PH030

GENERAL PHYSICS I
LABORATORY MANUAL

Southeast
Missouri State University

PHYSICS and ENGINEERING PHYSICS DEPARTMENT

Revised Spring 2009
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PH230 General Physics I

Laboratory

General Information

PURPOSE:

The purpose of the laboratory is to supply an opportunity to the student to gain the practical knowledge necessary to fully understand physical phenomena. This is done in several ways: performing measurements, analyzing data, working problems, developing computer programs, and writing reports. The student should become familiar with measurement techniques, measuring instruments, and experimental methods. Each laboratory exercise will deal with a topic covered in the lecture part of the course, thus expanding and reinforcing the students’ knowledge of that topic.

INSTRUCTIONS:

The instructions for each experiment should be read in advance of the regular laboratory period. A preliminary exercise or quiz may be given before the laboratory period and must be completed by each student before starting the laboratory exercise.

APPARATUS:

Every student must exercise the greatest care in the use of laboratory apparatus. Each one will be held personally responsible for the apparatus checked out to him. If anything is found missing or broken it should be reported to the instructor immediately. If additional apparatus is required ask the instructor for it. NO students are allowed in the physics equipment storeroom without permission.

ATTENDANCE:

Attendance is required for laboratory credit.
REPORT FORM:

A type written report on each laboratory exercise is required unless otherwise stated by the laboratory instructor. The report is due one week from the day the exercise is completed. The type written report should consist of the following items and section headings:

1. **Cover Page** – A single page containing
   a) title of the experiment
   b) your name
   c) your partners’ name(s)
   d) date performed
   e) date handed in

2. **Introduction:**
   a) **Purpose** – Why are we doing this experiment.
   b) **Theory** – What physical principles predict about the behavior investigated in the experiment. Include derivations of important formulas and note any approximations or assumptions you make in your experiment or its analysis.

3. **Procedure** – A brief summary of the procedure used in performing the experiment written in your own words in one or two paragraphs.

4. **Data** – This will usually take the form of a table showing measurements taken during the laboratory session. Make sure all units are clearly indicated.

5. **Analysis** – This section of the report should include an explanation of any tables or graphs included in the Data section. This section should also include a discussion of any errors made in making measurements and any assumptions or approximations made in calculations. Include graphs in the data section, or here, and discuss their meaning. Always include a brief discussion of the theory involved with the experiment and a comparison of your results with accepted results, or theory, and a calculation of per cent error. Sample calculations should also be included in this section of the report.

6. **Conclusions** – Summarize the experiment and its results. Did the experiment satisfy its purpose? Are there any things you would do differently next time?

7. **Questions** – The laboratory instruction sheet usually will contain questions about the procedure or results of the experiment. These questions should be answered in complete sentences and included in your report.

8. **Original Data** – The data, as taken in the laboratory, should be presented in tabular form and appended to the report. Plan and lay out the data table before coming to class. This will save valuable time in the laboratory. YOU MUST INCLUDE ORIGINAL MEASURED DATA in your report.

A grading rubric will be distributed in class showing how the labs will be graded and the points awarded for each part.
INTRODUCTION:

Most physical quantities can be divided into two groups: scalars and vectors. Scalar quantities have only magnitude to describe them. Some scalar quantities are the population of a city, the amount of gasoline in your car, the price of a new suit of clothes, etc. Vector quantities are represented by both magnitude and direction. Examples of vector quantities are the force of gravity acting on you (weight), the speed and direction (velocity) of an automobile, the magnitude and direction of the magnetic field of a magnet, etc.

The purpose of this laboratory exercise is to solve some vector algebra problems and verify the results using a force table.

THEORY:

Consider two vectors $A$ and $B$. Each of these vectors may be represented graphically by a directed line segment (an arrow) whose length represents the magnitude of the quantity and whose direction is the same as that of the vector quantity. These vectors may be added graphically in the following way. Beginning at a convenient point on your paper draw to scale each vector in turn. The tail of each arrow is drawn from the tip of the preceding arrow. They may be taken in any order. The resultant (sum) of these vectors is found by drawing an arrow from the tail of the first vector to the tip of the last vector.

Subtraction of vectors is carried out in the following way. To subtract vector $B$ from vector $A$, reverse the direction of $B$ and add it to $A$. Addition and subtraction of two vectors are shown in Figure 1.

![Addition and Subtraction Diagram](image-url)
Vectors may be represented mathematically in two ways: polar form and rectangular form.

Polar: \[ \vec{A} = A \angle \theta \]

Rectangular: \[ \vec{A} = A_x \hat{i} + A_y \hat{j} \]

where
\(A\) = magnitude of vector
\(\angle \theta\) = angle vector makes with +x axis
\(A_x\) = x component of A
\(A_y\) = y component of A
\(\hat{i}, \hat{j}\) = unit vectors in x and y direction, respectively

The formulas used to transform from one form of representation to the other can be derived by applying simple trigonometry to the typical vector shown in Figure 2.

![Figure 2](image)

\[ A_x = A \cos \theta \quad A_y = A \sin \theta \]
\[ |\vec{A}| = (A_x^2 + A_y^2)^{1/2} \]
\[ \theta = \tan^{-1} \left( \frac{A_y}{A_x} \right) \]

In order to add or subtract vectors, first write all vectors in rectangular form. Then add or subtract all x components and all y components separately. For example,

\[ \vec{A} = A_x \hat{i} + A_y \hat{j} \]
\[ \vec{B} = B_x \hat{i} + B_y \hat{j} \]

Resultant = \[ \vec{A} + \vec{B} = (A_x + B_x) \hat{i} + (A_y + B_y) \hat{j} \]

**EQUIPMENT:**

- Ruler
- Weight hangers
- Protractor
- String
- Weights
- Force Table
PROCEDURE:

1. Solve the vector problems given below graphically. For example, for problem 1, first choose a scale that will work. Say you take 3 cm to represent the length of $\vec{A}$ and 4 cm the length of $\vec{B}$. Draw a line 3 cm long at an angle of 45° to the x-axis. Then, starting at the end of that line, draw a line 4 cm long at an angle of 135° with the x-axis. The line joining the initial point to the final point is the vector $\vec{D} = \vec{A} + \vec{B}$. Measure the length of the line and scale it back to the original units. Also, measure the angle that the line makes with the x-axis.

2. Solve the same problems mathematically and express your results in polar form. Compare these results with those of procedure 1.

3. Set up the force table so that the tension in the strings represent the given vectors. The force table consists of a circular metal platform with degree markings. Some platforms have markings running both clockwise and counterclockwise. Choose one direction and use it consistently. Pulleys can be clamped at the degree markings and there is a central ring that fits over a peg with strings attached to it. The strings hang over the pulleys and weights can be attached to the ends. To solve the first problem, attach 150 grams (the 50-gram weight hanger plus 100 grams) to one string and hang it over a pulley placed at the 45° mark. Then attach 200 grams to a second string and hang it over a pulley placed at the 135° mark. Now tug at a third string to see in what direction you need to pull to get the ring centered over the page. Next, place a pulley at that location and hang enough weights until the ring is centered. This will give you the magnitude and direction of the vector that cancels $\vec{A} + \vec{B}$. This vector is called the equilibrant and is equal to $-\vec{D}$. To find $\vec{D}$, reverse the direction, i.e. add or subtract 180° from the angular location of the pulley.

4. Continue this procedure and solve for the remaining problems.

DATA ANALYSIS:

1. From the equilibrants found in Step 4 calculate the resultants (in polar form).

2. Calculate the per cent error between the magnitude of the resultants found using the force table and those calculated.

3. Arrange your results in a table showing the given vectors, the resultants and the per cent errors. Express all vectors in this table in polar form.
PROBLEMS:

1. \( \vec{A} = 150 \angle 45^\circ \)  \( \vec{B} = 200 \angle 135^\circ \)  
   Find \( \vec{D} = \vec{A} + \vec{B} \)

2. \( \vec{A} = 150i - 200j \)  \( \vec{B} = 100 \angle 180^\circ \)  
   Find \( \vec{D} = \vec{A} + \vec{B} \)

3. \( \vec{A} = 100i - 100j \)  \( \vec{B} = -100i - 200j \)  
   Find \( \vec{D} = \vec{A} + \vec{B} \)

4. \( \vec{A} = 100 \angle 30^\circ \)  \( \vec{B} = 200 \angle 150^\circ \)  \( \vec{C} = 100 \angle 75^\circ \)  
   Find \( \vec{D} = \vec{A} + \vec{B} + \vec{C} \)

5. \( \vec{A} = 50 \angle 45^\circ \)  \( \vec{B} = 100 \angle 120^\circ \)  \( \vec{C} = 180 \angle 240^\circ \)  
   Find \( \vec{D} = \vec{A} + \vec{B} + \vec{C} \)
INTRODUCTION: One of the most effective methods of describing motion is to plot graphs of position, velocity, and acceleration vs. time. From such a graphical representation, it is possible to determine in what direction an object is going, how fast it is moving, how far it traveled, and whether it is speeding up or slowing down. In this experiment, you will use a Motion Detector to determine this information by plotting a real time graph of your motion as you move across the classroom.

The Motion Detector measures the time it takes for a high frequency sound pulse to travel from the detector to an object and back. Using this round-trip time and the speed of sound, you can determine the position of the object. The computer will perform this calculation for you. It can then use the change in position to calculate the object’s velocity and acceleration. All of this information can be displayed either as a table or a graph. A qualitative analysis of the graphs of your motion will help you develop an understanding of the concepts of kinematics.

OBJECTIVES

- Analyze the motion of a student walking across the room.
- Predict, sketch, and test position vs. time kinematics graphs.
- Predict, sketch, and test velocity vs. time kinematics graphs.

