Texas Instruments

TEXAS INSTRUMENTS CBL SYSTEM

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INTERNAL XMIT 85 OFF

2nd MODE TRIGGER CH VIEW ON / HALT

CBL™ SYSTEM
Experiment Workbook

Acknowledgments

Texas Instruments would like to express its appreciation to the teachers listed below, and to their students, for the many hours they contributed in developing, writing, performing, and testing the experiments contained in this workbook.

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About the Experiments

The experiments described in this workbook are organized by subject: Math (M1–M7), Physics (P1–P7), and Chemistry (C1–C7). However, you may find that many of the experiments can be used across more than one discipline.

The TI-82 and TI-83 graphing calculators were used to perform these experiments. Consequently, some differences may occur for procedures, key presses, and captured screens when other CBL-compatible calculators are used. For information about specific calculators, refer to the *CBL System Compatible Calculators* guidebook.

About the Programs

The programs on the CBL program diskette are provided for use with a CBL-compatible calculators.

Note: Current program listings of all CBL programs may be downloaded from the World Wide Web site.

http://www.ti.com/calc

ftp://archive.ppp.ti.com/pub/graph-ti/cbl/programs

About Purchasing Probes and Adapters

To purchase Vernier probes or CBL adapters referenced in this workbook, contact your Instructional Dealer. For more information, call Texas Instruments (TI) Consumer Relations toll-free at:

1-800-TI-CARES (1-800-842-2737)

Setting Calculator Defaults

Before running CBL programs, it is a good idea to set the calculator to its default settings. (Refer to "Calculator Default Settings" in the *CBL System Compatible Calculators* guidebook for information about using the DEFAULTS program on the CBL program diskette.)

Calibrating the Probes

Calibrating Vernier Probes

Some of the programs in this workbook, which use Vernier probes, include standard calibration equations. If you find that the readings for a given probe are inaccurate, you may want to recalibrate it following these guidelines.

1 Connect the CBL to a calculator with the unit-to-unit cable using the input/output port located on the calculator. Press the cable ends in firmly.

2 Connect the CBL DIN adapter to the end of the probe that you wish to calibrate and plug it into CH1, CH2, or CH3 on the CBL.

Note: The channel used to calibrate the probe must be the same channel used in the experiment.
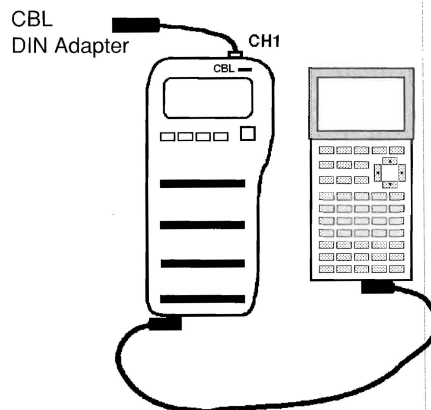
3 Download or enter the CALIBRAT program into the calculator.

4 Turn on the CBL and start the CALIBRAT program on the calculator.

5 At the first prompt, type the channel number (1, 2, or 3) that the probe is connected to, and then press ENTER.

6 At the second prompt, enter the number of points that you wish to use for the calibration (minimum of two points is required) and press ENTER.

Note: Generally, two points are usually enough to calibrate a probe. More points may improve accuracy.

7 For each point, place the probe in a different known situation and enter the expected reading at the prompt. For example, if you are calibrating the Vernier pH probe, you would place the probe in a buffer solution with a known pH and enter the pH value when prompted for the reading.

8 When you enter the last calibration point, the appropriate conversion coefficients (K_0 and K_1) are displayed on the calculator. Record these values for later use.

9 From the program editor on the calculator, select the CBL program that you will be using with the probe that has just been calibrated.

    a) If you wish to save the calibration as part of the program, revise the line for CMD4 in your program by entering the appropriate channel number and calibration coefficients as follows:

$$\{4, \textit{channel number}, 1, 1, K_0, K_1\} \rightarrow \text{L1}$$

    where K_0 and K_1 are the values recorded in step 8.

    b) If you do not want to save the calibration as part of the program, delete the line that contains CMD4 and the `Send(`L_1`)` or `Outpt("CBLSEND",`L_1`)` line that follows it.

