calculate the density of each of the solid samples. Record your answers in Data Table 1.

2. **Calculating**  Use the same formula as above to calculate the density of each of the liquid samples. Record the answers in Data Table 2.

3. **Applying Concepts**  Does the weight of an object or its density determine whether or not it will float in a fluid? Explain.

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66  Density and Buoyancy
4. Predicting Which of the solids will float in the olive oil? Explain.

Calculate the buoyant force on each of the objects in the olive oil. You have calculated the volume of fluid displaced by each of the objects and the density of the olive oil. Use the density equation to calculate the mass of olive oil displaced, from the density and volume that you have. To calculate the buoyant force, you need to calculate the weight of the displaced olive oil in each case.

Buoyant force on object = Weight of displaced fluid = Mass of displaced fluid × g

Record your results in Data Table 1. You can tell if each object will sink or float by comparing the weight of the object and the buoyant force. If the buoyant force is larger, the object has more force pushing up than the weight of the object pulling it down, so it will float. Compare the two forces to predict which objects will float.

5. Test your prediction by filling the cylinder with olive oil. Then move the dispenser head over the next cylinder by clicking it and dragging it until it clicks in place above the cylinder. Fill three cylinders with olive oil. Place each of the objects in one of the cylinders and release them all to see whether or not they will float.

6. Predicting What would you observe if olive oil and water were poured together?

Test your prediction by half filling one of the cylinders with olive oil by clicking the 1/2 button on the dispenser control before filling. That will allow you to add half a cylinder of oil, then toggle through the fluids and select water and dispense 1/2 of a fill of water to the same cylinder.

7. Drawing Conclusions If all three solids and all three liquids were mixed in the same cylinder at the same time, what would you observe? List the solids and liquids that you would see from the top of the cylinder to the bottom. Explain how you determined your placement.
Lab 21: Pressure and Volume of a Gas

Purpose
To discover how changing the pressure on a gas-filled balloon affects the volume of the balloon

Background
Robert Boyle, a philosopher and theologian, studied the properties of gases in the 17th century. He noticed that gases behave like springs. When compressed or expanded, gases tend to ‘spring’ back to their original volume. Boyle studied the relationship between the pressure and volume of a gas and summarized his results in what has become known as Boyle’s Law. You can make observations similar to those of Robert Boyle by changing the pressure of a gas and observing what happens to its volume.

Skills Focus
Graphing, drawing conclusions, interpreting data, predicting

Procedure
1. Start Virtual Physics and select Pressure and Volume of a Gas from the list of assignments. The lab will open in the Gases laboratory. Note that the balloon in the chamber is filled with a gas at a temperature of 25°C. The pressure of the gas is 100 kPa. The volume of the balloon is 7,436 cm³.

2. Predicting You are going to increase the pressure on the balloon. What do you think will happen to the volume of the balloon? Record your prediction.

3. Observe the beginning pressure and volume of the gas and record them in the table. Now, click on the 1 in the pressure window. The digit should turn green. Type 2 so that the pressure becomes 200 kPa. Record the new pressure and volume in the table. Repeat this step again but set the pressure to 300 kPa. Again, record your data. Continue to increase the pressure by 100 kPa each time and record your data until you reach 700 kPa.

<table>
<thead>
<tr>
<th>Pressure (kPa)</th>
<th>Volume (cm³)</th>
</tr>
</thead>
<tbody>
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</tbody>
</table>

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Analyze and Conclude

1. **Graphing**  Make a line graph of the data in the table. Show *Pressure* in kPa on the horizontal axis and *Volume* in cm$^3$ on the vertical axis.

2. **Drawing Conclusions**  Did your results support your prediction? Explain.

3. **Interpreting Data**  Is the relationship between pressure and volume linear or nonlinear?

4. **Predicting**  How would the volume of the gas be affected if the pressure were decreased?

Decrease the pressure on the balloon to check your prediction. Pull down on the lever on the pressure controller until the tens digit turns blue and hold it. This causes the pressure to decrease. Observe the balloon volume as the pressure decreases. What relationship do you observe?
Lab 22: Specific Heat of Metals

Purpose
To compare the specific heats of water and some common metals and draw conclusions about the application of the properties

Background
On a hot summer day, it is refreshing to jump into a pool because the water is cooler than the air around you and the ground that is roasting your feet. This may seem strange since the water and ground are being heated by the same source—the sun. This suggests that it takes more heat to raise the temperature of some substances than others, which is true. The amount of heat required to raise the temperature of 1 g of a substance by 1 degree Celsius is called the specific heat capacity, or specific heat, of that substance. Water, for instance, has a specific heat of 4.18 J/g°C. In this experiment, you will compare the specific heats of common metals and water to see how the specific heat of a substance affects how fast it changes temperature.

Skills Focus
Measuring, calculating, applying concepts, making judgments, predicting, designing experiments

Procedure
1. Start Virtual Physics and select Specific Heat of Metals from the list of assignments. The lab will open in the Calorimetry laboratory.

2. You will be measuring the heat capacity of aluminum (Al) and stainless steel, two common metals. Make sure to keep track of which sample you are testing by keeping accurate notes. Click on the Lab Book to open it. Record the mass in grams of the Al sample, which has already been placed on the balance. If it is too small to read, click on the Balance area to zoom in. Record the mass of Al in the data table on the next page. Then click on the Zoom out arrow to return to the laboratory.

3. Pick up the Al sample from the balance pan and place the sample in the oven. Click the oven door to close. The oven is set to heat to 200°C.

4. The calorimeter in the center of the table has been filled with 100 mL water. The density of water at 25°C is 0.998 g/mL. Use the density and volume of the water to determine its mass and record the volume and mass in the data table.

Make certain the stirrer is On (you should be able to see the shaft rotating). Click the thermometer window to bring it to the front and click Save to begin recording data. Allow 20–30 seconds to obtain a baseline temperature for the water.
5. Measuring  Click on the Oven to open it. Drag the hot aluminum sample from the oven until it snaps into place above the black lid of the calorimeter and then drop it in. Click the thermometer and graph windows to bring them to the front again and observe the change in temperature in the graph window until it reaches a constant value. Then wait an additional 20–30 seconds and click Stop in the thermometer window. (You can click on the clock on the wall labeled Accelerate to accelerate the time in the laboratory.) A blue data link will appear in the lab book. Click the blue data link and record in the data table the temperature before adding the Al and the highest temperature after adding the Al. (Remember that the water will begin to cool down after reaching the equilibrium temperature.)

6. Repeat the experiment with a steel sample. Click the red disposal bucket on the left of the screen to clear the lab. Click on the Stockroom to enter. Double-click the Dewar calorimeter to move it to the Stockroom counter. Click the metal sample cabinet. Open the bottom drawer (the samples are alphabetically arranged) by clicking on it. Select the steel sample by double-clicking on it and zoom out. Double-click on the Petri dish with the selected sample to move it to the Stockroom counter. Return to the laboratory.

7. Move the Petri dish with the sample to the spotlight next to the balance. Click on the Balance area to zoom and click on the Tare button to zero out the balance. Move the metal sample to the balance pan and record the mass in the data table. Return to the laboratory.

8. Double-click on the calorimeter to move it into position in the laboratory. Click the oven to open the door. Move the metal sample from the balance pan to the oven and click to close the oven door. Click above the tens place several times on the front of the oven to change the temperature to 200°C. Fill the 100 mL graduated cylinder with water by holding it under the tap until it returns to the counter and then pour it into the calorimeter. Turn on the stirrer. Turn on the thermometer. Click on the Graph and Save buttons. Move your metal sample from the oven to the calorimeter. Follow the procedures used with Al to obtain the equilibrium temperature. Record all of your observations in the data table below.

### Data Table

<table>
<thead>
<tr>
<th></th>
<th>Al</th>
<th>Stainless Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of metal (g)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume of water (mL)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass of water (g)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial temperature of water (°C)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial temperature of metal (°C)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max temp. of water + metal (°C)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specific Heat (J/g°C)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Analyze and Conclude

1. Calculating  Determine the changes in temperature of the water (ΔT\text{water}).

2. Calculate the heat (q) gained by the water using the following equation:
   \[ q_{\text{water}} = m_{\text{water}} \cdot \Delta T_{\text{water}} \cdot C_{\text{water}}, \text{ given } C_{\text{water}} = 4.184 \text{ J/(g}^\circ\text{C)}. \]

3. Determine the changes in temperature of the Al (ΔT\text{Al}).

4. Remembering that the heat gained by the water is equal to the heat lost by the metal (which is why the q is negative), calculate the specific heat of aluminum. \[ q_{\text{water}} = -q_{\text{metal}} = m_{\text{Al}} \cdot \Delta T_{\text{Al}} \cdot C_{\text{Al}} \] which when solved for the heat capacity is: \[ C_{\text{Al}} = \frac{q_{\text{metal}}}{(m_{\text{metal}})(\Delta T_{\text{metal}})}. \] Record your result in the data table.

5. Repeat the calculation of specific heat capacity for steel and record your result in the data table.

6. Applying Concepts  Heat capacity is a numerical way to express how much heat it takes to heat something up 1 degree. An object with low heat capacity requires very little heat to heat it up, while an object with high heat capacity takes a lot of heat to change its temperature. If you have a can made of steel and one made of aluminum, describe what will happen to the temperature of the can when you pull it out of the refrigerator. Include in your discussion connections to the specific heat of the metals.

7. Making Judgments  Many cooking pans are made out of steel and there are also some made of aluminum. Discuss which type of pan you think would be better.
8. You have just calculated that the specific heat of two common metals. You will now observe the heat content differences in another way.

**Predicting**  When the same amount of heat is applied to a given mass of water or that same total mass of water and steel together, which will heat up to a higher temperature? Explain why.

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9. **Designing Experiments**  Design and execute an experiment to test your hypothesis. Write a summary of your experiment and report your results. Also observe the cooling of pure water and water and steel together and report on the differences in how they cooled.

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Lab 23: Phase Changes

Purpose
To study the phase changes as water is heated from solid to liquid to water vapor

Background
Depending on the temperature, most substances can exist as either a solid or a liquid. A substance in its liquid state has more thermal energy than it has in its solid state. The temperature at which the transition from a solid to a liquid takes place is called the melting point of the substance.

The molecules that make up a gas have more thermal energy than do molecules of the same substance in the liquid state. The liquid’s molecules are in close contact with each other while gas particles are spaced significantly further apart. The transition from a liquid to a gas is known as vaporization and occurs by either evaporation or boiling. The normal boiling point is the temperature at which the substance boils at sea level. Melting and vaporization points are characteristic properties of a substance. Chemists often use these points to help identify or classify a substance.

Skills Focus
Graphing, interpreting data, applying concepts, drawing conclusions, relating cause and effect, making judgments

Procedure
1. Start Virtual Physics and select Phase Changes from the list of assignments. The lab will open in the Calorimetry laboratory.

2. The experiment will be set up with a coffee cup calorimeter filled with 65 mL of room temperature water on the lab bench. There is a beaker on the table next to the balance. Click on the balance area and then drag the beaker to the balance and click on the Tare button to zero out the balance. Drag the beaker back to the spotlight on the table and click Zoom Out. Click on the green ice bucket and drag the scoop down to fill it. Drag the scoop of ice over to the beaker until it snaps into place and then release the ice into the beaker. Click the Save button in the Thermometer window to begin saving the temperature data. Click on the balance to zoom down and drag the beaker to the balance. Record the mass of ice on the line below. You will observe the temperature change as the ice chills the water and then as the ice melts due to stirring and being out at room temperature.
3. *Zoom Out* again and carry the beaker over to the calorimeter to release the ice into the cup. Click the clock on the wall labeled *Accelerate* to accelerate the laboratory time. Click on the *Lab Book* to open it, and click the Plot window to bring it to the front.

4. Observe the temperature of the ice/water mixture graphed in the plot window as a function of time until the temperature starts to rise as the water heats up to room temperature, after about 4 minutes.

5. You will now heat up the water and observe the temperature change as the water turns into steam. Turn on the heater by clicking on the green light on the control panel labeled *Heat*. Observe the temperature of the water graphed in the Plot window as a function of time until steam begins to form above the coffee cup calorimeter. Record the temperature at which boiling begins in the data table. Continue to observe the graph until two more minutes have passed. (Use the graph to know when 2 minutes have passed.) Click *Stop* in the Thermometer window.