MATERIALS

- computer
- Vernier Motion Detector
- Vernier computer interface
- meter stick
- Logger Pro program
- masking tape
**PROCEDURE**

1. Connect the Motion Detector to the DIG/SONIC 1 channel of the LabPro.

2. Plug the transformer for the Lab pro into the outlet and the LabPro, this provides the power to run the device.

3. Use the black cable provided and plug the square end into the LabPro and the USB end into the computer USB port.

4. Place the Motion Detector so that it points toward an open space at least 4 m long.

5. On your computer, click on the Logger Pro 3.3 icon on the desk top. If the motion detector is connected then the program will immediately open a data table and two graphs: position vs. time and velocity vs. time. Look at the upper left hand corner of the page to make sure there is a little LoggerPro icon. If you see a message “No device connected,” then we will need to check all connections and make sure our detector is working.

6. Set up your data collection so that you take data for approximately 6 seconds, and scale your position and velocity graphs to approximately 4 meters and ± 2 m/s, respectively. Using LoggerPro, produce a graph of your motion when you walk away from the detector with constant velocity. To do this, stand about 0.5 m from the Motion Detector and have your lab partner click the small green box with the arrow in it in the upper right hand corner. Walk slowly away from the Motion Detector when you hear it begin to click. Check to make sure that the detector records your motion from about half a meter away to about 4 or 5 meters away.

7. You are now ready to take your data. Follow the directions given in the following steps and record your observations on the blank graphs provided. Be sure to keep the scales for position vs. time and velocity vs. time the same for each trial! The purpose here is to be able to see with a quick glance at your graph, whether you are moving faster or slower than in your previous trial.
DATA:
Walk as described below, then sketch the motion graphs. Do not show every tiny peak, instead draw a smooth curve of the most important details. Add numbers to the graphs according to the scale on your computer screen. Be sure to keep the scales the same for each trial.

1. Walk away from the detector slowly and steadily.

2. Walk away from the detector medium fast and steadily.

3. Walk toward the detector slowly and steadily.

4. Walk toward the detector medium fast and steadily.

5. Walk away from the detector, increasing your velocity.
Use the graphs you made for #1 through #5 to complete the following exercises. Be sure the scales of the graphs are the same when making comparisons.

6. Describe the difference between the distance graph made by walking away slowly and the distance graph made by walking away more quickly from the detector.

7. Describe the difference between the distance graph made by walking toward and the distance graph made walking away from the motion detector.

8. Describe the difference between the velocity graph made by walking away slowly and the velocity graph made by walking away more quickly from the detector.

9. Describe the difference between the velocity graph made by walking toward and the velocity graph made walking away from the motion detector.

10. Describe the difference between the distance graph made walking at a steady rate and the distance graph made at an increasing rate.

11. Describe the difference between the velocity graph made walking at a steady rate and the velocity graph made at an increasing rate.
Study of Motion Problems

Answer the following questions and/or complete the graphs. You may check your answers with the Sonic Ranger if you like.

1. How must you move to make a horizontal line on a distance graph?

2. An object moves away from the origin at a constant velocity.

3. How must you move to make a downward sloping straight line on a distance graph?

4. How must you move to make a curved line like a ski slope on a distance graph?

5. How must you move to make a downward sloping straight line which is above the origin on a velocity graph?
6. How must you move to make a horizontal line above the origin on a velocity graph?

<table>
<thead>
<tr>
<th>Distance</th>
<th>Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td></td>
</tr>
</tbody>
</table>

7. How must you move to make a horizontal line below the origin on a velocity graph?

<table>
<thead>
<tr>
<th>Distance</th>
<th>Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td></td>
</tr>
</tbody>
</table>

8. An object moves at a constant velocity toward the origin for half the time, then stands still.

<table>
<thead>
<tr>
<th>Distance</th>
<th>Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td></td>
</tr>
</tbody>
</table>

9. An object moves away from the origin at a constant velocity for half the time, then moves toward the origin at the same speed.

<table>
<thead>
<tr>
<th>Distance</th>
<th>Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td></td>
</tr>
</tbody>
</table>

10. How must you move to make a straight line distance graph that rises steeply, then rises gradually?

<table>
<thead>
<tr>
<th>Distance</th>
<th>Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td></td>
</tr>
</tbody>
</table>
The motions of two objects, A and B, are recorded on the distance-time graphs below. Use the graphs to answer the following questions.

11. a) Which object is moving faster, A or B?
   
   b) Which object started further from the origin?
   
   c) What does the intersection of the two lines mean?

12. a) Which object traveled the greatest distance in the time period?
   
   b) Which object is moving faster, A or B?
   
   c) Which object has a negative velocity?

13. a) Which object is moving at a constant velocity?
   
   b) Which object is moving toward the detector?
   
   c) How does the average speed of A compare with B?
   
   d) Was A traveling faster at the beginning or end of the time period?
Experiment No. 3

Linear Motion

**Purpose:** The purpose of the lab is to analyze the linear motion of an object subject to a constant force and verify the interrelationship between displacement, velocity, acceleration and force.

**Procedure:** Connect the air track to an air source and make sure that the cart selected rides smoothly on the track. Use the leveling screws to level the track which is determined when the cart stays motionless in the center of the track. Use the height adjustment screw at one end to tilt the track from level. Verify that one complete turn is 1 mm. The inclined angle can now be calculated from the length and height as indicated by

\[
\theta = \tan^{-1}\left(\frac{\text{height}}{\text{length}}\right)
\]

Next, affix the spark tape to the side of the track and attach the spark generator. Be careful as the spark generator produces a high voltage discharge which can be painful. At the moment the cart is released from the top of the track, start the spark generator and stop the generator when the cart reaches the end of the track.

Remove the spark tape and label the recorded marks. In a spreadsheet create a column that contains the time for each point and then record the displacement of the remaining marks from the first one in cm in the next column. In the third column write a formula that subtracts the two neighboring displacement cells and divides by the time between marks to calculate the velocity. In the fourth column enter the midpoint of the time interval for which the average speed applies. Finally, in column five, write a formula that calculates the change in velocity from the neighboring cells of velocity and divides by the time between marks to calculate the acceleration. Then, based on the angle of the track you calculated, determine the value of “g”.

Plot the displacement, velocity and acceleration as a function of time in Excel. Fit a trendline (power) to the data and include it on each graph. Compare results to the theoretical results of \(x = \frac{1}{2} at^2\), \(v = at\), and \(a = \text{const} = g \sin(\theta)\)

Repeat for one other angle of incline.

**Theory:** The cart feels a constant net force of \(mg \sin(\theta)\) down the track which produces an acceleration \(a = g \sin(\theta)\).
Objective: To measure the initial velocity of a projectile, and to study the motion of a projectile with a known initial velocity that is launched at an angle.

Equipment: The projectile motion device, adjustable inclined plane, meter sticks, carbon, cardboard, and plain paper, safety glasses.

CAUTION:

PLEASE WAIT FOR THE INSTRUCTOR TO DEMONSTRATE THE EQUIPMENT USED IN THIS EXPERIMENT. The experiment should be done with care, away from glass windows or other workers’ tables, etc. All members of the team must wear the safety glasses provided.

PART I: MEASUREMENT OF THE SPEED OF THE PROJECTILE

Introduction:

The range of a projectile when fired horizontally depends on the height (h) at the point of release, the initial velocity, \( v_0 \), and the acceleration due to gravity, “g”. In this part of the lab the range (x) and the height are measured when the projectile is fired horizontally and the initial velocity (\( v_0 \)) is calculated. Two or three different heights are needed to obtain a reasonably accurate value of the average velocity \( v_0 \). Also, three or four trials at each height are needed to ascertain the average value of the range (x) for a given value of h.

Theory:

The range of a projectile when fired from a certain height can be found from the time of flight (t). This value of t is the time taken by an object to fall freely from a vertical height \( y_o = h \). The height h and the time t are related by the equation:

\[
y = y_o + v_{oy} t + \frac{1}{2} a_y t^2
\]

Since the projectile is launched horizontally, the y-component of the initial velocity, \( v_{oy} \), is zero, and for a falling object, \( a_y = -g \). This reduces the above equation to:

\[
h = \frac{1}{2} gt^2
\]

(5.1)

Where “g” is the acceleration due to gravity in the lab (the accepted value for g is 9.796 m/s^2). Solving for the unknown quantity “t”, we get:
During this time, \( t \), the projectile moves a horizontal distance \( x \). The horizontal distance it moves during the time it falls is given by

\[
x = x_o + v_o t + \frac{1}{2} a_x t^2
\]

Since there is no acceleration (we ignore the small effect of air resistance) in the x-direction, all of the initial velocity is in the x-direction, and \( x_o \) is taken to be zero on our ruler, this reduces to

\[
x = v_o t
\]  

(5.3)

Combining equations 5.2 and 5.3, and solving for the unknown, \( v_o \), we get:

\[
v_o = \frac{x}{t} = x \sqrt{\frac{g}{2h}}
\]

(5.4)

Eq. (5.4) is the basis of determining the initial velocity of a horizontally launched projectile from the measurements of range \( x \) and height \( h \). Be sure that you understand the physical basis of this result.

**Procedure:**

1. Locate a suitable place for doing the experiment. Familiarize yourself with the equipment, its adjustments, etc. Be sure that you have chosen a safe area for launch, and watch out for wandering people.

2. Measure the height of the projectile above the floor and enter the value in Table 5.1. This is measured from the bottom of the projectile (sphere) to the surface of the floor. This is the distance the projectile will fall.

3. Use the lowest power setting on the launcher and perform a trial launch to determine the approximate location of impact of the projectile when fired from the table top. Then place a plain piece of paper backed by carbon paper near that location. Tape the corners to the floor to prevent sliding. Then fire the projectile to see if the point of impact is seen on the plain paper.