10 The calibration is now complete and you are ready to run the revised CBL program.

Note: Experiment C3, Determining the Equilibrium Constant, **requires** that you calibrate the colorimeter to successfully run the COLOR program.

This experiment allows students to develop the concept of the slope of a function by relating slope to the motion of a walking classmate. A discussion that leads to the concept of limits and slope of a curve can be included at almost any classroom level.

Introduction

This activity involves having students walk in such a way that the graph of their distance from the motion detector with respect to time forms different shapes.

This activity serves three purposes:

1. It serves as a good introduction to the CBL unit and the ultrasonic motion detector.

2. It allows students to work with slopes, and to relate the concept of slope to velocity.

3. By having the students try to walk "curved paths," and then find their velocity at a point, the calculus concepts of limits, slope of a curve at a point, and turning points can be developed early in the mathematics curriculum.

Defining velocity as $\dfrac{\text{Change in position}}{\text{Change in time}}$ easily leads to the mathematic definition of the slope of a function, $m = \dfrac{y_2 - y_1}{x_2 - x_1}$ or, $m = \dfrac{f(t_2) - f(t_1)}{t_2 - t_1}$.

Equipment Required

✓ CBL unit (optional power adapter recommended)

✓ CBL-compatible calculator with a unit-to-unit cable

✓ TI CBR™ (Calculator-Based Ranger™) or Vernier CBL motion detector (MD-CBL)

Program

Download or enter the HIKER program into the calculator.

Equipment Setup Procedure

To connect the equipment as shown by Figure 1:

❶ Connect the CBL to the calculator with the unit-to-unit cable using the input/output ports located on the bottom edge of each unit. Press the cable ends in firmly.

❷ Connect the motion detector to the SONIC port on the left side of the CBL.

❸ Turn on the CBL and the calculator.

❹ Place the motion detector on a table so it can detect the movement of a student walking away from the detector.

The CBL is now ready to receive commands from the calculator.
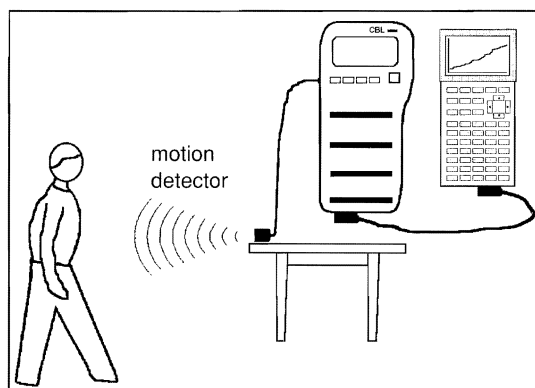
Figure 1: Equipment Setup

Experiment Procedure

❶ Clear a walkway in the middle of the classroom. Make sure that the walkway is wide enough so that no one else except the walking student's actions are detected by the motion detector.

❷ The motion detector should be perpendicular to the line of motion of the walker and sitting flat on the table top.

❸ The walking students should stay in the motion detector's beam and walk perpendicular to the detector.

Note: The student should not walk within 0.5 meters of the detector because the motion detector cannot detect objects closer than that distance.

❹ The detector takes measurements in feet every 0.1 seconds for 6 seconds, and displays the graph of the collected data on the calculator in real-time.

Note: If a TI ViewScreen™ is used, the entire class can see the display.

⑤ Make sure the CBL is turned on. Start the HIKER program on the calculator. The program will pause with a message PRESS ENTER TO START GRAPH. When you and the walker are ready, tell the walker to start walking after you press ENTER and hear the clicking sound from the motion detector.

⑥ A graph of distance (y-axis) versus time (x-axis), shown in Figure 2, is plotted on the calculator as the data is collected. When the walker has a reasonably good graph, move to the analysis section of the lab. Press TRACE to move along the plotted points to get the data (ordered pairs) needed for analysis.