6. Click on the barometer to the left of the green *Exit* sign to display the pressure in the virtual laboratory. Record this pressure in the data table. The pressure is displayed on this meter only in torr. A torr is another unit of pressure commonly used by scientists. There are 760 torr in 101.3 kPa.

**Data Table**

<table>
<thead>
<tr>
<th>Temperature at Boiling</th>
<th>Pressure at Boiling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7. A blue link will appear in the lab book after you have stopped the thermometer. Click on the data link to display the temperature data.

**Analyze and Conclude**

1. **Graphing** In the graph grid on the following page, graph the temperature of the water as a function of time. Use the data from the data link. You do not need to plot every point—just plot enough points to show all of the critical sections of the graph. Label the axes and label where on the line the ice was added, the mixture is a combination of liquid water and solid ice, and the mixture is all liquid water. Also label where the heater was turned on and where the water is changing to a gas. Remember to scale the axes appropriately.
2. **Interpreting Graphs**  What phase or phases are in the calorimeter at 0°C?

3. **Applying Concepts**  What happens to the temperature while there is still ice in the water? Why?

4. **Drawing Conclusions**  What happens to the temperature after all of the ice has melted? Why?

5. **Applying Concepts**  What happens to the temperature of the water as the heater continues to heat after the water has come to a boil? Why?
6. Relating Cause and Effect  The average or typical air pressure at sea level is 760 torr. This pressure may vary by about ±15 torr depending on the weather. In stormy weather, the pressure drops lower. Good weather brings higher pressure. The normal boiling point of water at sea level pressure is 100°C. From your observation of the boiling point and air pressure what can you conclude?

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Lab 24: Light Investigation

Problem
To study the properties of light when intercepting transparent and opaque objects and to examine reflections of images off plane mirrors from different angles.

Background
We are able to see things because visible light from the sun or some artificial light source reflects off objects and reaches the receptors in our eyes. Even if we close our eyes, or go blind, the light is still there, bouncing around, carrying information and energy. The light will continue to do so until it is absorbed by something or the source of the light is extinguished.

Skills Focus
Predicting, observing, drawing conclusions, designing experiments

Procedure
1. Start Virtual Physics and select Light Investigation from the list of assignments. The lab will open in the Optics laboratory.

2. The laboratory will be set up with a garden gnome on an optics table with a detector, or virtual eye, in front of it. The white line on the table shows the direction of the light leaving the object and bouncing into the eye. You will place a flat mirror in the path and observe what the eye detects.

3. Predicting What do you think you will see in the virtual eye window if a mirror is placed between it and the object?

4. Click on a mirror and pull it down into the row of pegs that the objects are on. The mirror is not ever visible to the eye, to help you keep track of the image of the object. Look in the virtual eye window. Were you correct in your prediction? What is visible to the eye?

5. Observing The eye cannot see the gnome, because there is an opaque object in the way, blocking the view. What will happen if you place a transparent object between the eye and the object? The object will be visible because light can travel through transparent objects. Pull the mirror off the table in any direction to return it to the counter. Pick up a lens and place it between the detector and the object. Now what does the eye detect?
6. Lenses are transparent, but because of their curvatures, they can be used to modify an image in many ways. Right click on the lens to access the control panel for the lens and click the Flat box for both \(L_1\) and \(L_2\). This makes both sides of the lens perfectly flat, like an ideal piece of transparent glass. Now what do you observe in the detector window?

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7. Remove the lens and replace it with a flat mirror again. Rotate the angle of the mirror by moving your cursor over the mirror until a rotation control appears. Then drag the mouse in the direction you want to rotate, or click the arrow controls. Rotate the mirror so you can see the light reflected off the mirror bouncing to the left side of the table. Now rotate the direction the eye is facing to 0 degrees and pull it down to the side of the gnome (i.e., the same column of pegs as the gnome), so it is in the path of the reflected light. What do you see in the detector window?

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8. Rotate the eye to 90 degrees and report what the eye sees as it is facing in that direction. Why does the image change?

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9. **Drawing Conclusions** Pull the eye to the left side of the table and down until you have both image lines intercepting the eye. Rotate the eye to 45 degrees, or until you can see 2 images in the eye at once. Explain what is happening.

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10. **Designing Experiments** Can you adjust things so both the front and the back of the gnome are visible at once? Report on your findings as you set up this experiment.

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Lab 25: Color in Light

Purpose
To observe light color addition and subtraction through filters, receptors in the eye, different types of color blindness, and prisms

Background
Throughout the ages, philosophers and scientists speculated about the substances that made up everything in the universe. Color was one of the properties that was not fully understood, as evidenced by the early belief that there were different colored atoms: blue atoms and green atoms and atoms of every color made up the colors of objects that we can see.

Isaac Newton was the first person on record to study light and its connection with the colors that we observe. He used prisms to break white light into its component wavelengths. Then, by recombining these component wavelengths, Newton came to understand that all of the colors together made up white light. Our understanding today of how different eyes detect color differently is largely due to early explorations with filters and prisms in ingenious optical setups.

Skills Focus
Observing, predicting, applying concepts, controlling variables, drawing conclusions

Procedure
1. Start Virtual Physics and select Color in Light from the list of assignments. The lab will open in the Optics laboratory.

2. The laboratory will be set up with a garden gnome on an optics table with a detector, or virtual eye, in front of it. The white line on the table shows the direction of the light leaving the object and bouncing into the eye. Observe the image in the Virtual Eye display.

3. Predicting What do you think you will see in the detector window if a red filter is placed between it and the object?

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4. **Observing** Filters block all light except the light that is the color of the filter itself. Pick up the filters from the counter and place them in the light path. The gray rectangular part of the piece is the part that needs to be in the light path. The filters flip up into that structure when engaged. Right click on the filters and click the red filter check box. Were you correct in your prediction? What is visible to the eye? Flip the filter in and out and compare the different parts of the gnome to see what happens to the different colors when viewed through the filter. Why do you think some parts of the gnome look black, while other parts, like the pillar, look red?

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5. **Predicting** What colors do you think you will see if a blue filter is also placed in the light path, in addition to the red filter?
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6. If all light but the blue light has been filtered out, and then a red filter is also applied, what color do you think you would see? Right click on the filters and click the red and blue filter check boxes to test your prediction. What do you observe?
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7. **Applying Concepts** Now pull the filter off the table in any direction to return it to the counter. In the Virtual Eye detector screen you can see checked boxes labeled with the primary colors of red, green and blue. These control the color receptors in the eye. Unchecking any of the boxes turns off the receptors that can detect the chosen colors. Experiment with turning on and off various colors and report your findings about color subtraction.
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8. Colorblindness occurs when certain color receptors in the eye don’t work as they should. Experiment with the two main types of colorblindness: red-green and blue-yellow, and report how the colorblindness affects the observed colors of the gnome. Select a colorblindness type by checking each of the types in the Virtual Eye detector screen.

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9. **Controlling Variables** Click on the Clipboard on the right hand side of the table to bring up a list of preset experiments. Select *Experiment 12: Color Addition and Subtraction*. The table is now set up with white light shining through four triangle-shaped prisms to diffuse the colors of the rainbow and a slit control in the center of the table to block out portions of the rainbow before the light is recombined through more prisms. Drag the second prism farther down on the mounted base to spread out the beam of light more. In the Virtual Eye, uncheck the Grid box to be able to see the light beam better. Move the windows, so you can see the display in the Virtual Eye, and the laboratory view at the same time. Change the amount of light passing through the slits by clicking the up and down green arrows on the shutter device. What color do you see when you add just red through yellow?

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What color results when you combine yellow through blue?
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What colors do you need to add to produce a light purple?
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10. **Drawing Conclusions** You have been experimenting with color addition and subtraction and the additive primary colors. Explain what happens when you add all of the colors together. Where do you see color addition of light occurring in your daily experience?

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82  Color in Light
Lab 26: Reflection and Refraction of Light

Purpose
To compare the reflection of light from flat and curved mirrors and to study the refraction of light through a lens

Background
What is the difference between a mirror and a lens? Light bounces, or reflects, off a mirror but passes through a lens. Mirrors and lenses have many different uses due to these properties. Mirrors are often used to allow people to see their reflections or to see things in places or at angles that you couldn’t see otherwise. Lenses are used commonly to magnify images, correct vision, or to focus light into a beam. These properties have been used for centuries as people discovered reflective surfaces and developed the first cameras and spectacles.

Skills Focus
Predicting, observing, applying concepts, controlling variables, drawing conclusions

Procedure
1. Start Virtual Physics and select Reflection and Refraction of Light from the list of assignments. The lab will open in the Optics laboratory.

2. The laboratory will be set up with a light bulb on an optics table with a flat mirror in front of it. An eye will be set up on the table to be used as a detector, to observe how light is reflected from the mirror. You will observe reflected light from various angles to determine how images are reflected in a flat mirror. You will then compare those to the reflections from curved mirrors. You will also study how light refracts through lenses.

3. Predicting What do you think you will see in the detector window if it is facing the direction of the reflected light?

4. Observing What do you notice about the relationship between (1) the angle of the light coming in to the mirror relative to the normal, which is a line perpendicular to the mirror’s surface, and (2) the angle of the light reflecting off the mirror? Hold up a piece of paper on the screen and position it as the normal would be to help you compare the angles.
5. Change the angle of the light striking the mirror by rotating the mirror. You can do this by moving the cursor over the mirror until a rotation control appears and increasing the angle by dragging the cursor in the direction you want the mirror rotated, or by clicking on the arrows. Now compare the angle of the incident light (the light striking the mirror) with the angle of the reflected light. How have the angles changed?

6. **Applying Concepts** The law of reflection explains the phenomenon that you just observed—that the angle of incidence always equals the angle of reflection. Do you think this will change if the mirror is a curved mirror? Predict how the angle of reflection will compare with the angle of incidence if the mirror is curved.

7. Test your prediction by right clicking on the mirror and unchecking the Flat box and changing the radius of curvature (r) to 60 cm. This is a concave mirror, which is what is used in a flashlight to focus light into a narrow beam of light. Record your observations of the angle of reflection and the beam diameter below.

8. Now change the mirror into a convex mirror by altering the radius of curvature to -50 cm. Note your observations of the angle of reflection and the beam diameter below.

9. **Observing** Now you will observe refraction with a lens. Pick up the detector and drag it off the table to return it to the counter. Change the mirror back into a flat mirror by clicking the Flat box. Pick up another mirror and place it on the table in the beam path reflected off the first mirror. Rotate the second mirror to an angle of around 0 degrees, where it reflects the light down at an angle onto the table, just not facing directly along a line of pins. Pull out a lens and place it in the beam path. What do you observe about the incident angle of the light on the lens and the angle of the transmitted light on the other side of the lens?
10. Light is refracted, or bent, as it travels through lenses of different materials. What is the index of refraction of the lens? The index is found in the lens variable panel by right clicking on the lens and noting the value of n. The index of refraction of air is approximately 1.

11. Change the index of refraction to 1 and report how the transmitted angle changes from the previous deflection.

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12. Controlling Variables Increase the index of refraction gradually from 1 to 10 and report on how the deflection angle changes.

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13. Drawing Conclusions Click the Reset Lab button in upper left corner to clear the table. Pull down the prism platform and release and it will snap into place on the table. Bring down the light bulb also and release it on the left side of the table. Click on the bottom prism on the stand and pull it down to the bottom of the base. Observe the way the beam of light bends as it passes through the first prism and then on to the second prism. Describe what you observe from what you understand about refraction. Mention how the light bends with respect to the normal for each face of the prism.

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Lab 27: Lenses

Problem
To make predictions about and study the formation of images with ray diagrams and lenses. Also to study the two common types of eyeglasses

Background
Did you know that the film for the movies in theaters is placed in the projector upside down? Projectors have convex lenses inside which flip the image on the film and magnify it so it can be projected up on a screen a long distance away. That is a type of image that you can see without even looking through the lens. However, there are many images that you can only see by looking through a lens. To see magnified objects with a microscope or magnifying glass, you must look through the lens and carefully adjust the distance of the lens from the object to see the image clearly with your eye. The distance of an object from a lens and from the lens to the image are variables that can be controlled for many different applications, from eyeglasses to cameras to light houses.