4. Obtain three trial values of the range (\( x \)) when the projectile is fired horizontally. Check to see if they agree within 1-2\% of each other.
5. Determine the average value of three trials to determine x.

6. Calculate the values of the initial velocities \( v_0 \) using Eq. (5.4).

**PART II: RANGE OF A PROJECTILE LAUNCHED AT AN ANGLE**

As explained in the text (see reference), the range, x, of a projectile when fired from the ground depends on the initial velocity, \( v_0 \), and the acceleration due to gravity, \( g \). Since we now know the initial speed with which the launcher fires the projectile, and the angle and height from which we will launch it, we have all the information necessary to predict its landing point. Your challenge, for this part of the lab, is to predict the landing point of your projectile. The initial velocity is defined by the speed \( (v_0) \) and the angle \( (\theta_0) \), and the range \( (x) \) is measured. This measured value of x will be compared to the calculated value \( x' \). If the experiment is done carefully, the measured value \( x \) should agree with the calculated value \( x' \) within 3%. A percent difference of 5% is acceptable. Good luck!

**Theory:**

When a projectile is fired from a height \( h \), with a speed \( v_0 \) at an angle \( \theta_0 \) the range \( x \) can be calculated from the time of flight \( t \), as explained in PART I. The time of flight \( t \) is the same as that of a body released vertically with a velocity of \( v_{oy} = v_0 \sin \theta_0 \). The equation of motion for the vertical part is given by

\[
y = y_o + v_{oy}t + \frac{1}{2}a_y t^2
\]

(5.5)

where \( y_0 = h \), the initial height of the projectile, \( y = 0 \), the final height of the projectile, and \( a_y = -g = -9.796 \text{ m/s}^2 \). The value \( t \) is the time the projectile is in the air; the time for it to go from point \( y_0 \) to point \( y \). Thus, we get the equation for solving for the time of flight \( t \) as:

\[
h = - (v_0 \sin \theta_0)t + \frac{1}{2}gt^2
\]

(5.6a)

or in standard form

\[
\frac{1}{2}gt^2 - (v_0 \sin \theta_0)t - h = 0
\]

(5.6b)

Eq. (5.6b) is a quadratic equation in \( t \), so we can use the quadratic formula to write down the solution for \( t \) using the larger of the two roots as:

\[
t = \left( v_0 \sin \theta_0 + \sqrt{(v_0 \sin \theta_0)^2 + 2gh} \right)/g
\]

(5.6c)

During the time \( t \), the horizontal component of the velocity of the projectile is practically unchanged. The horizontal component is \( v_0 \cos \theta_0 \), and so the range \( x \) is simply the distance traveled by an object with a constant speed in time \( t \). This is given by
Eq. (5.8) is the basis for PART II of the experiment, namely, comparison of the calculated and the measured values of range \(x\).

**Procedure:**

Locate a suitable place for using the equipment and set up the device on a table top.

1. Set up the launcher, raised to the angle of 20°, and record the height. Calculate the value of \(x'\), the distance you predict the projectile will travel when shot from this angle.

2. Take a sheet of plane paper, backed with carbon paper and place the center of your page at the distance you predict the ball will land. Mark this distance on your paper. A horizontal line at the distance \(x'\) from the launcher works well.

3. Show your predicted projectile range to your instructor, or check with other groups, to see if your predicted value seems reasonable. Sign errors in calculations or incorrect computation of initial velocity components can cause errors in predictions.

4. Recheck your measured values, then launch your projectile. Obtain three values for \(x\). Check to make sure that the values of \(x\) agree with each other to within about 1-2%. A common problem at this step is a shift in the value of \(\theta_o\) after a launch, due to one or both screws holding the launcher at an angle not being tight enough. Sometimes the launcher itself will shift on the table.

5. Find the average \(x\) of the three trials and compare your measured value of \(x\) with the value \(x'\) you predicted. Calculate the percent difference in your values of \(x\) and \(x'\). Were you close? What might have caused your error?
OBJECTIVE: To measure the Young’s Modulus (Y) of a metal wire using an optical lever and a laser beam; to look at the relationship between the stress on a material and its resulting strain.

EQUIPMENT:
(1) The Young’s Modulus Apparatus (YMA).
(2) Set of 1 and 2 kg weights to total between 10 and 20 kg.
(3) The optical lever with mirror.
(4) Milliwatt Laser
(5) Meter stick & Tape measure for measuring distances 5 < D < 10 meters.
(6) Graphing program (such as Excel) for analyzing (Stress) vs Strain.
(7) Micrometer for measuring radius “r” of the wire (∓0.01 mm)

THEORY: Interatomic forces that hold atoms together are particularly strong, so considerable force must be used to stretch a solid object. Experiments have shown that the magnitude of the force can be expressed by the following relation, provided that the amount of stretch is small compared to the original length of the object: Young’s modulus is defined as Stress/Strain which are defined as

$$\text{Stress} = \frac{F}{A}, \quad \text{Strain} = \frac{\Delta L}{L_0}, \quad \text{and} \quad Y = \frac{\text{Stress}}{\text{Strain}} = \frac{FL_0}{A\Delta L}$$  \hspace{1cm} \text{Eq. 1}

where F is the force applied to stretch the material, A is its cross-sectional area, \(\Delta L\) is the amount the object stretches, and \(L_0\) is its original length. The quantity Y is called Young’s modulus, or the modulus of elasticity, and is a property of the material itself that describes the way it responds to applied stresses. The quantity \(F/A\) is the stress applied to the object, and its response is called strain and is designated by \(\Delta L/L_0\). In this experiment we will add weights to stretch a metal wire attached to a support. The stretch of the wire \(\Delta L\) depends on the modulus of the particular material (Y), radius of the wire (r), length of the wire from the attachment point at the top to the point where we attach the optical lever (L), and the load we apply to the wire (Mg). For a steel wire, with a load of 1 kg (9.8 N) the change in length \(\Delta L\) is a fraction of a mm and so it takes a special technique to measure this. An optical method using the laser and an optical lever is used to measure this small change in length \(\Delta L\) accurately.

![Fig. 1: Relationship between applied force and stretch of a wire.](image-url)
Equation 1 can be rearranged, and substitution for A made, so that it takes the form:

\[
\text{Stress} = \frac{Mg}{\pi \nu^2} \quad \text{and} \quad \text{Strain} = \frac{\Delta L}{L} \quad \text{Eqns. (2)}
\]

In the above equation, the value of Y is determined from the slope of the Stress vs Strain graph (which should yield a straight line). For each value of the load Mg, the change in length \(\Delta L\) is calculated from the deflection \(\Delta y\) of the laser beam. This deflection \(\Delta y\) and change in length \(\Delta L\) are computed from the following equations:

\[\tan(2\theta) = \frac{\Delta y}{D} \Rightarrow 2\theta = \frac{\Delta y}{D}, \quad \text{for } 2\theta \text{ small, where } 2\theta \text{ is the angle of the reflected ray, and}\]

\[D \text{ is the distance from the mirror on the optical lever to the image of the laser beam and,}\]

\[\tan(\theta) = \frac{\Delta L}{d} \Rightarrow \theta = \frac{\Delta L}{d}, \quad \text{for small } \theta, \text{ where } d \text{ is the length of the optical lever.}\]

Thus, \(\Delta L = \frac{d}{2} \frac{\Delta y}{D}\)

(Note: When the OL turns thru angle \(\theta\), the reflected beam turn thru \(2\theta\).)

**Figure 2**: Set-up of laser and optical lever.

**PROCEDURE**:

1. Start by taking a level and making sure that the Young’s modulus apparatus is level. This will prevent the weights from leaning against the supports as you load them. Set up the optical lever (OL) so that the two legs under the mirror are in the groove of the fixed support of the YMA, and the other single leg is resting on the movable support attached to the steel wire as shown in Fig. 2.

2. Next place a small board or a few small slotted weights under the laser tube so that the laser beam falls approximately at the center of the mirror attached to OL.

3. Next, change the tilt of the mirror so that the reflected laser beam lands on the black-board showing a bright spot. Adjust the tilt of the mirror so that the bright spot is at the lowest part
of the paper attached on the blackboard. Circle and label the initial laser beam spot on the paper.

4. Next you are ready to take the data of load (Mg) vs. deflection (Δy). During this data acquisition, be careful not to touch or change the positions of the OL, its mirror, or the laser.

5. Increase the load W from 2 kg to 10 or 12 kg, in one or two kilogram increments, circling the laser beam spot on the paper attached to the black-board each time, and noting the total mass on the weight hanger. The corresponding deflection Δy is the distance of the center of the beam spot from the initial dot. Enter your data in the table below.

6. Measure the distance, D, from the board to the mirror and enter in the space below.

7. Next plot your data Stress F/A (y axis) and Strain ΔL/L₀ (x axis) and using linear fit, obtain the slope (Young’s Modulus) in the units of N/m².

8. Be sure to list the letter of apparatus your group used for its measurements, so that your results can be checked against that apparatus’ known parameters. Your report should also have the names of all partners in the group.

9. Attach your graph of Stress verses Strain including the equation of the best fit line in your data or analysis.

10. Complete the problem below as part of your analysis.
INTRODUCTION:

Vibrations occur in a system when it is displaced from a configuration of stable equilibrium. When this happens, a restoring force acts so as to bring the object back to its equilibrium position. Inertia causes the system to overshoot this position, and thus oscillations occur. When the restoring force is directly proportional to the displacement the system is said to obey Hooke's Law and the resulting motion is called Simple Harmonic Motion (SHM). Because the shape of the displacement-graph is a sine or cosine curve, SHM is sometimes called sinusoidal motion.

All systems are deformed in some way by the application of a force, no matter how small that force may be. A perfectly elastic system will return to its original shape when the force is removed. In any actual case, there is a practical limit to the magnitude of the force which may be applied if the system is to return to its original shape. This is called the elastic limit of the system. If a force larger than this is applied, a permanent distortion will occur and the system will never return to its original shape.

The object of this experiment is to study a system that obeys Hooke's Law and vibrates in the simple manner called simple harmonic motion and to study a system that departs from SHM when the amplitude of the displacements is large.

THEORY:

One of the most important properties of an elastic body is that the ratio of the magnitude of the applied force to the deformation is constant. This is known as Hooke's Law. In the case of a coil spring the law can be expressed in the form of a simple equation:

\[ F = -kx \]

where \( F \) = force exerted by the spring
\( x \) = amount of stretch
\( k \) = spring constant

If an object of mass \( m \) is attached to the spring and the spring is stretched, the motion of the mass obeys Newton’s second law:

\[ m \frac{d^2x}{dt^2} = -kx \]

The solution of this equation is:

\[ x = A \cos(\omega t + \phi) \]

where \( A \) = amplitude
\( \omega \) = angular frequency
\( \phi = \text{phase angle} \)
and the frequency is related to the spring constant and the mass as follows:

\[
\omega = \sqrt{\frac{k}{m}}
\]

For the pendulum of mass \( m \) and length \( l \), the equation of motion is

\[
ml \frac{d^2 \theta}{dt^2} = -mg \sin \theta
\]

If \( \theta \) is small, this can be approximated by

\[
ml \frac{d^2 \theta}{dt^2} = -mg \theta
\]

The solution is

\[
\theta = \theta_o \cos(\omega t + \phi)
\]

where \( \theta_o \) is the amplitude, and \( \omega \) is given by

\[
\omega = \sqrt{\frac{g}{l}}
\]

**EQUIPMENT:**
- Hooke's law apparatus
- Meter stick
- Pendulum
- Stop watches or computer for timing oscillations
- Weights and weight hangers
- Ringstand and clamps

**PROCEDURE:**

1. Read the initial position of the pointer (to the nearest 0.001 m) on the weight hanger attached to the spring and record it in your data table. This position corresponds to an applied weight of 0.0 N (even though the weight hanger does have some mass and stretches the spring a bit). Attach the weights supplied in steps of 20 g recording the new position of the pointer and the applied mass for each trial. Continue the process until the maximum stretch is reached, or you have 8 readings.

2. Next, determine the Period of oscillation (T) for 4 different known masses (200-350 g).

3. Finally, set up a pendulum apparatus, and make measurements of the period of oscillation as follows:
   a) Keeping the angle of oscillation constant at 5 degrees, measure the time for 20 oscillations of the pendulum at lengths of 20 cm, 40 cm, etc., up to 120 cm. Calculate the period of oscillation.
   b) Keeping the length of the pendulum at 100 cm, vary the angle from 10 degrees to
c) Keeping the length of the pendulum at 100 cm and the angle at 5 degrees, replace the mass hanging from the bob by two other masses, and repeat the measurement of the period.

DATA ANALYSIS:

1. Plot the data for the spring from procedure 1 on the with the force on the y-axis and displacement on the x-axis. Fit a straight line curve to the data and determine the slope. Does this spring obey Hooke's law? Find the fitted spring constant in newtons/meter.

2. Plot the data for the spring from procedure 2 with frequency on the vertical axis and mass on the horizontal axis. Include in this mass the mass of the weight hanger and 1/3 of the mass of the spring.

3. Fit a power law curve to the data and compare it with the theoretical value.

4. Using the coefficient from the above curve fit, determine the spring constant. Compare this value with the value found from part 1 above.

6. Analyze the results obtained from the pendulum in part 3 a in a similar manner by fitting a power law curve and compare with theory.

7. Make a graph of the dependence of the period on the angle.

QUESTIONS:

1. How can one determine if a system will or will not vibrate with SHM?

2. Describe what would happen to the oscillation of a spring if the mass on the end was a container of water and the water slowly leaked out as the mass vibrated. Sketch the displacement vs. time graph.

3. We usually assume the mass of a spring to be negligible in comparison to the mass at its end. But if it is not negligible, does the mass of the spring increase or decrease the frequency of the motion?

4. Why must the mass of the weight hanger be included in the calculation of the period while it can be ignored in determining the spring constant?
INTRODUCTION:

The object of this experiment is to study uniform circular motion and to measure the centripetal force necessary to produce circular motion. Although the speed of an object in circular motion may be constant, a force is necessary to change the direction of the object. This is the centripetal force.

The apparatus used for the study and verification of the laws of motion for uniform circular motion consists of a heavy mass supported from a crossarm attached to a vertical shaft. A spring is attached from the vertical shaft to the mass. An adjustable position vertical rod, mounted on the base, serves as a radius indicator. When a constant speed is reached, the rotating mass will pass continuously over the radius indicator. The static force required to stretch the spring the same amount can be measured directly by means of the pulley arrangement mounted near the end of the base. If a string is attached to a weight hanger, passed over the pulley, and connected to the mass, weights can be added to the hanger until the spring is stretched the same amount as when the mass is rotating. This way we can find measure of the centripetal force exerted by the spring on the mass when the mass is rotating. Adjust the height of the pulleys as necessary to make the string horizontal when the weight is vertical so the force due to gravity on the weight has no horizontal component.

THEORY:
If an object is moving in uniform circular motion, its speed is constant along the circular path. Therefore, its tangential acceleration and angular acceleration are equal to zero. \( a_r = 0, \ a = 0 \) However, its direction is changing so its velocity is not constant. Consequently, the object has acceleration. Because the acceleration produces a change in direction only, it must be directed at right angles to the velocity; that is, toward the center of the circle. The acceleration is called radial or centripetal acceleration and is given by

\[
a_c = \frac{v_r^2}{r}
\]

A net force is necessary to produce any acceleration, whether it involves a change in magnitude or a change in direction. The magnitude of this force is, from Newton’s 2nd law:

\[
F_c = ma_c
\]

\[
= m \frac{v_r^2}{r}
\]

And the direction of the force is in the same direction as the acceleration, toward the center of the circle.

**EQUIPMENT:**

- Centripetal force apparatus
- Weights
- Meter stick
- String
- Weight hanger
- Stopwatch or Photocell Timer

**PROCEDURE:**

1. Determine the mass of the object that is to be rotated.

2. Replace the object and adjust the radial indicator to its closest position to the vertical shaft. Position the crossarm so that the object hangs freely directly over the indicator. Measure the radius of rotation of the object.

3. Attach the spring from the vertical shaft to the object and rotate the system at a constant speed so that the object passes over the indicator. Time the motion for 50 complete rotations. Repeat twice more to get an average time.

4. Connect the weight hanger to the mass by means of a string and suspend it over the pulley. Add weights until the object is again positioned over the indicator.

5. Repeat procedures 1-4 above for two or more positions of the radial indicator.
6. Now choose one of the radial positions used above and keep it constant for the next series of measurements. Remove one of the side weights on the object and repeat the above procedures keeping the radius of rotation constant. Again determine the force necessary to stretch the spring so that the mass is directly over the indicator. Repeat once more by removing the other side mass on the weight.

**DATA ANALYSIS:**

1. Design a Summary of Results Table
2. Calculate the average angular speed of the object in radians per second for each case.
3. Calculate the tangential velocity for each case.
4. Calculate the centripetal acceleration of the object for each case.
5. Calculate the centripetal force on the object for each case.
6. Compare the force required to stretch the spring to the calculated centripetal force. Using the measured force as the actual value, calculate the percent error.

**QUESTIONS:**

1. Draw a force diagram on the rotating mass. How many forces act in the horizontal direction?
2. Using vector diagrams show the direction of the following vector quantities studied in this experiment.
3. How does the magnitude of the centripetal force vary when the radius of rotation is increased? When the mass of the rotating object is increased?
4. Explain the different between “centripetal” force and “centrifugal” force.
Experiment No. 8

WORK, ENERGY AND POWER

Objectives: To understand work and its relation to energy and power; To understand how energy can be transformed from one form into another.

Equipment and Supplies: Balloons, golf/tennis/super balls, meter stick, and a timer.

Introduction: In the physical world, the possession of energy by an object means that it has an ability to do work. Work done is a measure of the “effect” the application of a force produces. If the applied force and the displacement of the object are in the same direction, then the work done is given by,

\[ \text{Work Done} = \text{Force} \times \text{Distance}. \]

Mechanical energy has several different forms. Elastic Potential Energy is the stored energy by virtue of an object’s configuration. When you stretch a spring, you are doing work on the spring and in turn the spring stores that work in the form of elastic potential energy. Gravitational Potential Energy, on the other hand, is the stored energy by virtue of an object’s height (position). When the gravitational force is the only force on an object, the gravitational potential energy is calculated from

\[ \text{Gravitational Potential Energy} = \text{Weight} \times \text{Height} \]

Energy that exists by virtue of an object’s motion is called the Kinetic Energy. The law of conservation of energy is a universal principle that says that the total energy of a system always remains constant. In other words, energy cannot be created or destroyed but it can be converted from one form into another.

When work is done on an object, any of the following things can happen:
- The object may, in turn, do work on another object,
- The object’s speed may increase (gain in kinetic energy),
- The object’s temperature may rise (gain in thermal energy),
- The object may store the energy for later use (gain in potential energy),
- The object may rise in the earth’s gravitational field (gain in gravitational potential energy).