Skills Focus
Graphing, observing, applying concepts

Procedure
1. Start Virtual Physics and select Lenses from the list of assignments. The lab will open in the Optics laboratory.

2. The laboratory will be set up with a candle on an optics table with a convex lens in front of it. An eye will be on the other side of the lens so it can look at the image produced by the candle through the lens. You will observe the image of the candle from various distances to determine how images are changed in a convex lens.

3. Graphing Lenses produce very different images of an object depending on where the object is with respect to the lens. Ray diagrams are often used to construct the image that would be viewed through a lens. The following is a set of ray diagrams for a convex lens. Draw the necessary rays to determine where the image will be in each of the cases.
4. Observing. Now you will confirm your predictions with the given lens. The focal point of this lens is 20.32 cm, or 8 in. Each of the pin locations, or holes, on the table is 2 inches apart. You will be placing the object at different distances from the lens, and then using the eye as a detector on the far side of the lens to find the location of the image produced by the lens. There is only one point at which an image is truly in focus. Turn off the autofocus feature in the detector screen by unchecking the Auto Focus box. Uncheck the grid box also to allow yourself to see the image better. Move the detector eye until the image is in focus. Record in the table below the distance from the lens to the image. Also record the Height Factor displayed in the bottom of the detector screen. This is the magnifying factor of the image from the original size of the object. Repeat the experiment for each of the different cases that you drew with the ray diagrams.

### Data Table 1

<table>
<thead>
<tr>
<th>Distance of object from lens (cm)</th>
<th>Distance of image from lens (cm)</th>
<th>Inverted? (yes/no)</th>
<th>Image bigger or smaller than object?</th>
<th>Height Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

5. Did the data you collected and the images you observed match your predictions from the ray diagrams? Explain.

6. You have been using a symmetrical lens that has the same curvature on each side, which creates more predictable images, as you have observed. Now you will test two types of lenses that are used in glasses and are more complicated. Click on the Clipboard on the right side of the table to bring up a list of preset experiments. Select Experiment 15: Farsighted Eyeglasses: Converging Lens. The table is set up with a candle, lens and detector as before, but the lens is different because it is the type of lens that is used in glasses for farsighted people, and in reading glasses. Right click on the lens to pop up the control panel. The values for r1 and r2 reported are measures of the curvature of the lens. r1 is the first side of the lens that the light from the candle strikes. A small radius of curvature means that the lens is more curved, or that it would be part of a circle of smaller radius. Which side of the lens is more curved? Draw a picture of what the lens would look like with the different radii of curvature. Which part of the lens is thicker—the middle or the edges?
7. The type of lens used in Step 6 is called a converging lens, because it helps light to converge down to a point. Glasses for farsighted people are used for looking at things that are close, to help the light to focus on the retina farther forward than it would normally. This is necessary because the eye in this case is misshapen enough to cause the light to focus too far behind the retina. If you turn off auto-focus and move the detector around, you can see precisely how the lens is made to focus the light at one specific distance into the eye for a focused image.

8. Repeat Step 6 with Experiment 14: Nearsighted Eyeglasses: Diverging Lens. Which side of the lens is more curved in this setup? Sketch the lens and describe which part of the lens is thicker.

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9. Applying Concepts  The type of lens used in Step 6 is called a diverging lens. Explain what this type of lens would do for a nearsighted person.

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Lab 28: Diffraction and Interference

Purpose
To study single slit diffraction and double slit interference patterns

Background
It has long been known that if you shine light through narrow slits that are spaced at small intervals, the light will form a diffraction pattern. A diffraction pattern is a series of light and dark areas caused by wave interference. The wave interference can be either constructive (light areas) or destructive (dark areas). In this experiment, you will shine a laser through a device with two slits where the spacing can be adjusted and investigate the patterns that are produced on the far side of the slits.

Skills Focus
Predicting, drawing conclusions, observing, interpreting data, making generalizations, applying concepts

Procedure
1. Start Virtual Physics and select Diffraction and Interference from the list of assignments. The lab will open in the Quantum laboratory.

2. A laser is used as the light source in this experiment because it has a single wavelength. Therefore, you will not see diffraction patterns from other wavelengths interfering in the image. What is the wavelength of the laser?

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What is the spacing of the two slits on the two slit device? This is the gap between the two different slits. How do the wavelength of the laser and the spacing of the slits compare?

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3. Predicting How will the diffraction pattern change as the wavelength is made smaller and the slit spacing remains the same? Hint: Think about the spacing as an obstacle that the waves are running into.

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4. **Drawing Conclusions** Observe the pattern displayed on the video screen as you reduce the wavelength to 600 nm and then down to 300 nm by one-hundred nanometer increments. Click on the down arrow below the hundreds place to change these values. What can you state about the relationship between wavelength and diffraction pattern when the wavelength is greater than the obstacle?

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5. **Observing** Now you will investigate other interference effects. Once you spread out the slits farther, you can start to see interference when waves passing through the two different slits interfere with each other. Change the wavelength of the laser to 500 nm and the slit spacing to 3 µm. Describe what you observe. What is causing this effect?

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6. Change the intensity of the laser from 1 nW to 1 W. Does the intensity of the light affect the diffraction pattern?

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7. **Interpreting Data** Change the slit spacing to 1 µm. Then observe the pattern displayed on the video screen as you change the slit spacing from 1 µm to 7 µm by one-micrometer increments. What can you state about the relationship between slit spacing and diffraction pattern?

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8. Return the slit spacing to 3 µm. Increase the wavelength of the laser to 700 nm. What affect does an increase in the wavelength have on the interference pattern?

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9. **Making Generalizations** Decrease the intensity on the laser to 1000 photons/second. Click on the *Persist* button (the button with a black arrow) on the video camera to look at individual photons coming through the slits. Observe for one minute. What observation can you make about this pattern as compared to the pattern from the continuous beam of photons?

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10. Decrease the intensity to 100 photons/second. Observe for another minute after clicking Persist. At these lower intensities (1,000 and 100 photons/second), there is never a time when two photons go through both slits at the same time. How can a single photon diffract?

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11. From this experiment, what conclusions can you make about the nature of light?

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12. **Applying Concepts** Click in the *Stockroom*. Click on the Clipboard and select *Preset Experiment 8: Two-Slit Diffraction—Electrons*. Click the green *Return to Lab* arrow. This setup is similar to the previous one, except that the source is emitting electrons, rather than photons of light, so the detector is a phosphor screen which can detect charged particles. How does this diffraction pattern compare to the diffraction pattern for light?

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Lab 29: The Effect of an Electric Field on Moving Charges

Problem
To investigate the effect of a static electric field on various moving charges

Background
As scientists first began investigating the properties of atoms, they discovered that they could extract negatively charged particles. They called these particles electrons. In order to understand the nature of these particles, scientists wanted to know how much charge they carried and how much they weighed. J.J. Thomson was a physics professor at the famous Cavendish Laboratory at Cambridge University. In 1897, Thomson showed that if you could measure how far a beam of electrons was bent in an electric field and in a magnetic field, you could determine the charge-to-mass ratio \( \frac{q}{m} \) for the electrons. Knowing this ratio, the individual charge and mass of an electron could be calculated.

Another particle ejected during nuclear decay is the alpha particle. An alpha particle is a helium nucleus, that is, a helium atom without its two electrons. As you will see, a beam of alpha particles can also be deflected by an electric field.

Skills Focus
Predicting, observing, drawing conclusions

Procedure
1. Start Virtual Physics and select Effect of an Electric Field on Moving Charges from the list of assignments. The lab will open in the Quantum laboratory.

2. The experiment will be set up on the table. There is an electron gun on the left side of the as the source. What type of charge do electrons have? ______________

3. There is a phosphor screen on the right side of the table to detect the charged particles. Turn on the phosphor screen by clicking on the green/red button. What do you observe and what do you think that it shows?
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4. Drag the lab window down and left and the phosphor screen window up and right in order to minimize the overlap. Push the Grid button on the phosphor screen. Click once above the ones place on the Electric Field modifier meter near the center of the table. Observe the spot. Click a few more times above the ones place on the Electric Field, until the field is at 5V. (If you mistakenly click between digits, it will move the decimal point. To move the decimal point back again, click where it was originally.) What happens to the spot from the electron gun on the phosphor screen?

5. Predicting What do you think would happen to the spot if you increased the voltage of the electrons leaving the electron gun? Why?

6. Observing Increase the voltage of the source by clicking above the hundreds place on the electron gun voltage controller (the second meter from the left). You are not changing the number of electrons leaving the gun, just giving each of them greater electrical potential energy. What happens to the spot on the phosphor screen? Why does this happen?

7. Predicting What do you think would happen to the spot now if you increased the voltage on the Electric Field modifier that the electron beam is passing through? Why?

8. Test your prediction, then zero out the Electric Field meter by clicking on the appropriate digit buttons until the spot on the phosphor screen is once again centered.

9. Double-click or click and drag the electron gun to move it to the Stockroom counter. Enter the Stockroom by clicking inside it. Double-click the electron gun to move it back to the shelf. Double-click on the alpha source to select it and move it to the Stockroom counter. Click on the green Return to Lab arrow to return to the lab. Drag the alpha source from the Stockroom counter and place it on the table where the electron gun was originally placed (the middle spotlight). Click on the front of the alpha source to open the shutter. What appears on the phosphor screen? What charge do alpha particles have?
10. Change the unit for the *Electric Field* from V (volts) to kV (kilovolts) by clicking once above the unit. This electric field is one thousand times stronger than what you used previously for the electron gun. Observe the spot as you increase the *Electric Field* strength from 0 kV to 5 kV. The movement is slight so pay careful attention. Which direction did the spot move when you increased the electric field?

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How does this direction of movement compare with the direction of movement for the electron beam in the electric field?

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11. **Drawing Conclusions** Why do you think that it takes a significantly stronger electric field strength to move the beam of alpha particles compared to the beam of electrons?

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Lab 30: Capacitors

Purpose
To understand electrical energy storage by observing how capacitors charge and discharge

Background
Many modern machines rely on electronic signals to work properly. For example, consider the windshield wipers of a car. They store energy in a capacitor and then release that energy through the mechanical swing of the wiper. Or, think about the computer in front of you—it has capacitors that store charge to filter electronic signals inside the computer. Capacitors take time to charge and discharge, so they don’t instantly gain or lose all of their charge. In this lab, you will examine different capacitors and the maximum voltages they operate under.

Skills Focus
Predicting, observing, relating cause and effect, applying concepts, problem solving

Procedure
1. Start Virtual Physics and select Capacitors from the list of assignments. The lab will open in the Circuits laboratory.

2. The laboratory will be set up with a resistor (initially 10,000 Ω) and a capacitor connected on a breadboard. A function generator is also connected to the breadboard. The function generator will be set to 10 V DC and will initially be turned off.

   NOTE: Because capacitors charge fairly quickly, we use the resistor to impede, or block, the current. This will allow you to see the charging and discharging of the capacitor.

3. The oscilloscope will be connected across the capacitor. You will need to click on the oscilloscope in the upper left corner to turn it on. A multimeter, which will display the voltage across the capacitor, is also connected.

4. Turn on the function generator at the top center of the screen using the Power button at the top. Observe what happens to the voltage across the capacitor and record your observations in the data table on the next page. You may want to use the Acceleration button on the oscilloscope to increase the speed of the charging process, but remember to change the setting back to 1 when you are done charging it. This may take a few minutes. Read the next steps of the lab as the capacitor is charging. You may also want to change the resistor on the breadboard to smaller or larger values (1,000 Ω or 100,000 Ω) and observe what happens. You can change component values on the breadboard by right clicking on the value above the component.
Predicting  What will happen to the time it takes to charge the capacitor and its maximum voltage if you increase the capacitance of the capacitor?  
Note: capacitance is related to the amount of voltage potential in a capacitor.

5. Once the capacitor is fully charged, clear the breadboard by clicking on the Reset Lab button at the bottom of the table, click on the clipboard on the right, and click on Preset Experiment 7: Discharging Capacitor. You should see the same experiment except this time the capacitor is discharging. Record in the table your observations of how the voltage changes over time for the discharging capacitor.

6. Repeat step 5 except this time when the preset experiment starts, change the resistor to 1,000Ω.

Data Table

<table>
<thead>
<tr>
<th>Capacitor</th>
<th>Resistor</th>
<th>State</th>
<th>Observations about voltage</th>
<th>Maximum Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 F</td>
<td>10,000 Ω</td>
<td>Charging</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 F</td>
<td>100 Ω</td>
<td>Discharging</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 F</td>
<td>1,000 Ω</td>
<td>Discharging</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Analyze and Conclude

1. Observing  What happened to the voltage across the capacitor when the function generator was turned on?

2. Relating Cause and Effect  How did the time for the capacitor to discharge change when you changed the resistance of the resistor?
3. **Applying Concepts**  Using the information gathered, explain why keyboards would use capacitors for each key button. *Hint:* Think about how you got the capacitor to charge and discharge.

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4. **Problem Solving**  Why must you be careful when taking apart your video game system or television?

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Lab 31: Electric Current

Purpose
To observe how electric current changes when passing through resistors

Background
Think about when you click on a light, turn on a computer, or start a car. Electricity must flow through each of these devices in order for them to work. The flow of electricity in a wire is called electric current. You can measure the amount of electric current passing through a wire using a multimeter. The standard unit for measuring current is amperes, or amps. The SI symbol of the ampere is the letter A.

Skills Focus
Predicting, interpreting data, calculating, making judgments, comparing and contrasting, applying concepts

Procedure
1. Start Virtual Physics and select Electric Current from the list of assignments. The lab will open in the Circuits laboratory.
2. The laboratory will be set up on the breadboard with three simple circuits made of resistors. You will need to connect the function generator to the circuit you will be examining. Using the oscilloscope and the multimeter, you will measure the electric current at different locations on the basic circuits and then you will measure it at different locations on a more complex circuit.
3. The function generator at the top center of the screen is already connected to the single resistor circuit and is set to 12 V DC. The yellow wire is connected to the positive side of the generator and the green wire is connected to the negative side. Use these wires when its time to connect the other circuits.

Predicting How do you think the current going out of the resistor will compare to the current entering the resistor?

Single Resistor
4. Turn on the function generator using the Power button at the top. The multimeter is set to record the current flowing through the circuit in amperes (A). It is already attached to pin 23C on the positive side of the resistor. The current flows through the multimeter and then into the circuit. Record the current in Data Table 1 on the next page.
5. Move the leads to the other side of the resistor by dragging the red multimeter lead to pin 20C. Record the current in Data Table 1. Current flows from negative to positive, so Current IN refers to the current at the negative side of the resistor and Current OUT refers to the other side of the resistor. The negative side of the resistor leads back to the black or negative lead of the function generator. The positive side leads back to the positive lead of the function generator.

**Data Table 1**

<table>
<thead>
<tr>
<th>Resistor</th>
<th>Current IN (A)</th>
<th>Current OUT (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Predicting**

What will happen to the current if more resistors are put in the circuit?

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**Series Resistors**

6. Move the yellow wire (pin 23A) from the single resistor to the set of three connected resistors at the bottom of the breadboard. Place the yellow wire on pin 19F. It should be connected to the positive side of the function generator and the first resistor in the series. Move the green wire (18A) to the last resistor in series, which is pin 4F. It should also still be connected to the negative side of the function generator. (Note that you may have to move the multimeter probes to reach the wires.)

**Predicting**

How do you think this new circuit arrangement will affect the current?

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7. Now measure the current going into and out of each resistor like before. Record all your data in Data Table 2 below.

**Data Table 2**

<table>
<thead>
<tr>
<th>Resistor</th>
<th>Current IN (A)</th>
<th>Current OUT (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Parallel Resistors

8. Now move the yellow wire to pin 11A to the positive part of the function generator. Then move the green wire to pin 2A.

9. Record the current into and out of each resistor in Data Table 3 below.

Data Table 3

<table>
<thead>
<tr>
<th>Resistor</th>
<th>Current IN (A)</th>
<th>Current OUT (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
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<td>3</td>
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<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Analyze and Conclude

1. Interpreting Data Is current lost in a resistor? Use the data to support your conclusion.

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2. Calculating What is the sum of the currents coming out of the parallel circuit? How does this compare to the current entering the parallel circuit?

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3. Making Judgments Compare your predictions to what actually happened.

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4. Comparing and Contrasting How did the current in the parallel circuit compare with that in the series circuit?

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5. How did the current change in the three series resistor circuit compared to the single resistor circuit?

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6. **Applying Concepts** Think of an analogy that could model your understanding of current.

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Lab 32: Series and Parallel Circuits

Purpose
To build series and parallel circuits and study the differences between them

Background
Electricians are called upon whenever new buildings need electrical work. The electrician surveys the site and determines what kind of currents and voltages are required to satisfy the client’s needs. Sometimes the circuit requires components to be connected like you would in plumbing so the water could flow. This is called a series circuit. Sometimes the components need to be connected in parallel, like the rungs on a ladder. Each type of circuit has its advantages. In this lab, you will study the advantages of and the differences between series and parallel circuits.

Skills Focus
Classifying, inferring, comparing and contrasting, drawing conclusions

Procedure
1. Start Virtual Physics and select Series and Parallel Circuits from the list of assignments. The lab will open in the Circuits laboratory.

2. The laboratory will be set up with a function generator set to 12 V DC already on the engineering paper, which is the schematic or plan of the circuit built on the breadboard. In this assignment, you will have to add resistors to create a circuit. To add resistors, simply click on the resistor symbol at the top of the engineering paper and drag it onto the paper. You may move resistors around by clicking them on the middle blue dot. You can also extend their leads by clicking on the end red dots and dragging them to where you want to connect them to other components. The line will be green if it is in an allowable location. You will notice that the breadboard will automatically populate with the resistors that you add to the schematic.

3. You need to build a circuit that has only one path for the current to follow. This is called a series circuit. Use only resistors to make this circuit. On the engineering paper, place five resistors in series using the resistor symbol at the top. First start by connecting the first resistor to an open end of the function generator. Then drag out a new resistor and place it next to the open end of the last placed resistor. Follow the same process until you have five resistors in series. Complete the circuit by connecting the last resistor you added to the other side of the voltage source.

4. Make sure that there is only one path for the current to flow through the resistors you connected in Step 3. After you have placed the resistors on the circuit, you will need to change the resistance of each of the resistors as specified in Step 5. You can do this by clicking on the number next to the resistor. A small box will pop up where you can adjust the value of the resistor.
5. Change the value of each resistor to the match the values found in Data Table 1. Assume that resistor 1 is the one connected to the positive side of the voltage source and resistor 5 is the one connected to the negative side of the voltage source.

**Data Table 1**

<table>
<thead>
<tr>
<th>Resistor Number</th>
<th>Resistor Value (Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>120</td>
</tr>
<tr>
<td>2</td>
<td>500</td>
</tr>
<tr>
<td>3</td>
<td>200</td>
</tr>
<tr>
<td>4</td>
<td>135</td>
</tr>
<tr>
<td>5</td>
<td>10,000</td>
</tr>
</tbody>
</table>

6. Using the multimeter to measure the current and the voltages across each resistor. The symbol for the multimeter has a DMM in the middle of it. Click and drag the red lead to one side of the resistor. It should lock into place. Then click and drag the black lead to the other side of that same resistor to measure the drop in voltage across the resistor. You can read the voltage and current from the yellow multimeter display. To measure the current passing through the resistor, change the multimeter from VDC to IDC, which changes the variable being measured from voltage to current. Record your measurements in Data Table 2.

NOTE: For the ammeter to measure current, it should be placed with both leads on one side of the resistor. This is because the current must flow through the ammeter to measure it. However, the voltmeter needs to compare voltages at two points, so it should be hooked up across the resistor.

**Data Table 2**

<table>
<thead>
<tr>
<th>Resistor Number</th>
<th>Voltage (V)</th>
<th>Current (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7. Now, using the same resistors as before, you will build a parallel circuit. This is done by creating multiple paths for the current to follow. To do this, first move all the resistors to the bottom half of the paper, but don’t delete them.
8. First add a new resistor in series to the beginning of the function generator. Change its resistance to equal 1 Ω.

9. Drag and set the other five resistors back onto the lines so that the circuit looks like a ladder with the resistors as the steps. Your final schematic should look like the picture on the right.

10. Using the same technique as Step 6, measure the voltage and current across each of the five resistors listed in Data Table 1. Remember that it is a DC source, so you must use the DC Voltmeter and DC Ammeter. Record your results in Data Table 3 below.

Data Table 3

<table>
<thead>
<tr>
<th>Resistor Number</th>
<th>Voltage (V)</th>
<th>Current (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Analyze and Conclude

1. **Classifying**  What are the variables in this experiment?

2. **Inferring**  Which variables stay the same, and which change in the series circuit?

3. Which variables stay the same, and which change in the parallel circuit?

4. **Comparing and Contrasting**  How do parallel and series circuits differ?
5. **Drawing Conclusions**  In what way does a series circuit look like it would have the same current throughout?

__________________________________________________________________
__________________________________________________________________
__________________________________________________________________

6. In what way would your answer to question 4 above be important for an electrician to know?

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__________________________________________________________________
__________________________________________________________________

**Going Further**

7. Now go back to the circuits and replace the resistors with light bulbs. The symbol for a light bulb is a white circle with an X in the middle. Place them on the engineering paper. Create a series circuit and a parallel circuit like the ones you made earlier. Then try removing one of the light bulbs. Record below what happens in each case. Also, record the relative brightnesses of the bulbs in each circuit.

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Lab 33: The Effect of a Magnetic Field on Moving Charges

Problem
To investigate the effect of a magnetic field on moving charges

Background
Charged particles at rest are not affected by static magnetic fields. However, when such charged particles are in motion, they are deflected by magnetic fields. The discovery that flowing electrons are affected by magnets was a pivotal discovery at the turn of the 20th century. Today, many common technological applications, from electric motors to television screens, make use of this interaction.

In cathode ray television tubes, for example, magnets are used to move a stream of electrons. As the electrons hit the screen, the screen glows momentarily where it was hit. Similarly, Earth’s magnetic field deflects charged particles from the sun. In this lab, you will study the effect of a magnetic field on different types of charged particles.

Skills Focus
Predicting, observing, developing hypotheses, drawing conclusions, applying concepts

Procedure
1. Start Virtual Physics and select Effect of a Magnetic Field on Moving Charges from the list of assignments. The lab will open in the Quantum laboratory.

2. The experiment will be set up on the table. An electron gun on the left side of the table serves as the source of electrons. What type of charge do electrons have?

3. There is a phosphor screen on the right side of the table to detect charged particles. Turn on the phosphor screen by clicking on the green/red button. What do you observe? What do you think that it shows?
4. Drag the lab window down and to the left and the phosphor screen window up and to the right in order to minimize the overlap between the two. Then push the Grid button on the phosphor screen. Set the Magnetic Field to 30 µT (microtesla) on the magnetic meter near the phosphor screen by clicking the button above the tens place three times. (If you mistakenly click between the digits, it will move the decimal point. To move the decimal point back again, click where it was originally.) What happens to the spot from the electron gun on the phosphor screen?
__________________________________________________________________
__________________________________________________________________

5. Predicting What do you think would happen to the spot if you increased the voltage of the electrons leaving the electron gun? Why?
__________________________________________________________________
__________________________________________________________________
__________________________________________________________________

6. Observing Increase the voltage of the source by clicking above the hundreds place on the electron gun voltage controller (the second meter from the left). This does not change the number of electrons leaving the gun. Rather, it just gives each electron more electrical potential energy. What happens to the spot on the phosphor screen when the voltage is increased? Why does this happen?
__________________________________________________________________
__________________________________________________________________

7. Predicting What do you think would happen to the spot now if you increased the strength of the magnetic field that the electron beam is passing through? Why?
__________________________________________________________________

8. Test your prediction, then zero out the Magnetic Field meter by clicking on the appropriate digit buttons until the spot on the phosphor screen is centered once again.

9. Double-click or click and drag the electron gun to move it to the Stockroom counter. Enter the Stockroom by clicking inside it. Double-click the electron gun to move it back to the shelf. Double-click on the alpha source to select it and move it to the Stockroom counter. Click on the green Return to Lab arrow to return to the lab. Drag the alpha source from the Stockroom counter and place it on the table where the electron gun was originally placed (the middle spotlight). Click on the front of the alpha source to open the shutter. What appears on the phosphor screen? What charge do alpha particles have?
__________________________________________________________________
10. Change the unit for the Magnetic Field from μT to mT (millitesla) by clicking once above the unit. Click above the hundreds place three times to set the Magnetic Field to 300 mT. This magnetic field is 10,000 times stronger than the one you used for the electron gun. Which direction did the spot move when you increased the magnetic field?