In many situations not only is the amount of work done important, but also how slowly or how quickly it is done is also important. The rate at which work is done or energy is transformed is called Power. Therefore, the power is calculated as follows.

\[ \text{Power} = \frac{\text{Work Done}}{\text{time}} = \frac{\text{Energy used}}{\text{time}} \]

In the first part of this lab you will learn how the work done on an object is stored as potential energy of that object. Then you will figure out the work done during various activities.
and compute the power expended. In the second part of the lab you will analyze a single phenomenon using both the momentum principle and the energy principle.

**PART I: Developing concepts of work, energy and power.**

**Procedure:**
1. Answer the questions given in your data sheet after doing the following:
   - Blow up a balloon and then release it.
   - From the ground, raise the ball to a height of about 1-meter and then release it.
2. Go to the nearest stairway. Measure the height of one step and the number of steps to the 2nd floor. Record your measurements.
   a. Have one of your partners climb the stairs slowly. Record the time taken.
   b. Next, climb at a faster speed and record the time.
   c. Complete the calculations to find the energy used to raise your center of mass, and your power output.

**Analysis Questions:**
1. When you drop the golf ball from a certain height, does it return to the same height after bouncing from the floor? Does that violate the conservation of energy principle? Explain.
2. When climbing the stairs, is the work done greater, smaller or the same when you climb fast or slow? What about the power output? Explain.
3. Given that 4200 Joules = 1 Food Calorie, calculate the number of Calories used by you in climbing to the 2nd floor. How many stories (approximately) would you have to climb to turn 100 Calories (energy equivalent of 1 cookie!) of energy into gravitational potential energy? Comment on these results.

**PART II: Analyzing a phenomenon using the momentum principle and the energy principle.**

**Procedure:** (You will need 3 people for this activity.)
1. Throw a ball straight up as high as possible, but not so high that it’s difficult to measure the maximum height attained. This can be done in an ordinary room, though if you can find a place to throw the ball higher, you’ll be able to measure the longer time of flight more accurately.
2. The second person starts the stopwatch just after the ball is released and stops it when the ball returns to the height at which it was released. In the approximation that we neglect air resistance, the round trip time is twice the time required to get up to the maximum height. Note that during the round trip time, no one is touching the ball.
3. A third person stands off to the side, observes the flight of the ball, and uses a meter stick to determine how high the ball goes from the point where it was released.
4. Record the round trip time, the time to reach maximum height, and the maximum height for two trials in a data table.

**Analysis Questions:**
1. Using the **momentum principle**, use your experimental observations to determine the initial speed of the ball. *(Notes: Do NOT use numbers (except for zero) until asked to*
do so, and be careful of signs. Use \( m \) for the mass of the ball, \( v \) for the initial speed, and \( \Delta t \) for the time to reach the top. Use \( g \) to represent +9.8 N/kg.) For the system of the ball, write the momentum principle for this specific situation, where

a. Initial state: just after the ball leaves your hand
b. Final state: when the ball reached its maximum height

Solve for an expression for the initial speed, \( v \). (Note: expression should have NO numbers!)

CHECKPOINT Compare your results with another group

2. Now use your experimental numbers to predict the initial speed for each of your two trials. Show your calculations. Check your units and the reasonableness of your values. (Note: a professional pitcher can throw a baseball at about 40 m/s (90 mi/hr)).

3. Using the energy principle, use your experimental observations to determine the initial speed. (Notes: Do NOT use numbers (except for zero) until asked to do so, and be careful of signs. Use \( m \) for the mass of the ball, \( v \) for the initial speed, and \( y \) for the maximum height. Use \( g \) to represent +9.8 N/kg.) For the system of the ball, write the energy principle for this specific situation, where
   o Initial state: just after the ball leaves your hand
   o Final state: when the ball reached its maximum height

Solve for an expression for the initial speed, \( v \). (Note: expression should have NO numbers!)

CHECKPOINT Compare your results with another group

4. Now use your experimental numbers to predict the initial speeds for each of your two trials. Show your calculations. Check your units and the reasonableness of your values.

5. Results: For each trial, compare the initial speed predicted by the two different methods. Are your results consistent?

6. What is the momentum at the maximum height? Explain.

7. If the initial velocity were doubled, how would the time to reach maximum height change? Explain.

8. If the initial velocity were doubled, how would the maximum height change? Explain.

Reflection: The momentum principle involves time; the energy principle involves distance. Look back over your analysis and see how the two principles complement each other, involving different kinds of information about the phenomenon.
Data:

**Part I:** Answer the following questions as you complete the lab

**Energy storage in a balloon:**
1. Do you do work when you blow up a balloon? How do you know?

2. In what form is energy stored in a blown up balloon?

3. How can you get the stored energy out of the balloon? Where does it go?

**Energy storage in a ball:**
1. Do you do work when you raise the ball to 1 meter height? How do you know?

2. In what form is the energy stored at 1 m height?
3. What happens to this stored energy as the ball falls to the ground? Explain.

Work and Power:

Your mass: ________________________________  Sample Calculations:
Your weight: _______________________________
Height of one step: _________________________
Number of steps to 2nd floor: ________________
Total distance to 2nd floor: __________________
Work done climbing to 2nd floor:______________
Time taken while climbing slowly: ____________
Time taken while climbing faster: ____________
Power output (slow): _________________________
Power output (fast): _________________________

Part II:

Table: Throwing a ball up in the air

<table>
<thead>
<tr>
<th>Round trip time (s)</th>
<th>One-Way time (s)</th>
<th>Maximum Height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
MECHANICAL EQUIVALENT OF HEAT

OBJECT: To determine the mechanical equivalent of heat, i.e., the number of joules in one calorie.

EQUIPMENT:

Mechanical Equivalent of Heat Apparatus  
(aluminum cylinders must be cooled in the refrigerator ahead of time, or ice is needed to cool them quickly during the experiment)
Digital Ohmmeter
Known mass (pail of sand)
Thermometer
Calipers
Balance
Rubber bands

INTRODUCTION:

The Mechanical Equivalent of Heat apparatus consists of a crank, which is used to rotate an aluminum cylinder. The rotation is opposed by the torque applied by the known weight through a nylon rope that is wrapped around the cylinder. The apparatus is equipped with a counter to keep track of the number of turns, and the aluminum cylinder has a thermistor embedded in it, which is a resistor whose resistance changes with temperature. The work done by the crank is the torque multiplied by the angle $\theta$ turned by the crank. $\theta$ is $2\pi$ times the number of revolutions turned, and the torque is the tension on the string multiplied by the radius of the aluminum cylinder. This work is converted into heat, and the amount of heat, in calories, can be found by multiplying the mass of the aluminum cylinder by the specific heat of aluminum (0.22 calories per gram per degree centigrade) and by the change in temperature of the cylinder. Equating work to heat gives the mechanical equivalent of heat. To compensate for heat transfer between the cylinder and the room, we start with a cylinder that is, say, 10$^\circ$ colder than the room, and heat it until it is 10$^\circ$ warmer than the room. In this way, the heat gained from the room in the initial stages should be approximately equal to the heat lost in the final stages of the experiment.
PROCEDURE:

1. Clamp the apparatus securely to the workbench.

2. Measure and record room temperature.

3. Wipe the cooled cylinder dry and slide it into the crank shaft, with the copper plated board facing towards the crank. The pins on the drive shaft should fit into the slots in the plastic ring on the cylinder. Tighten securely with the black knob.

4. Connect the digital ohmmeter to the apparatus, and select the appropriate range for the ohmmeter. A calibration curve of resistance vs. temperature for the thermistor is provided.

5. Wrap the nylon cord 4 to 6 times around the aluminum cylinder in a single layer. The end nearest to the crank should hang through the slot in the base plate and be attached to the pail of sand.

6. Attach a rubber band to the other end of the nylon cord. Applying a slight amount of tension at this end, turn the crank until the pail is lifted about 3 cm off the floor. Stop cranking and, while keeping the tension, attach the rubber band to the eyebolt on the baseplate. Adjust the number of turns that the rope is wound, if necessary. With more turns, the pail will rise more.

7. Set the counter to zero. The temperature of the cylinder will be rising as it absorbs heat from the room. Determine a suitable starting temperature. When the ohmmeter registers the correct starting value, start ranking rapidly until you reach a temperature one degree below the ending value. Then crank slowly until it reaches the final value, and stop cranking. The temperature may rise further after you stop cranking; watch the ohmmeter and record the highest temperature reached as your final temperature.

8. Record the number of turns shown on the counter.

9. Measure and record the diameter of the cylinder and the mass of the cylinder.

10. Using the procedure outlined in the introduction, calculate the mechanical equivalent of heat.

Answer the following questions in your analysis:

1. Why is it best to start the experiment below room temperature and to end above?
2. What were the major sources of error in determining the amount of heat gained by the aluminum cylinder?
3. What were the major sources of error in determining the amount of work done?
4. Where does the energy produced by the friction in the band as it rubs against the aluminum cylinder go? On an atomic level, what is happening?
Experiment No. 10

AIR RESISTANCE

When you solve physics problems involving free fall, often you are told to ignore air resistance and to assume the acceleration is constant and unending. In the real world, because of air resistance, objects do not fall indefinitely with constant acceleration. One way to see this is by comparing the fall of a baseball and a sheet of paper when dropped from the same height. The baseball is still accelerating when it hits the floor. Air has a much greater effect on the motion of the paper than it does on the motion of the baseball. The paper does not accelerate very long before air resistance reduces the acceleration so that it moves at an almost constant velocity. When an object is falling with a constant velocity, we prefer to use the term terminal velocity, or $v_T$. The paper reaches terminal velocity very quickly, but on a short drop to the floor, the baseball does not.