__________________________________________________________________

How does this direction of movement compare with the direction of movement for the electron beam in the magnetic field?

__________________________________________________________________

11. Developing Hypotheses  A charged particle at rest wouldn’t be affected by a magnetic field at all, so why are moving charged particles affected?

__________________________________________________________________

__________________________________________________________________

__________________________________________________________________

12. Drawing Conclusions  Why do you think it takes a significantly stronger magnetic field strength to move the beam of alpha particles compared with the beam of electrons?

__________________________________________________________________

13. Applying Concepts  What technologies or applications of the connection between electricity and magnetism can you think of? Describe the physical processes.

__________________________________________________________________

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Lab 34: The Photoelectric Effect

Purpose
To study the photoelectric effect and understand the connection between the wavelength and energy of incident light and the photoelectrons emitted.

Background
Although Albert Einstein is most famous for the equation $E = mc^2$ and his work describing relativity in mechanics, his Nobel Prize was awarded primarily for understanding a very simple experiment. It was long known that if you directed light of a certain wavelength at a piece of metal, the metal would emit electrons. But light of other wavelengths, no matter how intense, or bright, wouldn’t cause any electrons to be emitted from the metal. In classical physics theory, the energy of the light was thought to be related to its intensity and not its frequency, or wavelength. However, the results of the photoelectric effect experiment contradicted classical theory. Inconsistencies led Einstein to suggest thinking of light as being composed of particles (photons) rather than just as waves. In this lab, you will reproduce a photoelectric effect experiment and show that the energy ($E$) of a photon of light is related to its frequency and not its intensity.

Skills Focus
Calculating, observing, graphing, interpreting data, drawing conclusions

Procedure
1. Start Virtual Physics and select Photoelectric Effect from the list of assignments. The lab will open in the Quantum laboratory.

2. The laboratory will be set up with a laser shining at an angle on a sheet of sodium metal. Atoms in the metal absorb the energy from the light and emit electrons. The detector in the bottom corner detects the electrons that bounce off the metal. The intensity and wavelength of the laser can be adjusted. At what intensity and wavelength is the laser initially set?

3. Calculating Record the wavelength (in nm) in the data table on the following page. Calculate the frequency (in Hz, or #/s) and the energy (in J) of the laser light using $f = \frac{c}{\lambda}$ and $E = h \times f$ where $c = 3.0 \times 10^8$ m/s is the speed of light in a vacuum and $h = 6.626 \times 10^{-34}$ J*s. Don’t forget to convert your wavelength units into meters. Remember that $10^9$ nm = 1m.

4. Turn on the detector by clicking on the red/green light switch. Turn on the phosphor screen and click on the grid button. What does the signal on the phosphor screen indicate about the laser light shining on the sodium foil?
5. Decrease the intensity of the laser to 1 photon/second by clicking on the leftmost meter. How does the signal change? What does this show about the relationship between the amount of emitted photons and the intensity of the incident light?
__________________________________________________________________
__________________________________________________________________

6. Observing  Change the intensity of the laser back to 1 nW and increase the wavelength to 600 nm. What do you observe on the phosphor screen?
__________________________________________________________________

7. Determine the maximum wavelength at which emission of electrons occurs in the metal.
__________________________________________________________________

8. Click inside the Stockroom to enter it. Click on the clipboard and select Preset Experiment 5: Photoelectric Effect (2). Click on the green Return to Lab arrow to return to the laboratory. The intensity of the laser will be set at 1 nW and the wavelength at 400 nm. The detector used in this experiment is a bolometer and will automatically be turned on. This instrument measures the kinetic energy of electrons. Click the handle to switch from electron volts to Joules. You should see a green peak in the lower left corner of the detection screen. The intensity or height of the signal corresponds to the number of electrons being emitted from the metal, and the x-axis is the kinetic energy of the electrons. Zoom in on the peak by clicking next to the peak and dragging the box that appears around the peak.
9. Move the cursor over the top of the peak and record the kinetic energy of the electrons and their intensity in the data table. The kinetic energy is actually displayed in $10^{-19}$ Joule units, so record $10^{-19}$ J for every energy recorded. Increase the wavelength in 10 nm increments and record the kinetic energy and intensity of the peak for each new wavelength in the data table. When you hit the maximum emission wavelength, observe what happens as you continue to increase the wavelength. Is that consistent with what you observed before?

__________________________________________________________________
__________________________________________________________________
__________________________________________________________________

Analyze and Conclude

1. Graphing  Make a graph below of incident light wavelength vs. ejected electron kinetic energy from your data in the data table. Include a couple of the higher wavelength values that you observed in Step 9. Graph the Wavelength in nanometers on the x-axis and the Kinetic Energy in $10^{-19}$ Joules (just plot the fractional part, not the power of ten) on the y-axis.

2. Interpreting Data  What does the shape of the graph show? What does it mean on the graph when the kinetic energy drops to zero?

__________________________________________________________________
__________________________________________________________________
__________________________________________________________________
3. **Graphing**  Make a graph below of laser energy vs. the kinetic energy of the ejected electrons from your data in the data table. Include a couple of the higher wavelength values that you observed in Step 9. Graph the *Laser Energy* in units of $10^{-19}$ Joules on the $x$-axis and the *Electron Kinetic Energy* in units of $10^{-19}$ Joules on the $y$-axis.

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4. **Interpreting Data**  What relationship do you see between the energy of the incident light on the foil and the energy of the ejected electrons?

__________________________________________________________________
__________________________________________________________________
__________________________________________________________________

5. Decrease the wavelength to a value where electrons are emitted. Observe what happens to the peak when you increase and decrease the intensity. You may need to zoom out to see the changes.

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6. **Drawing Conclusions**  Based on this experiment, explain why violet light causes the emission of electrons but orange light does not. Which matters in the formation of photoelectrons: intensity or wavelength?

__________________________________________________________________
__________________________________________________________________
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112  The Photoelectric Effect
Answers

Lab 1: Forces

Procedure

3. The ball still fell even though the rocket was on, but it fell more slowly.

4. The object of the lab is to find the rocket force that will make the net force on the ball zero. Then the forces on the ball are balanced. This occurs when the ball doesn’t go up or down. Data for Table 1 will vary.

5. The pull of gravity can be calculated as the weight of the object from the equation Weight = mass \times g = 196 N. A rocket force of 196 N would balance the pull of gravity.

Data Table 2

<table>
<thead>
<tr>
<th>Angle</th>
<th>Force (N)</th>
<th>Effect on the ball</th>
<th>Balanced/Unbalanced</th>
</tr>
</thead>
<tbody>
<tr>
<td>270°</td>
<td>200</td>
<td>Forced downward</td>
<td>Unbalanced</td>
</tr>
<tr>
<td>0°</td>
<td>200</td>
<td>Forced to the right, moves to the bottom right corner</td>
<td>Unbalanced</td>
</tr>
<tr>
<td>180°</td>
<td>200</td>
<td>Forced to the left, moves to the bottom left corner</td>
<td>Unbalanced</td>
</tr>
</tbody>
</table>

Data will vary for the fourth trial, in which students choose a rocket angle to observe.

Analyze and Conclude

1. The forces in Data Table 2 were applied in different directions. They caused the ball to move in different directions due to the net combination of forces. The gravity pulling down and the rocket pushing either to the right or to the left created a net diagonal motion.

2. Answers will vary. You would need a force of 196 N pushing to the left, 180 degrees.

3. Answers will vary.

4. Stronger gravity would require a larger force to balance it.

5. Rocket scientists need to design a rocket that can produce a force stronger than the force of gravity and other forces opposing motion. They also need to make sure that the rocket itself is built strongly enough to withstand these forces.
Lab 2: Newton’s First Law

Analyze and Conclude

1. Graphs will vary.
2. The lighter mass was easiest to stop, and the more massive ball was harder to stop. In general, the more mass the ball has, the greater is its inertia and harder it is to stop.
3. Since there is no friction, the rocket force is the only force working to change the motion, or inertia, of the ball. Any force will be enough to stop the ball.
4. The ball would keep moving at the constant velocity forever. It doesn’t matter what the mass is.
5. Various types of forces could change the motion of the ball—friction, air resistance, or gravity.
6. The ball doesn’t ever move at constant velocity because air resistance is a force that is constantly changing the ball’s motion. The ball doesn’t move solely because of its inertia because a net force is being applied to it. The ball traveled a much shorter distance in this experiment because it was constantly slowing down.

Lab 3: Measuring Speed

Procedure

2. The block that slides across the table in a short time is going faster than the block that takes a long time. The speed of the first block is greater than the speed of the second.

Analyze and Conclude

1. The graph shows a straight line starting from the point (0 s, 0 cm) and ending at the point corresponding to the time and distance at which the ball reached the end of the table. The line slopes upward from left to right.
3. Table 1: answers will vary. Sample answer: 78 N, 500 cm, 1.47 s, 340.1 cm/s
6. The friction will slow down the block. The speed will not be constant.
7. Answers will vary. 500 cm traveled in 2.54 seconds. Average speed: 196.9 cm/s
9. The instantaneous speed was constantly changing because of friction. The average speed is an average value over the entire length of the table. It doesn’t show the speed from moment to moment. The average speed was much lower in this experiment than in the experiments without friction.
Lab 4: Graphing Motion

Analyze and Conclude

1. Graphs will vary depending on the masses used.
2. Each point on the graph shows the distance a ball traveled in a certain amount of time.
3. Each line has a different slope. Each ball reached the side of the table at different times. The ball with the smaller mass traveled faster. The steeper slope shows that it traveled the same distance in less time. The direction of travel isn’t shown on the graph.
4. The total displacement when the ball returned to x = 0 was 0 m. The velocity was positive when the ball was traveling away from the origin, and negative when it came back.
5. Displacement graphs just show how far an object has traveled from the origin, regardless of which direction the motion is in. Velocity graphs show the speed of an object in a given direction. X vs. Y graphs show absolute position, but don’t show how long the motion took.

Lab 5: Inclined to Roll

Analyze and Conclude

1. The graphs are curves starting at the lower left and curving upward.
2. The graphs are straight lines starting at the lower left and rising to the right.
3. The steeper the ramp, the greater the slope of the lines for both the position versus time graphs and the velocity versus time graphs. The steeper the ramp, the faster the ball moves, meaning that it has greater velocity.
4. Data in the table will vary.
5. Acceleration
6. The velocity is changing by the same amount in each unit of time.
7. The graphs have a constant horizontal slope showing constant acceleration. The velocity changed at a constant rate.
8. The graphs would still be increasing, but the rate of increase in velocity would be falling. The object would still be moving forward, but would eventually slow down to a constant positive velocity. The position would also be moving forward, at first at an increasing rate, but eventually reaching a constant positive rate of motion.
Lab 6: Acceleration of Gravity

Procedure

2. As the ball rises, it will slow down. As the ball falls, it will speed up.

6. Answers will vary. Sample data: 75 N, off, 3.21 s, 14.9 m/s; 75 N, on, 1.53 s, 3.16 m/s;

Analyze and Conclude

3. The graphs with air resistance show that the ball accelerates less than the same ball without air resistance. The ball with air resistance that falls the longest distance stops accelerating as it falls.

4. The velocity is changing, which indicates acceleration. The slope of a velocity versus time graph is a measure of the acceleration. The velocity versus time graphs are not horizontal lines, they show a finite slope, meaning that there is acceleration.

5. The acceleration is the same in all of the experiments without air resistance. The slopes are the same. The experiments with air resistance have much smaller accelerations.

7. The ball accelerates all along its path. As the ball rises, it slows down, so it experiences negative acceleration or deceleration. At the peak of the trajectory, the ball’s direction changes, so it is accelerating. As the ball falls it speeds up, so it is accelerating.

6. As the balls begin to fall, they have almost constant acceleration, just as if they were in free fall. As the balls speed up, air resistance increases and they can’t accelerate as much. At some point, the force of air resistance becomes equal to the force of gravity and the balls stop accelerating.