Air resistance is sometimes referred to as a drag force. Experiments have been done with a variety of objects falling in air. These sometimes show that the drag force is proportional to the velocity and sometimes that the drag force is proportional to the square of the velocity. In either case, the direction of the drag force is opposite to the direction of motion. Mathematically, the drag force can be described using $F_{\text{drag}} = -bv$ or $F_{\text{drag}} = -cv^2$. The constants $b$ and $c$ are called the drag coefficients that depend on the size and shape of the object.

When falling, there are two forces acting on an object: the weight, $mg$, and air resistance, $-bv$ or $-cv^2$. At terminal velocity, the downward force is equal to the upward force, so $mg = -bv$ or $mg = -cv^2$, depending on whether the drag force follows the first or second relationship. In either case, since $g$ and $b$ or $c$ are constants, the terminal velocity is affected by the mass of the object. Taking out the constants, this yields either

$$v_T \propto m \quad \text{or} \quad v_T^2 \propto m$$

If we plot mass versus $v_T$ or $v_T^2$, we can determine which relationship is more appropriate.

In this experiment, you will measure terminal velocity as a function of mass for falling coffee filters and use the data to choose between the two models for the drag force. Coffee filters were chosen because they are light enough to reach terminal velocity in a short distance.

OBJECTIVES

- Observe the effect of air resistance on falling coffee filters.
- Determine how the terminal velocity of a falling object is affected by air resistance and mass.
- Choose between two competing force models for the air resistance on falling coffee filters.

MATERIALS

- computer
- Vernier computer interface
- Logger Pro
- Vernier Motion Detector
- Stop watch
- 20-30 basket-style coffee filters
PRELIMINARY QUESTIONS: (ANSWER IN ANALYSIS: PART I SECTION)

1. Hold a single coffee filter in your hand. Release it and watch it fall to the ground. Next, nest two filters and release them. Did two filters fall faster, slower, or at the same rate as one filter? What kind of mathematical relationship do you predict will exist between the velocity of fall and the number of filters?

2. If there was no air resistance, how would the rate of fall of a coffee filter compare to the rate of fall of a baseball?

3. Sketch a graph of the velocity vs. time for one falling coffee filter.

4. When the filter reaches terminal velocity, what is the net force acting upon it? Draw a free-body diagram.

PROCEDURE: Part I – Computer Data Acquisition:

1. Connect the Motion Detector to the DIG/SONIC 1 channel of the interface.

2. Support the Motion Detector about 2 m above the floor, pointing down, as shown in Figure 1.

3. Open the file “13 Air Resistance” from the Physics with Computers folder.

4. Place a coffee filter in the palm of your hand and hold it about 0.5 m under the Motion Detector. Do not hold the filter closer than 0.4 m.

5. Click to begin data collection. When the Motion Detector begins to click, release the coffee filter directly below the Motion Detector so that it falls toward the floor. Move your hand out of the beam of the Motion Detector as quickly as possible so that only the motion of the filter is recorded on the graph.

6. If the motion of the filter was too erratic to get a smooth graph, repeat the measurement. With practice, the filter will fall almost straight down with little sideways motion.

7. The velocity of the coffee filter can be determined from the slope of the position vs. time graph. At the start of the graph, there should be a region of increasing slope (increasing velocity), and then it should become linear. Since the slope of this line is velocity, the linear portion indicates that the filter was falling with a constant or terminal velocity ($v_T$) during that time. Drag your mouse pointer to select the portion of the graph that appears the most linear. Determine the slope by clicking the Linear Fit button, $\text{ Fit }$.

8. Record the slope in the data table (a velocity in m/s).
9. Repeat Steps 4 – 8 for two, three, four, and five coffee filters.

**PROCEDURE: PART II – MANUAL DATA ACQUISITION** *(prob. 5.2, p. 183 in Chabay & Sherwood)*

1. Use a stopwatch to time the drop of coffee filters from as high a starting position as you can conveniently manage. If a stairwell is available drop the coffee filters there to time a longer fall. In your data draw a figure of your experimental set-up labeling the distances involved.

2. By stacking the coffee filters you can change the mass of a falling object without changing the shape. With this scheme you can explore how the terminal speed depends on the mass. Time the fall for different numbers of stacked filters, taking some care that the shape of the bottom filter is always the same (the filters tend to flatten out when removed from a stack). Start the measurement after the filters have fallen somewhat, to allow them to reach terminal speed. Average the results of several repeated measurements of time and height. Can you think of a simple experiment you can do to verify that the coffee filters do in fact reach terminal speed before you start timing?

**ANALYSIS: PART I**

1. To help choose between the two models for the drag force, plot terminal velocity $v_T$ vs. number of filters (mass) for the filters dropped and measured by computer. On a separate graph, plot $v_T^2$ vs. number of filters. Use either Logger Pro or graph paper.

2. During terminal velocity the drag force is equal to the weight $(mg)$ of the filter. If the drag force is proportional to velocity, then $v_T \propto m$. Or, if the drag force is proportional to the square of velocity, then $v_T \propto m$. From your graphs, which proportionality is consistent with your data; that is, which graph is closer to a straight line that goes through the origin?

3. From the choice of proportionalities in the previous step, which of the drag force relationships ($-bv$ or $-cv^2$) appears to model the real data better? Notice that you are choosing between two different descriptions of air resistance—one or both may not correspond to what you observed.

4. How does the time of fall relate to the weight $(mg)$ of the coffee filters (drag force)? If one filter falls in time, $t$, how long would it take four filters to fall, assuming the filters are always moving at terminal velocity?

**ANALYSIS: PART II**

1. Plot your data for the air resistance force vs. the terminal speed for the filters dropped from a large height. (The air resistance force is equal to the gravitational force when terminal speed has been reached, so it is proportional to the number of filters in a stack). How does the air resistance force depend on $v_T$?

2. There is an important constraint on the graph of speed dependence: Should the curve of the air resistance force vs. terminal speed go through the origin (force and terminal speed both very small), or not?

   Analysis hint: If you suspect that the force is proportional to $v^3$, then try plotting force vs. $v^3$ and see if a straight line fits the data. Likewise for other powers.
INTRODUCTION: The object of this experiment is to study thermal expansion of metals and, from the data obtained, to calculate the coefficient of linear expansion for these metals.

Experiment has shown that the change in length of a metal rod undergoing expansion as a result of a change in its temperature is proportional to its original length and to the change in temperature. This can be expressed mathematically as:

\[ \Delta L = \alpha L_0 \Delta T \]

where \( \Delta L \) is the change in length of the rod, \( L_0 \) is its original length, and \( \Delta T \) is the change in temperature. The constant of proportionality, \( \alpha \), is called the coefficient of linear expansion of the rod and is different for different rods, depending on the material of which the rod is made. It is defined as:

\[ \alpha = \frac{\Delta L}{L_0 \Delta T} \]

If a metal rod of known length \( L_0 \) is heated uniformly through a temperature change \( \Delta T \) and the corresponding increase in its length is measured, the coefficient of linear expansion for this rod can be obtained. In fact, this method can be used to determine coefficients of linear expansion for unknown rods and they can be identified by comparison with standard tables, if proper laboratory techniques are employed.

EQUIPMENT:

- Linear Expansion Apparatus
- Battery Eliminator
- Rubber Tubing
- Meter Stick
- Metal Rods
- Bunsen Burner
- Water Boiler and Stand
- Matches
- Centigrade Thermometer
- Glass Beaker
- Glycerin

PROCEDURE:

1. Measure the length of the standard rod with a meter stick to the nearest millimeter and record its value. Record room temperature.

2. Connect the battery eliminator to the terminal posts and turn it on.
   CAUTION: DO NOT EXCEED 4 VOLTS.

3. Insert the standard rod in the steam jacket and fit the rubber stoppers in the ends of the jacket. Use a small amount of glycerin as a lubricant. Adjust the rod so that it rests against the metal.
screw on one end of the jacket and then carefully tighten the microcomputer screw till it just
makes contact with the rod. The lamp should just barely glow. Record the setting of the
micrometer screw, and then carefully turn it back several millimeters to allow room for
expansion of the rod, insert the thermometer through the rubber stopper at the top of the
steam jacket and record the temperature inside the jacket. Fill the boiler about one half full
(about 400 ml) of water and connect it with rubber tubing to the insert at the top of the steam
jacket. Another piece of tubing should be connected from the bottom insert to the beaker to
catch the condensed steam.

4. Light the Bunsen burner and bring the water to a boil. Allow the steam to pass through the
jacket until a steady temperature has been reached, usually around 98 degrees C. When this
occurs, carefully turn the micrometer screw until it again just makes contact with the rod.
Record the setting of the micrometer screw and the final temperature inside the jacket.

5. Be careful! STEAM IS HOT!

6. Allow the apparatus to cool down and then replace the standard rod with the unknown rod.
Repeat procedures 1 through 3 again, being very careful in obtaining your data, since the rod
is to be identified by its coefficient of linear expansion. Repeat the measurements on the
unknown to verify your previous data.

DATA ANALYSIS:

1. Calculate the coefficient of linear expansion of the standard rod.

2. Compare the value of the coefficient with the accepted value. (You should be within 5%.)

3. Calculate the average coefficient of linear expansion of the unknown rod.

4. Identify the unknown rod by comparing your value with a table of known values of the
coefficient.

QUESTIONS:

1. How did the experimental and unknown values for the coefficient of linear expansion compare?
What major sources of error could account for any discrepancy?

2. Why must the increase in length of each rod be measured so carefully although the length
itself can be determined by using an ordinary meter stick.

3. Why should the thermometer be placed near the middle of the steam jacket?

4. A compound bar made of an aluminum strip and an iron strip fastened firmly together is
heated. Explain what happens to the shape of the bar and why?