7. The plunger force affects how fast the ball is initially rising, but the acceleration is always the same going either up or down in the experiments without air resistance. The slopes of the graphs of the falling and rising balls are the same. The acceleration is not affected by the force of the plunger.
Lab 7: Gravity and Projectile Motion

Procedure

2. The ball would keep going forever. It would never fall back to the ground because nothing would be pulling it down.

Analyse and Conclude

1. The ball hit at an angle of 45° without air resistance traveled the farthest. The angle affects how much horizontal velocity the ball has, which determines how far it can go. If the angle is small, gravity pulls the ball to the ground quickly. With larger angles, it takes gravity longer to pull the ball down, but the ball doesn’t travel very far horizontally because there is little horizontal velocity.

4. Graphs will vary. Sample data for Distance Traveled: 63.4 m (45°), 31.5 m (15° and 75°), 41 m (45° with air resistance).

2. Graphs will vary.

3. Yes, 15° and 75°. The ball hit at the lower angle traveled more out than up, but got pulled to the ground faster. The ball hit at the higher angle traveled up but not very far before it was pulled down to the ground.

4. The force on the balls was constant, so a heavier ball travels a shorter distance and a lighter ball travels a greater distance. If the initial velocity of the balls was the same, the masses of the balls would have no affect on the distance traveled.

5. The ball traveled a shorter distance with air resistance.

6. The ball shot up at an angle of 15° with air resistance would travel farther than the ball hit at an angle of 75°. The shallow angle ball isn’t slowed down as much as a ball shot nearly straight up.

Lab 8: Newton’s Second Law

Procedure

2. The graph will have a positive slope; the velocity will be changing over time.

7. Data will vary. Sample data: 10 N, 2 kg, 44.72 m/s, 8.94 s, 5 m/s²

Analyse and Conclude

1., 2., & 6. Graphs will vary.

3. The velocity vs. time graphs show that the velocity is increasing linearly.

The ball with the smallest mass and the greatest force applied to it had the greatest acceleration.

5. Yes, both calculations match.

7. The slope of the graph is the mass of the ball.

8. Use a ball with a very small mass.

9. You can decrease the mass of the object being accelerated, increase the applied force, or do both.
Lab 9: Acceleration and Friction

Procedure

4. Data will vary. Sample data: Wood, Plastic, 41.82 m, 6.18 s

Analyze and Conclude

1. & 5. Graphs will vary.
2. The lines are not as steep for the graphs of the trials with greater friction. This shows that the sled can't accelerate as well with greater friction.
3. The sled continues to move forward, but at a much slower rate, so the curves become less steep very quickly. The more friction there is, the faster the sled slows down.
4. The rocket force makes the sled accelerate. When the rocket turns off, that force isn’t acting on the sled anymore, even when the sled is still moving. Friction is what makes the sled decelerate. Friction acts on the sled whenever it is in motion.
6. The velocity-time graphs have constant slopes, showing that the acceleration is constant before the rocket is turned off and then again afterwards. The acceleration is positive when the rocket is pushing and the sled is speeding up, and negative when the rocket turns off and the sled slows down.
7. It would take more force to move the sled and friction would stop the sled faster.

Lab 10: Newton’s Third Law

Procedure

2. The heavy ball will hit the lighter ball just as hard as the light ball hits back. The light ball will bounce back going faster and the heavy ball will bounce back going slower.

Analyze and Conclude

1. When the masses were the same, the velocities of each ball after the collision were the same. When one ball was much more massive than the other, the lighter ball moved with a high velocity after the collision and the heavy ball barely moved.
2. Newton’s third law says that two colliding objects exert equal and opposite forces on each other. A force, exerted on a small mass, results in a large acceleration or velocity. The same force exerted on a large mass cannot accelerate it very much, so it moves more slowly.
3. Answers will vary depending on the prediction.

6. Sample Data for Velocity After (m/s): Trial 1—Ball 1: 10, Ball 2: −10; Trial 2—Ball 1: 3.33, Ball 2: −16.67; Trial 3—Ball 1: −9.22, Ball 2: −29.22;
4. Forces can cancel out, causing an object to stop moving. A light object doesn’t exert enough force on a heavy object to cause it to move at all because it still has to overcome the force of gravity holding the object down, which causes a frictional force opposing the motion.

5. Because the forces act on different objects.

Lab 11: Conservation of Momentum

Procedure

Data Tables: values will vary, but in all trials the total momentum before and after the collision are equal.

Analyze and Conclude

1. Yes, because in each trial the total momentum before the collision equaled the total momentum afterwards.

2. Answers may vary, but should note that sum of the momentums of Ball 1 and Ball 2 are unchanged by the collision.

3. The ball with a small mass could be moving at a high velocity.

4. Answers will vary but should include a description of momentum as the product of mass and velocity and/or a measure of how difficult it would be to stop an object in motion.

Lab 12: Energy Conversions

Procedure

Data Tables: values will vary

Analyze and Conclude


2. When the ball was at the top of the ramp, because at that point it was farthest from the ground.

3. When it was going the fastest, at the bottom of the ramp.

4. They should be about the same amount.

5. As the ball moved, its energy was continuously transformed between potential energy and kinetic energy. The ball gained energy from the plunger. It was pushed to the top of the ramp, where its energy was all in the form of potential energy. Then, it started to roll down the ramp, losing potential energy and gaining speed and so gaining kinetic energy. At the bottom of the ramp, the ball had zero potential energy and its kinetic energy was at a maximum, so it was moving fast.
Lab 13: Centripetal Motion

Procedure
4. Observations may vary. The tip of the rod will be traveling the fastest.

Analyze and Conclude
1. The angular speed is the same regardless of distance from the pivot point.
2. Tangential speed increases as you move farther out from the pivot point.
3. Based on observed trends, the next plot would have a higher tangential speed but the same angular speed.
4. Answers will vary depending on students’ predictions.
5. Answers may vary. One possible answer is that the rod should be stronger out near the tip because the tangential speed is faster at that point.

Lab 14: Rotational Inertia

Procedure
4. Answers will vary. Balls of the same shape but different radii accelerate equally when rolled down a ramp. The velocity would increase exactly the same for both balls. They would take the same amount of time to reach the bottom.

5. The acceleration of each ball was the same. They each had the same velocity when they got to the bottom of the ramp.

Data Table

<table>
<thead>
<tr>
<th>Ball Diameter (m)</th>
<th>Solid or Hollow?</th>
<th>Final Velocity (m/s)</th>
<th>Linear Acceleration (m/s²)</th>
<th>Time (s)</th>
<th>Final Rotational Velocity (rad/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>solid</td>
<td>18.7</td>
<td>3.5</td>
<td>5.3</td>
<td>18.7</td>
</tr>
<tr>
<td>3</td>
<td>solid</td>
<td>18.7</td>
<td>3.5</td>
<td>5.3</td>
<td>12.5</td>
</tr>
<tr>
<td>0.5</td>
<td>solid</td>
<td>18.7</td>
<td>3.5</td>
<td>5.3</td>
<td>74.9</td>
</tr>
<tr>
<td>2</td>
<td>hollow</td>
<td>17.2</td>
<td>2.9</td>
<td>5.8</td>
<td>17.2</td>
</tr>
<tr>
<td>3</td>
<td>hollow</td>
<td>17.2</td>
<td>2.9</td>
<td>5.8</td>
<td>11.4</td>
</tr>
<tr>
<td>0.5</td>
<td>hollow</td>
<td>17.2</td>
<td>2.9</td>
<td>5.8</td>
<td>68.6</td>
</tr>
</tbody>
</table>
6. Small balls make more rotations than large balls. They have to spin faster than large balls to cover the same distance in the same amount of time.

8. Answers will vary. The solid ball will roll down the ramp faster. The velocity will increase faster and it will rotate more than the hollow ball.

Analyze and Conclude

1. The rotational inertia of the hollow sphere is greater than that of the solid sphere. It takes more time to get the ball with greater inertia moving and so it gains speed at a slower rate. Radius cancels when calculating total acceleration. Objects of larger radius may have a greater moment of inertia, but they have smaller angular speed, which offset one another. All objects of the same shape have the same rotational inertia per mass ratio.

2. Your rotational inertia is greater when you extend your arms out, which distributes your weight in a different way. You spin slower when your mass is distributed farther from your center of mass.

Lab 15: Universal Gravitation

4. $1.9891 \times 10^{30}$ kg

6. & 8.

Data Table 1

<table>
<thead>
<tr>
<th>Planet</th>
<th>Radius of Orbit (meters)</th>
<th>Mass of Planet (kg)</th>
<th>$F_g$ (N)</th>
<th>$g$ (m/s$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth</td>
<td>$1.48 \times 10^{11}$</td>
<td>$5.9742 \times 10^{24}$</td>
<td>$3.62 \times 10^{22}$</td>
<td>.006</td>
</tr>
<tr>
<td>Mars</td>
<td>$2.07 \times 10^{11}$</td>
<td>$6.4185 \times 10^{23}$</td>
<td>$1.99 \times 10^{21}$</td>
<td>.003</td>
</tr>
<tr>
<td>Jupiter</td>
<td>$7.84 \times 10^{11}$</td>
<td>$1.8986 \times 10^{27}$</td>
<td>$4.10 \times 10^{23}$</td>
<td>.0002</td>
</tr>
</tbody>
</table>

7. Each planet exerts a different gravitational force on the Sun. The amount of force is not just a function of how close a planet is to the Sun, it depends on mass and radius. Jupiter has a much larger mass.

9. Yes, although Jupiter did not display enough significant digits to show the correct value.
10. **Data Table 2**

<table>
<thead>
<tr>
<th>Object</th>
<th>Radius of Orbit (meters)</th>
<th>Mass of object (kg)</th>
<th>Mass of Planet (kg)</th>
<th>$F_g$ (N)</th>
<th>$g$ (m/s$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moon</td>
<td>3.93*10$^8$</td>
<td>7.35*10$^{22}$</td>
<td>5.9742*10$^{24}$</td>
<td>1.90*10$^{20}$</td>
<td>.003</td>
</tr>
</tbody>
</table>

11. $F = G m_{person} M_{Earth} / R^2 = 6.67*10^{-11} \text{Nm}^2/\text{kg}^2$\text{50kg} \times 5.9742*10^{24} \text{kg} / (6.37*10^6 \text{m})^2 = 491 \text{N}$

12. The gravitational force between a person and Earth is much smaller. The mass of the person is much less than the mass of the Sun, so the force attracting the person to Earth is smaller.

13. $g = F / m_{person} = 491 \text{N} / 50 \text{kg} = 9.8 \text{m/s}^2$

   The gravitational acceleration of a person toward Earth is much larger than the acceleration of the moon towards Earth.

14. The planets and the moon all have a tangential component of their velocity. Their inertia keeps them in an elliptical orbit around the sun or Earth. The planets are constantly falling down toward the sun and the moon towards Earth, but their tangential velocity keeps them moving in orbit.

15. Answers will vary. Earth could end up in a small elliptical orbit around the sun, or could head away from the Sun, depending on students’ choices.

---

**Lab 16: Gravitational Interactions**

**Analyze and Conclude**

1. & 2. Graphs and data will vary, depending on the planets or moons chosen.

3. The speed at which the balls fall is higher on some planets (Jupiter, Neptune) and lower on other bodies such as Earth or the moon. The planets on which the ball fell fastest or slowest will vary, depending on student choices.

4. The speed is changing at a constant rate. That is, acceleration is constant. The ball is subject to a constant gravitational force.

5. Predictions will vary, but acceleration is independent of the mass of the ball.

6. Acceleration is the same on each planet, independent of the mass. The force of gravity is greater for larger mass, but acceleration equals $F / m$ (Newton’s 2nd Law), so the ball’s mass in the equation for gravitational attraction cancels.
Lab 17: Satellite Motion

Procedure
3. The ball will go straight towards the source.
7. Data will vary. For example, a force of \(2 \times 10^6\) N produces a circular orbit. A force of \(1 \times 10^6\) N produces an elliptical orbit and a force of \(3 \times 10^6\) N sends the object drifting out into space.
8. The ball’s mass, its distance from the source, the strength of the gravity source.
9. Answers will vary depending on the variable chosen.

Analyze and Conclude
2. Answers will vary. One option is 10 s at 9,900 N and 90 degrees.
3. You can adjust the orbit faster if you fire multiple times, but you can also create unstable orbits easily this way.
4. Answers will vary.