5. Calculate how much a single steel beam the length of the Mississippi River bridge (length
1000 meters) in Cape would expand from the extreme temperature change between winter
(-10°C) and summer (50°C). Why are "expansion joints" necessary in the construction of long
bridges and railroad tracks.
Table 10.1: Linear expansion coefficients for various metals

<table>
<thead>
<tr>
<th>Metal</th>
<th>Linear expansion coefficient, $\alpha$ $\left(1/^{\circ}C\right)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>$23 \times 10^{-6}$</td>
</tr>
<tr>
<td>Brass</td>
<td>$19 \times 10^{-6}$</td>
</tr>
<tr>
<td>Copper</td>
<td>$17 \times 10^{-6}$</td>
</tr>
<tr>
<td>Gold</td>
<td>$14 \times 10^{-6}$</td>
</tr>
<tr>
<td>Iron or steel</td>
<td>$12 \times 10^{-6}$</td>
</tr>
<tr>
<td>Lead</td>
<td>$29 \times 10^{-6}$</td>
</tr>
<tr>
<td>Nickel</td>
<td>$13 \times 10^{-6}$</td>
</tr>
<tr>
<td>Silver</td>
<td>$19 \times 10^{-6}$</td>
</tr>
</tbody>
</table>
Purpose:

In this lab we will use the collision of two hockey pucks on an air table to verify that momentum is conserved and calculate the change in kinetic energy to determine if an elastic collision has occurred.

Theory:

Newton’s second law states that a net force from a system’s surroundings causes a change in the system’s momentum

$$\vec{F}_{\text{net,surr}} = \frac{d\vec{p}}{dt}$$

If a system is isolated then the net force from the surroundings is zero which implies that the momentum is constant (i.e. conserved).

An air table is a way to investigate the collision process where friction can be minimized. Momentum is always conserved in such a collision. If energy is conserved then we have an elastic collision, otherwise an inelastic collision occurs.

Procedure:

The air table will be positioned underneath a video camera to record the collision event. Level the table so that a puck placed in the center of the table stays there when released. Fix a puck launcher in one corner of the table where a threaded hole exists for the launcher. Place a puck in the center of the table and hold it still with a meter stick. When the camera begins recording release the pucks from the meter stick and launcher and record the collision. Make sure the image is saved as a mpeg 2 video file. Transfer the file to a laptop or other computer.

The Gnu Image Manipulation Package (GIMP) is a popular open source image processing package and the GIMP Animation Package (GAP) add on extends the capabilities to video processing. Double click the GIMP icon and start the program. Under the file option choose New and accept defaults. Under the Video on the New image
GUI, select “Split Video Into Frames” and then “Extract Video Range”. Another GUI/dialog window opens up. Click the Video filename box to select the video file you want to analyze. Next click on the “Video Range” button which brings up the video GUI/dialog window. Towards the bottom of this window select the “Deinterlace” option to be “odd lines only”.

Using a combination of the slider and/or arrow buttons, find the frame where the collision occurred. Determine two frames before and two frames after the collision. These will be used to calculate the momentum before and after the collision.

Use the slider, or text entry box, to select the first frame before the collision and then double click on the image. A new window should appear containing that image. Determine the pixel location of the head of the screw in the center of the first puck and record this. Do the same for the second “before the collision” image. Likewise, record the positions of both pucks in the two images after the collision. Also record the distance between holes in the table using the “measure” feature under the “Tools” pull down menu.

With this information, calculate the momentum before and after the collision. It may be easier to use VPython for the calculations as it is vector ready and has the mag() function.

Calculate the percent error as the difference in the before/after momentum using the before momentum as the reference.

Calculate the kinetic energy before and after the collision and also calculate the percent error. Was the collision elastic?
INTRODUCTION:

When a rigid body is moving through space its motion may be thought of as a sum of the motion of its center of mass and its rotation about the center of mass. The total energy of the object is the sum of the energies associated with each of the two types of motion. The purpose of this experiment is to demonstrate that a rolling object has a total kinetic energy that is the sum of two forms of energy: translational kinetic energy and rotational kinetic energy.

In this experiment you will calculate the initial velocity of a projectile, with rotation and without rotation, using the conservation of energy principle. With these values of velocity you will calculate the range of the projectile with and without rotation and compare those values with the measured value. In this way you can verify the law of conservation of energy and determine in what way the total energy is divided into translational energy and rotational energy.

THEORY:

The total kinetic energy of an object can be written as

\[
\text{Total K.E.} = \text{Translational K.E.} + \text{Rotational K.E.}
\]

\[
\text{K.E.} = \frac{1}{2} mv^2 + \frac{1}{2} I\omega^2
\]

where, \( m \) = mass,
\( v \) = velocity of center of mass,
\( I \) = moment of inertia, and
\( \omega \) = angular velocity about the center of mass.
Consider the path of a sphere rolling between a pair of parallel tracks as shown in the figure above. The energy of the sphere at the top of the track is

\[ E_{\text{top}} = mgh \]

If the sphere is not rotating the energy at the bottom of the track is

\[ E_{\text{bottom}} = \frac{1}{2}mv^2 \]

while if the sphere is rotating

\[ E_{\text{bottom}} = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2 \]

Equating the energy at the top with the energy at the bottom we have:

\[ mgh = \frac{1}{2}mv^2 \quad \text{(no rotation)} \quad (1) \]

or

\[ mgh = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2 \quad \text{(with rotation)} \quad (2) \]

The first term in the right-hand side of this equation is the translational kinetic energy of the center of mass and the second term is the rotational kinetic energy relative to the center of mass.

Notice that the relationship between \( \omega \) and \( v \) in equation (2) for a sphere rolling between parallel tracks is not the same as for a sphere rolling on a flat surface. Refer to the figures below.

When a ball rolls without slipping on a flat surface, \( v = \omega R \), but when it rotates on rails, the radius in question is not the radius of the ball, but a somewhat smaller radius to the point of contact between the ball and the rails. This is called the rotating radius, \( r \). Its value, in terms of the radius of the ball \( R \), the radius of the rails \( r_1 \), and the center-to-center distance between the rails, \( d \), is found by rationing similar sides of the triangles.
Solving for \( r \) we have:

\[
\frac{d}{(R + r)^2} = \sqrt{1 - \frac{d}{2(R + r)}} = r
\]

Solving equation (1) for \( v \),

\[
v = \sqrt{2gh} \quad \text{(no rotation)} \quad (3)
\]

If we include the rotation, equation (2) can be solved for \( v \):

\[
v = \sqrt{\frac{2gh}{1 + \frac{I}{mR^2}}} \quad \text{(rotating sphere)} \quad (4)
\]

For a uniform sphere, using \( I = \frac{2}{5} mR^2 \),

so

\[
v = \sqrt{\frac{2gh}{1 + \frac{2R^2}{5r^2}}} \quad \text{(uniform sphere)} \quad \text{(rolling without slipping)} \quad (5)
\]

Since the sphere will have some slippage, the resulting velocity will be between the values given by Eq (3) and Eq (5) (for a uniform sphere) but it should be fairly close to the second value.

Equations (3) and (4) are the velocities of a sphere as it reaches the bottom of the track without rotation (3) and with rotation but no slippage (4).

Once the sphere leaves the track, it can be treated as a projectile and the distance traveled in the x direction can be found from

\[
x = vt \quad (6)
\]

\[
y = \frac{1}{2}gt^2 \quad (7)
\]

Solving the above equation for \( v \), we can find the velocity with which the ball left the track:

\[
v = x \frac{\sqrt{\frac{g}{2y}}}{(8)
\]

We can thus compare this measured velocity with the velocity calculated using Eq. (3) or Eq. (4). Since there will be some slip, the value should be somewhere in between these two values, but closer to the rotational one.
EQUIPMENT: Track, ringstand and clamps, steel spheres, golf balls, Vernier caliper

PROCEDURE:
1. Set up the track so that the bottom portion of the track is horizontal.
2. Choose a sphere and determine the geometric radius and the "rolling" radius.
3. Release the sphere from a height $h$ and measure its range $x$. Do this by taping a sheet of paper to the floor and marking the position at which the projectile strikes the floor. Drop the sphere ten times to get an average value for $x$.
4. Repeat this procedure with a golf ball. The golf ball is not a uniform sphere.

DATA ANALYSIS:
1. Calculate the velocity at which the sphere leaves the track as if it is rotating and again as if it were not rotating.
2. Calculate the range of the projectile for each case.
3. Compare the measured range of the projectile with the two different calculated ranges. Use percent errors for the comparisons. Which velocity calculation (with or without rotation) results in the smaller error?
4. Calculate the fraction of the total energy that is rotational and the fraction that is translational for each sphere. Do the fractions depend on the size of the sphere? On the mass of the spheres?
5. Assuming that the golf ball rolls without slipping, use Eq (4) to calculate the moment of inertia of the golf ball.
6. Arrange your results in a table to clearly show support for your conclusions.

QUESTIONS:
1. Using equations (1) and (2), derive equations (3) and (4).
2. Derive equation (8) using equations (6) and (7).
3. How would the rotational energy compare with the translational energy if the sphere were rolling on an axle made of a very thin wire through the center of the sphere as shown before?
4. When a car rolls down a hill estimate the fraction of its total kinetic energy is the rotational energy of its wheels.
5. Answer question 4 for a bicycle.
6. Comparing the experimental value of the moment of inertia of the golf ball with the value it would have if it were a uniform sphere, what can you conclude about the distribution of mass inside the ball?
INTRODUCTION:

When a torque $\tau$ is applied to an object with a moment of inertia $I$, the object will undergo an angular acceleration $\alpha$. In this experiment, a mass attached to a string will force a flywheel to rotate. The relationship between the torque, the angular acceleration of the flywheel, and the moment of inertia of the flywheel will be investigated.

THEORY:

The apparatus in this experiment consists of a turntable, equipped with a disk flywheel and an additional ring attachment. A string is wrapped around the axle of the turntable, and a mass is hung from the string. When the mass is released, it accelerates downward under the pull of gravity opposed by the tension in the string. The tension of the string is given by

$$T = m(g-a)$$

The tension $T$, in turn, exerts a torque $\tau = rT$ on the turntable where $r$ is the radius of the spindle. The turntable then undergoes an angular acceleration $\alpha$ given by

$$\tau = I\alpha$$

Finally, if the string does not stretch, the acceleration of the mass and the angular acceleration of the turntable are related by

$$a = r\alpha$$

The acceleration can be measured easily. If the mass, starting from rest, falls a distance $h$ in a time $t$, its acceleration is given by

$$a = \frac{2h}{t^2}$$

and similarly, if a system rotates through an angle $\theta$ in a time $t$, then its angular acceleration is

$$\alpha = \frac{2\theta}{t^2}$$

It thus becomes possible to verify experimentally the relationship between torque and angular acceleration.
**EQUIPMENT:**

Angular acceleration apparatus
String
Weights
Meter stick
Stop watch
Triple-beam balance

**PROCEDURE:**

1. Using the disk alone, use 5 different weights and measure the resulting accelerations.

2. Verify that the relation \( \tau = I\alpha \) holds. Note that for a disk of radius \( R \) and mass \( M \), the moment of inertia is given by \( I = \frac{1}{2} MR^2 \).

Repeat the experiment with the ring placed on top of the disk. The moment of inertia due to a ring of mass \( M \) and radii \( R_1 \) and \( R_2 \) is \( I = M(R_2^2 + R_1^2)/2 \). The total moment of inertia is just the sum of the two. \( I_{\text{tot}} = I_{\text{ring}} + I_{\text{disk}} \)

**ANALYSIS:**

Plot graphs of \( \tau \) versus \( \alpha \) for the two values of \( I \) used in the experiment. Determine the slope of the lines (moment of inertia of the system) and compare with the theoretical values.

**QUESTIONS:**

Can the tension in the string be approximated by the weight of the hanging mass? Why or why not?
PERMUTATIONS AND COMBINATIONS

INTRODUCTION: To investigate counting techniques used to determine the statistical probability of various outcomes when selecting sub samples of objects. To verify the probability of obtaining various poker hands in the game of five card stud.

THEORY: Statistical mechanics is based on finding the most probable configuration of a system of oscillators and quanta of energy. Permutations and Combinations allow us to write a formula for counting large numbers of possibilities when order does and does not matter respectively.

Consider the total number of possible ways to draw 5 different cards from a standard deck containing 53 cards. The first card has 52 possibilities, the second 51, the third 50, the fourth 49, and the fifth 48 possible cards. The total number of ways is then the product of each probability thus the total number of ways to draw 5 different cards is 52*51*50*49*48. A shorthand notation for the product of decreasing numbers going all the way down to 1 is the factorial represented as N!. Thus 5! = 5*4*3*2*1 = 120. We can rewrite our result for the total number of ways to draw five cards as 52!/47!. Thus is called a Permutation and is described as taking N things q at a time and represented as P(N/q) = N!/(N-q)!. In this way of counting the order in which the five cards were drawn is counted as significant. That is the sequence 1, 2, 3, 4, 5 would be considered different if the order had been 2, 1, 3, 4, 5 instead. In poker the order in which you draw cards has no effect (you don’t care when you drew the ace). Since order does not matter in poker we must reduce the total number of ways we calculated previously by the number of ways to arrange the 5 cards which is 5!. Thus the total number of ways to take 52 things 5 at a time when order does not matter is 52!/47!5!. This is called a Combination and is written as C(N/q)=N!/((N-q)!q!)

EQUIPMENT: Decks of playing cards; sets of 3 dice.

Part I – Probabilities in a Game of Poker

PROCEDURE:

Divide the class into groups of two a deal at least 50 hands of poker and keep track of the number and types of hands dealt. Combine the numbers of the entire class and calculate the experimental probability of obtaining the various hands. Compare with the theoretical table below.

ANALYSIS:

1. How do your results compare with the predicted probabilities listed in the table below? Explain.
2. How do the class’s totals for each type of hand compare with the probabilities listed in the table below? Explain.
<table>
<thead>
<tr>
<th>Hand</th>
<th>Combinations</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Royal flush</td>
<td>4</td>
<td>0.00000154</td>
</tr>
<tr>
<td>Straight flush</td>
<td>36</td>
<td>0.00001385</td>
</tr>
<tr>
<td>Four of a kind</td>
<td>624</td>
<td>0.00024010</td>
</tr>
<tr>
<td>Full house</td>
<td>3,744</td>
<td>0.00144058</td>
</tr>
<tr>
<td>Flush</td>
<td>5,108</td>
<td>0.00196540</td>
</tr>
<tr>
<td>Straight</td>
<td>10,200</td>
<td>0.00392465</td>
</tr>
<tr>
<td>Three of a kind</td>
<td>54,912</td>
<td>0.02112845</td>
</tr>
<tr>
<td>Two pair</td>
<td>123,552</td>
<td>0.04753902</td>
</tr>
<tr>
<td>Pair</td>
<td>1,098,240</td>
<td>0.42256903</td>
</tr>
<tr>
<td>Nothing</td>
<td>1,302,540</td>
<td>0.50117739</td>
</tr>
</tbody>
</table>

**Part II – Probabilities Rolling Die**

**PROCEDURE:**

1. Have each group of two create a table, like the one for poker above, showing the probability of rolling each of the totals 3 through 16 when 2 dice are rolled at once. You will need to decide how many ways you can roll each of these totals.
2. Once you have determined the totals for each of the values listed, then add those up to determine the total number of possible ways the die can be cast. The probability for a certain outcome (total) will be the ratio of the number of ways this outcome can be obtained divided by the total possible ways the dice can end up. Be sure that the sum of your probabilities for each outcome equals 1.
3. Next, roll 2 dice 50 times, recording the total of the dots on the upturned faces for each roll. Keep track of these results and pool them with the other groups in the class.

**ANALYSIS:**

1. How do your results compare with the table you constructed? How do these results compare with your results from your card playing? Explain.
INTRODUCTION:

Heat is a form of energy. The units most commonly used to measure heat energy are the joule, calorie, kilocalorie, and BTU. One calorie equals 4.184 joules and is the amount of heat required to raise 1 gm of water 1°C. A kilocalorie is equal to 1000 calories and is the unit used by nutritionists to measure food energy. One food "calorie" is actually a kilocalorie. One British Thermal Unit (BTU) is equal to 252 calories and is the amount of heat required to raise the temperature of 1 lb. of water 1°F.

The heat of fusion of a substance is the amount of heat required to change a unit mass of the substance from a solid to a liquid without a change in temperature. This constant temperature at which the change takes place is called the melting point. The object of this experiment is to measure the heat of fusion of ice.

The experimental determination of the heat of fusion of ice will be made by the method of mixtures. This method makes use of the conservation of energy principle in that when heat energy is transferred from a warm object to a cool object, the amount of heat lost by the warm object is equal to the amount of heat gained by the cool object. This is true, of course, only if no heat is gained or lost to the surroundings.

In doing heat experiments where the quantity of heat transferred to or from a substance is to be measured, the range of temperatures used should be equally above and below room temperature, so that the amount of heat transferred to and from the surroundings will approximately cancel out, reducing the error caused by such heat transfers.

THEORY:

In determining the heat of fusion of ice, a few small pieces of ice are placed, one by one, into a calorimeter containing water. As the ice melts, heat is absorbed by the ice from the warmer water and calorimeter until an equilibrium temperature is reached. The heat absorbed by the ice to melt it and then heat it up is equal to the heat lost by the warm water and calorimeter. In equation form:

\[ Ml + MC(T_2 - 0) = mC(T_1 - T_2) + m_1C_1(T_1 - T_2) + m_2C_2(T_1 - T_2) \]

\[ Ml + MCT_2 = (mC + m_1C_1 + m_2C_2)(T_1 - T_2) \]

where \( M \) = mass of ice,

\( m \) = mass of warm water,
\[ m_1 = \text{mass of calorimeter} \]
\[ m_2 = \text{mass of stirrer} \]
\[ C = \text{specific heat of water} \]
\[ C_1 = \text{specific heat of calorimeter} \]
\[ C_2 = \text{specific heat of stirrer} \]
\[ T_1 = \text{initial temperature of warm water} \]
\[ T_2 = \text{equilibrium temperature} \]
\[ l = \text{heat of fusion of ice} \]

This equation can be solved for \( l \), the heat of fusion of ice.

**EQUIPMENT:**

- Calorimeter
- Thermometer
- Warm water
- Ice
- Wire gauze
- Paper towels
- Balance

**PROCEDURE:**

1. Weigh the calorimeter cup and stirrer separately.
2. Fill the calorimeter about half full of water at a temperature approximately 10 degrees above room temperature. Weigh the calorimeter again to obtain the mass of water. Record the temperature of the water.
3. Dry a few small pieces of ice and add them to the water without touching them with your fingers. The ice must be dry. Add ice and stir the mixture until the temperature is about 10 degrees below room temperature. Record the equilibrium temperature after the ice has completely melted.
4. Weigh the calorimeter cup again to obtain the mass of the ice added.
5. Repeat the entire procedure twice more.

**DATA ANALYSIS:**

1. Calculate the average value of the heat of fusion for ice.
2. Find the per cent error between your measured value and the actual value of the heat of fusion.
QUESTIONS:

1. What are the units of the heat of fusion?

2. Discuss the principal sources of error in this experiment.

3. What error would have been introduced if the ice were not dry?

4. Outline a procedure including the equipment required to measure the heat of fusion of lead. What extra precautions against errors would have to be taken?