Lab 18: Rutherford and the Nucleus

3. The signal in the middle shows the alpha particles that pass straight through the foil without being deflected. There are other small flashes across the screen at different angles. They show where alpha particles that are deflected a little by the electrons pass through.
4. The old model would explain that some alpha particles would be deflected because they were attracted by the electrons distributed throughout the positive mass of the atom.
5. The hits are not quite as frequent and the forward scattering spot is no longer visible.
6. There are much fewer hits than in the first two positions. A hit occurs once every few seconds.
7. The hits in this position are very rare, but alpha particles do occasionally hit. There is nearly a minute between each new hit.
8. The alpha particles would have to be hitting a large mass in the center of the atom to deflect the alpha particles backward. The mass of the gold atom is not spread evenly throughout the atom; it is concentrated in a central atomic nucleus. No particles would deflect at such large angles if the mass of the atom were distributed evenly.
9. Most of the alpha particles came straight through the foil or were only slightly deflected. This evidence suggests that the atom is mostly empty space. But some alpha particles were deflected at large angles. These deflections could happen only if an alpha particle came close to or hit a relatively large positive mass.
10. The gold atoms have larger nuclei than most of the other metals available, so there would be more deflections because there would be a larger target for the alpha particles to hit.
Lab 19: Solid Structure Model

3. Mass 9kg, Area = 3 diameters * 3 diameters = \(9 \times (0.5 \text{ m})^2 = 2.25 \text{ m}^2\)

4. Pack the balls tighter together, increase the mass of the atoms.

5. Answers will vary. Move the balls to fill in the spaces by off-setting the rows.

6. Answers will vary.

7. Have them tightly packed, so the volume is smaller.

8. Predictions will vary.

9. The tighter packed structure is not as mobile and the atoms can’t vibrate as much.

10. The atoms don’t vibrate around as much when the elasticity has been decreased. The whole structure doesn’t deform as much.

11. Very tightly packed atoms can’t vibrate as much so they don’t deform as much when a force is applied. When atoms are inelastic in collisions, they don’t bounce back to their original shape easily.

Lab 20: Density and Buoyancy

Procedure

5. Subtract the volume of the Virtual Fluid from the volume of both the Virtual Fluid and the plastic sample.

7.

Table 1 (Sample data, answers will vary)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Mass of Sample (g)</th>
<th>Volume of Virtual Fluid (mL)</th>
<th>Volume of Virtual Fluid and Sample (mL)</th>
<th>Volume of Sample (mL)</th>
<th>Weight of solid (N)</th>
<th>Density (g/mL)</th>
<th>Buoyant force in olive oil (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ice</td>
<td>17.071</td>
<td>229</td>
<td>248</td>
<td>19</td>
<td>0.1673</td>
<td>.898</td>
<td>.167</td>
</tr>
<tr>
<td>Aluminum</td>
<td>46.698</td>
<td>227.5</td>
<td>245</td>
<td>17.5</td>
<td>0.458</td>
<td>2.67</td>
<td>.154</td>
</tr>
<tr>
<td>Pine Wood</td>
<td>9.302</td>
<td>229</td>
<td>243.5</td>
<td>14.5</td>
<td>0.091</td>
<td>.64</td>
<td>.127</td>
</tr>
</tbody>
</table>

12.

Table 2 (Sample data, answers will vary)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Volume of Sample (mL)</th>
<th>Mass of Empty Beaker (g)</th>
<th>Mass of Beaker and Sample (g)</th>
<th>Mass of Sample (g)</th>
<th>Density (g/mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanol</td>
<td>227</td>
<td>101.309</td>
<td>230.992</td>
<td>129.683</td>
<td>.57</td>
</tr>
<tr>
<td>Water</td>
<td>226</td>
<td>101.309</td>
<td>327.856</td>
<td>226.547</td>
<td>1.00</td>
</tr>
<tr>
<td>Olive oil</td>
<td>229</td>
<td>101.309</td>
<td>306.665</td>
<td>205.36</td>
<td>.897</td>
</tr>
</tbody>
</table>
Analyze and Conclude

1. See Table 1.
2. See Table 2.
3. Density, not weight, determines whether or not an object will float or sink in a given fluid. An object that is denser than the fluid it is in will sink. An object that is less dense than the fluid will float.
4. The density of the olive oil is .898 g/mL. Only the pine wood has a lower density (.64 g/mL), so only pine wood will float. The buoyant force on the pine wood is greater than its weight, so that object will float. Ice and aluminum both have larger weights than their buoyant forces, so they will sink.
6. The density of olive oil is about .90 g/mL. The density of water is 1.00 g/mL. Olive oil would float on water.
7. From top to bottom: ethanol, pine wood, olive oil, ice, water, and aluminum. Density determines where the items are placed, with substances having the lowest density on top and those with the highest density on bottom.

Lab 21: Pressure and Volume of a Gas

Procedure

2. Student predictions will vary.
3.

<table>
<thead>
<tr>
<th>Pressure (kPa)</th>
<th>Volume (cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>7,436</td>
</tr>
<tr>
<td>200</td>
<td>3,718</td>
</tr>
<tr>
<td>300</td>
<td>2,478</td>
</tr>
<tr>
<td>400</td>
<td>1,859</td>
</tr>
<tr>
<td>500</td>
<td>1,487</td>
</tr>
<tr>
<td>600</td>
<td>1,239</td>
</tr>
<tr>
<td>700</td>
<td>1,062</td>
</tr>
</tbody>
</table>

Analyze and Conclude

1. The graph is a curve sloping down from the upper left. The curve comes closer and closer to a volume of 1,000 cm³ as the pressure approaches 700 kPa. The volume is largest when the pressure is lowest.
2. The graph shows that as pressure of a gas increases, its volume decreases.
3. Nonlinear
4. If the pressure were decreased, the volume of the gas would increase because pressure and volume vary inversely.
Lab 22: Specific Heat of Metals

Data Table

<table>
<thead>
<tr>
<th></th>
<th>Al</th>
<th>Stainless Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of metal (g)</td>
<td>7.3547</td>
<td>23.3374</td>
</tr>
<tr>
<td>Volume of water (mL)</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Mass of water (g)</td>
<td>99.8</td>
<td>99.8</td>
</tr>
<tr>
<td>Initial temperature of water (°C)</td>
<td>25.00</td>
<td>25.00</td>
</tr>
<tr>
<td>Initial temperature of metal (°C)</td>
<td>200.00</td>
<td>200.00</td>
</tr>
<tr>
<td>Max temp. of water + metal (°C)</td>
<td>27.38</td>
<td>29.21</td>
</tr>
<tr>
<td>Specific Heat (J/g°C)</td>
<td>.783</td>
<td>.441</td>
</tr>
</tbody>
</table>

Analyze and Conclude

1. Answers will vary. \( T_{\text{water}} = 27.38°C - 25°C = 2.38°C \)
2. Answers will vary. \( q = 99.8 \times 2.38°C \times 4.184 \text{ J/(g°C)} = 993.8 \text{ J} \)
3. Answers will vary. \( T_{\text{aluminum}} = 200°C - 27.38°C = 172.62°C \)
4. Answers will vary. \( C_{\text{Al}} = 993.8 \text{ J/(7.3547 g)(172.62°C)} = 0.783 \text{ J/g°C} \)
5. Answers will vary. \( C_{\text{Steel}} = 1757.94 \text{ J/(23.3374 g)(170.79°C)} = 0.441 \text{ J/g°C} \)
6. Answers will vary. The steel can will absorb the heat in the room faster and your drink will heat up faster than in the aluminum can.
7. Answers will vary. The steel would heat up faster than the aluminum, but that could lead to hot spots. Once the aluminum heats up, it would retain the heat longer than the steel pot would.
8. Answers will vary. The water and steel together will heat up hotter because the steel can absorb more heat. The pure water will not heat up as much with the same amount of energy added.
9. Answers will vary. The metal-water combination heated to a higher temperature and cooled more than the straight water.

Lab 23: Phase Changes

Procedure

2. Answers will vary but, in general, the mass of the ice will be about 25 grams.

Analyze and Conclude

1. Graphs will vary.
2. Liquid and solid water

6. Sample data—Temperature at boiling: 100.44 °C; Pressure at boiling: 772 torr
3. The temperature remains constant at 0°C. This occurs when the solid is melting and becoming a liquid. Normally, the temperature increases as the thermal energy increases since the molecules vibrate faster at higher temperatures. However, during the change from solid to liquid, the molecules are breaking free from each other and changing to a liquid and the temperature stays constant.

4. The temperature begins to rise as soon as all of the ice has melted. This happens because the thermal energy of the molecules is increasing, causing the molecules to move faster.

5. The temperature remains constant during the boiling process. This occurs because the heat that is being added to the water is being used to create water vapor instead of raising the temperature.

6. The boiling point is normally 100°C but was higher in the virtual laboratory by 0.44°C. This occurred because the air pressure was 772 torr instead of 760 torr. An increase in air pressure increases the boiling point. (The opposite argument works if the air pressure in the virtual laboratory happens to be lower than 760 torr that day.)

7. The phase change from liquid to gas required more energy. The heater had to be turned on to cause that change to occur and much more energy was required to raise the temperature to boiling.

Lab 24: Light Investigation

3. Predictions will vary. No images can be seen in the detector window.

4. Answers will vary depending on the student’s predictions. No images can be seen in the detector window.

5. Answers will vary. The gnome is visible but the size and orientation have changed.

6. The gnome is not distorted in any way and is the same size as the original.

7. The detector shows an image of the front side of the gnome.

8. The detector shows the side of the gnome. This is the actual object, not a reflection. The eye is facing the direction of the object and can no longer see the reflection from the mirror of the front of the gnome.

9. Light is now hitting the eye from 2 directions at once and both images are visible.

10. Answers will vary. It isn’t possible to see from directly behind the gnome, because the gnome itself blocks the reflection. However, if you move and rotate the mirror and eye, moving the eye down to a different row, it is possible to see most of the back and the front of the gnome at once.
Lab 25: Color in Light

3. Predictions will vary but the gnome should look red.

4. Answers will vary. The gnome looks red. The gnome’s outfit, which was darkly colored, looks black. The green boots and pants can’t be seen through the red filter, because there isn’t any red in the color green. The pillar beneath the gnome was white, and red is one of the colors that makes up white, so when every other color is filtered out, the red part is still visible.

5. Predictions will vary but nothing will be visible. The screen will appear black.

6. Nothing will be visible. The screen will appear black.

7. When color receptors are turned off, the corresponding color on the gnome seems black. If all light is subtracted off, the whole screen goes black.

8. Each type of color blindness subtracts specific parts of the color off of the gnome. The red-green type made it hard to see the red and green colors specifically, but it also changed the shade of blue on the jacket. The blue-yellow type also changed the shades of green and blue by subtracting out part of those colors.

9. Orange; Green or light blue; Light blue through dark purple

10. White light is the combination of all of the wavelengths of light. Color television and most computer monitors add pixels of a few colors together to produce all of the colors.

Lab 26: Reflection and Refraction of Light

3. Predictions will vary. The detector will show the light spot produced by the reflected light.

4. The angles of incoming and reflected light relative to the normal are the same.

5. The angles are larger, but the angles of the incident and reflected light are still the same.

6. Predictions will vary. The angles will still be the same.

7. The angle of reflection stayed the same but the beam diameter was smaller.

8. The angle of reflection stayed the same but the beam diameter was larger.

9. The light looks like it travels straight through the lens and isn’t deflected at all.

10. 1.5

11. The beam bent down, so now you can see that the light really does pass straight through the lens when the index of refraction is 1.

12. As the index of refraction increases, the beam bends at a greater and greater angle from what it would if it just passed straight through.

13. As the light hits the first face of the prism, it bends towards the normal because the prism has a higher index of refraction than air. Then, when the light exits the prism, it bends away from the normal and separates into the colors of the rainbow. When the light hits the second prism it bends towards the normal again, and all of the colors exit the second prism in a parallel beam of light.
Lab 27: Reflection and Refraction of Light

4.

Data Table 1

<table>
<thead>
<tr>
<th>Distance of object from lens (cm)</th>
<th>Distance of image from lens (cm)</th>
<th>Inverted? (yes/no)</th>
<th>Image bigger or smaller than object?</th>
<th>Height Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>60.96</td>
<td>30.48</td>
<td>Yes</td>
<td>Smaller</td>
<td>0.5</td>
</tr>
<tr>
<td>40.64</td>
<td>40.64</td>
<td>Yes</td>
<td>Same size</td>
<td>1.0</td>
</tr>
<tr>
<td>Between 40.64 and 20.32</td>
<td>Greater than 40.64</td>
<td>Yes</td>
<td>Bigger</td>
<td>Greater than 1.0</td>
</tr>
<tr>
<td>20.32</td>
<td>No image</td>
<td>No image</td>
<td>No image</td>
<td>No image</td>
</tr>
<tr>
<td>15.24</td>
<td>60.96</td>
<td>No</td>
<td>Bigger</td>
<td>4.0</td>
</tr>
</tbody>
</table>

5. Answers will vary depending on the student’s predictions.

6. r1 is more curved, like this:
   The middle is thicker than the edges.

8. r2 is more curved, like this:
   The edges are thicker than the middle.

9. This type of lens spreads the rays out so they focus farther back in the eye. Nearsighted eyes are shaped so light focuses too far forward in the eye, so the lens helps the light to focus at a more distant point in the eye.

Lab 28: Diffraction and Interference

2. 700 nm; 0.2 μm spacing; The spacing between the slits is much smaller than the wavelength.

3. Predictions will vary. Smaller wavelengths won’t diffract as much.

4. The bright band in the middle becomes narrower and more defined. There is less diffraction out along the sides, making a shadow. Longer wavelengths diffract more.

5. There is an interference pattern with many bright and dark bands due to the constructive and destructive interference of light through the slits.

6. No, the intensity of light doesn’t affect the diffraction pattern.

7. Wider spacing between the slits results in many more interference bands. With smaller spacing, there are just a few very wide interference bands. Diffraction patterns increase with increased spacing.

8. There are fewer interference bands at higher wavelengths. Shorter wavelengths have interference lines that are closer together.

9. The pattern is the same after allowing enough photons to diffract.
10. A single photon cannot diffract. What you see as a diffraction pattern that builds up over time is really the statistics of where each individual photon will hit the screen. It is uncertain what each individual photon will do, but the properties of a large collection of photons can be easily predicted.

11. Light behaves like a particle, and the wave-nature of light is really a representation of the statistics or uncertainty exhibited in an experiment.

12. The diffraction pattern looks just like the pattern with photons. Electrons diffract just like photons.

**Lab 29: The Effect of an Electric Field on Moving Charges**

2. Negative

3. You observe a spot in the center of the phosphor screen. It glows where the particles impact the screen.

4. The spot moves left

5. Predictions will vary. The spot will move to the right because the electrons have more energy and won’t be deflected as much by the electric field modifier.

6. The spot moves to the right because the electrons aren’t deflected as much by the electric field modifier because they have more energy than before.

7. Answers will vary. The spot would move to the left because the electrons would be deflected more by the electric field modifier.

9. Another spot appears on the screen. Alpha particles have positive charge.

10. The spot moved to the right. It is in the opposite direction to the movement of the electron beam. Electrons move left in the electric field and alpha particles move right.

11. Alpha particles are massive compared with electrons. They are more than 7000 times heavier!
Lab 30: Capacitors

Procedure

4. When you increase the capacitance, the maximum voltage will increase and the amount of time should increase.

6.

Data Table

<table>
<thead>
<tr>
<th>Capacitor</th>
<th>Resistor</th>
<th>State</th>
<th>Observations about voltage</th>
<th>Maximum Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 F</td>
<td>10,000 Ω</td>
<td>Charging</td>
<td>Answers may vary. It seems that the charging slows down when it gets near the maximum voltage.</td>
<td>10</td>
</tr>
<tr>
<td>10 F</td>
<td></td>
<td>Charging</td>
<td>Answers will vary.</td>
<td></td>
</tr>
<tr>
<td>10 F</td>
<td>100 Ω</td>
<td>Discharging</td>
<td>Not as fast as charging.</td>
<td></td>
</tr>
<tr>
<td>10 F</td>
<td>1,000 Ω</td>
<td>Discharging</td>
<td>Faster than a 1000 Ω resistor.</td>
<td></td>
</tr>
</tbody>
</table>

Analyze and Conclude

1. The voltage increased steadily until the capacitor charged completely.

2. When the resistance is increased, the discharging time decreased. When the resistance is decreased, the discharge time increases.

3. Answers may vary. The key could complete the circuit and thus discharge a capacitor. A key only sends a signal when it is hit, so each key would remain charged until it is pressed. At that time, the capacitor would release its voltage, producing a signal.

4. The charge on the capacitor inside the game or television might not have fully discharged so there might still be some charge left that could hurt you.
Lab 31: Electric Current

Procedure

3. Predictions may vary. The current will be the same as the current going into the resistor.

5. It depends on how the resistors are placed in the circuit. It may increase or decrease.

7.

Data Table 1

<table>
<thead>
<tr>
<th>Resistor</th>
<th>Current IN (A)</th>
<th>Current OUT (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.12</td>
<td>.12</td>
</tr>
</tbody>
</table>

Answers will vary.

9.

Data Table 2

<table>
<thead>
<tr>
<th>Resistor</th>
<th>Current IN (A)</th>
<th>Current OUT (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.028</td>
<td>.028</td>
</tr>
<tr>
<td>2</td>
<td>.028</td>
<td>.028</td>
</tr>
<tr>
<td>3</td>
<td>.028</td>
<td>.028</td>
</tr>
</tbody>
</table>

Data Table 3

<table>
<thead>
<tr>
<th>Resistor</th>
<th>Current IN (A)</th>
<th>Current OUT (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.095</td>
<td>.095</td>
</tr>
<tr>
<td>2</td>
<td>.060</td>
<td>.060</td>
</tr>
<tr>
<td>3</td>
<td>.024</td>
<td>.024</td>
</tr>
<tr>
<td>4</td>
<td>.012</td>
<td>.012</td>
</tr>
</tbody>
</table>

Analyze and Conclude

1. The current is the same going in as it is coming out. Therefore no current was lost in the resistor.

2. .095 A.

3. Answers may vary depending on the student’s prediction.

4. In the parallel circuit, the currents were different in each resistor. In the series circuit, the current was the same through the whole circuit.
5. The current was less in the three series resistor circuit. But the same current flowed through all of the resistors, just as in the single resistor circuit.

6. Answers may vary. The flow of water is a good example.

Lab 32: Series and Parallel Circuits

Procedure

Data Table 2

<table>
<thead>
<tr>
<th>Resistor Number</th>
<th>Voltage (V)</th>
<th>Current (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (120 Ω)</td>
<td>.131</td>
<td>.001</td>
</tr>
<tr>
<td>2 (500 Ω)</td>
<td>.548</td>
<td>.001</td>
</tr>
<tr>
<td>3 (200 Ω)</td>
<td>.219</td>
<td>.001</td>
</tr>
<tr>
<td>4 (135 Ω)</td>
<td>.148</td>
<td>.001</td>
</tr>
<tr>
<td>5 (10,000 Ω)</td>
<td>10.95</td>
<td>.001</td>
</tr>
</tbody>
</table>

Data Table 3

<table>
<thead>
<tr>
<th>Resistor Number</th>
<th>Voltage (V)</th>
<th>Current (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (120 Ω)</td>
<td>11.73</td>
<td>.098</td>
</tr>
<tr>
<td>2 (500 Ω)</td>
<td>11.73</td>
<td>.023</td>
</tr>
<tr>
<td>3 (200 Ω)</td>
<td>11.73</td>
<td>.059</td>
</tr>
<tr>
<td>4 (135 Ω)</td>
<td>11.73</td>
<td>.087</td>
</tr>
<tr>
<td>5 (10,000 Ω)</td>
<td>11.73</td>
<td>.001</td>
</tr>
</tbody>
</table>

Analyze and Conclude

1. The resistors, the current, and the voltage
2. The voltage input and the current remain unchanged.
3. The voltage is the same and the current changes.
4. The parallel circuit has many paths for the current to flow through. The series circuit has only one path for the current to go.
5. Answers may vary. It only has one path for current to flow through, so the current should be the same throughout.
6. Some devices need more current and some need less. Also, some wires are restricted in the amount of current that they can safely carry. So the electrician would need to determine what is best given the various needs and constraints of the home.
7. In the series circuit, all of the remaining bulbs will go dark because a complete circuit no longer exists. In the parallel circuit, the remaining bulbs will stay lit and their brightnesses will be unchanged.
Lab 33: The Effect of an Magnetic Field on Moving Charges

2. Negative

3. You can see a spot in the center of the phosphor screen. It glows where the particles strike the screen.

4. The spot moves to the right.

5. Predictions will vary. The spot will move to the left because the electrons have more energy and won’t be deflected as much by the magnetic field modifier.

6. The spot moves to the left because the electrons aren’t deflected as much by the magnetic field modifier since they have more energy than before.

7. Answers will vary. The spot would move to the right because the electrons would be deflected more by the magnetic field modifier.

9. Another spot appears on the screen. Alpha particles have a positive charge.

10. The spot moved to the left. It is in the opposite direction to the movement of the electron beam. Electrons move right in the magnetic field and alpha particles are deflected to the left.

11. The magnetic force on a charged particle is perpendicular to both the local magnetic field and the particle’s direction of motion. No magnetic force is exerted on a stationary charged particle because it isn’t moving. Magnetic force is not created with particles with zero velocity.

12. Alpha particles are much more massive than electrons. They are more than 7000 times heavier!

13. Answers will vary. Motors, generators, power plants, and electromagnets are some possible examples.
Lab 34: The Photoelectric Effect

Procedure

2. It is set at an intensity of 1 nw intensity and a wavelength of 400 nm.

3.

Data Table

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>Frequency (Hz)</th>
<th>Laser Energy (J)</th>
<th>Ejected Electron Kinetic Energy (J)</th>
<th>Electron Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>7.5*10^14</td>
<td>5.0*10^-19</td>
<td>.5817*10^-19</td>
<td>.0502</td>
</tr>
<tr>
<td>410</td>
<td>7.3*10^14</td>
<td>4.9*10^-19</td>
<td>.4488*10^-19</td>
<td>.0502</td>
</tr>
<tr>
<td>420</td>
<td>7.1*10^14</td>
<td>4.7*10^-19</td>
<td>.3324*10^-19</td>
<td>.0502</td>
</tr>
<tr>
<td>430</td>
<td>7.0*10^14</td>
<td>4.6*10^-19</td>
<td>.2327*10^-19</td>
<td>.0502</td>
</tr>
<tr>
<td>440</td>
<td>6.8*10^14</td>
<td>4.5*10^-19</td>
<td>.1330*10^-19</td>
<td>.0502</td>
</tr>
<tr>
<td>450</td>
<td>6.7*10^14</td>
<td>4.4*10^-19</td>
<td>.0332*10^-19</td>
<td>.0502</td>
</tr>
<tr>
<td>460 and greater</td>
<td>6.5*10^14 and smaller</td>
<td>4.3*10^-19 and smaller</td>
<td>Zero</td>
<td>Zero</td>
</tr>
</tbody>
</table>

4. At this wavelength, electrons are being emitted from the metal foil and are picked up by the detector screen.

5. The detected light flickers and is faint. Fewer electrons are emitted from the foil with dimmer light of the same wavelength.

6. There are no electrons detected on the screen at this wavelength.

7. 450 nm

9. Above the maximum emission wavelength, the peak disappears and no electrons are emitted. This is consistent with previous results.

Analyze and Conclude

1. & 3. Graphs will vary.

2. With increasing wavelength, the ejected electron energy drops gradually, until the wavelength reaches a critical point, above which the energy is zero for all greater wavelengths.

4. As the energy of the incident light decreases, the ejected electron energy drops also, until it hits the critical point, when the energy is zero for all smaller laser energies.

5. With increasing laser intensity, the peak stays at the same energy, but the intensity increases. A decrease in laser intensity corresponds to a decrease in electron intensity.

6. Violet light has a higher frequency and is more energetic than orange light. It has enough energy to cause electrons to be emitted, whereas orange light does not. The wavelength of the incident light matters more than the intensity of that light in determining whether photoelectrons will be emitted.