⑦ Repeat Steps 5 and 6, and the analysis for each of the following figures: (Pick a different student to walk each shape.)

> ▶ Line with a positive slope.

> ▶ Line with a steeper positive slope.

> ▶ Line with a negative slope.

> ▶ Line without a slope.

> ▶ Parabola opening down.

Note: If the CBL is used only with its internal batteries, and the calculator is not attached to a ViewScreen, the walking students can hold the CBL, the calculator, and the motion detector in their hands as they walk. With the detector pointed towards a wall, the distance between each walker and the wall is measured.

Analysis and Conclusion

For the line segments:

❶ Use TRACE on the calculator to find the end points of the line segments that were walked. From these points, find the total distance and elapsed time that was walked (example shown in Figure 2). Find the average velocity for the total trip. Find the velocity for any segment of the walk. For example, how fast was the student walking for the first second? Note that if the plot is actually a line, then the walker moved at a constant rate, and the slope of the line gives this rate.

Figure 2:
Distance versus Time

❷ Find the rate the walker was walking at any instant. If the student walked a line, this rate should be the slope of the line.

❸ To walk a line with a steeper slope, the student should walk faster, but at a constant rate. To walk with a negative slope, the student had to walk toward the sensor.
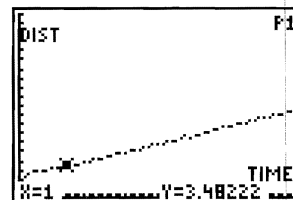
For the parabola:

❶ Use TRACE to find the coordinate of the vertex of the parabola and the coordinate of the student's first movement (refer to Figure 3). Find the average velocity for the first half of the walk (from start to the vertex point).
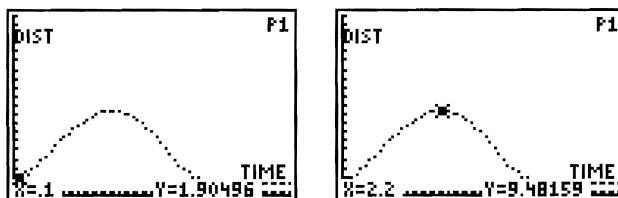
Figure 3: Distance versus Time

❷ Is the average velocity for the first half of the walk the same as the velocity at any specific instance, as it was on the line? If the plot looks like a parabola, the walker had to start close to the sensor, begin by walking quickly, gradually slowing until they stopped (this being the vertex point). On the return trip to the sensor, they would start slowly, gradually picking up speed.

Note that, unlike the line, to walk a parabola, the walker had to walk at a variable rate. Since the slope represents velocity, the slope would also have to be variable.

❸ Pick a point along the trip out. It is best to pick a point about 1 second from the vertex. For example, if the student walked 3 seconds to get to the vertex, pick the point at x = 2 seconds. Use TRACE to find the endpoints of a line segment centered at this point, one unit on either side (in the example above, the line segment would have endpoints at x=1 and x=3). Find the slope of this line segment. This slope should not be the same as the velocity found in Step 1 for the parabola.

Pick a second, smaller, interval centered at the same point (for example, x=1.9 and x=2.1 seconds). Find the slope of this line. Is it the same as the others? It should not be, but the students have already realized this was going to happen because they saw the walker was slowing down and knew the velocity was changing.

For the example pictured in Figure 3, the walker's motion started at x=0.1 and reached the vertex at x=2.2. You would want to work with a point near the center of this interval, such as x=1. Your first interval could be 0.5 to 1.5, with the second interval being 0.9 to 1.1.

❹ Find the velocity of the walking student at any particular instant. Note that you cannot find the exact rate, but can get it over a small interval centered at any point. If this interval is very small, it will be very close to the actual velocity at the point of interest. Discuss the calculus concepts of limits and slopes of curves.

❺ Take three points and find the equation of the parabola that was walked. How good a parabola was it? Discuss the statistical methods that determine the accuracy of the fit.

This experiment allows students to work with quadratic functions as models of projectile motion.

Introduction

In Algebra classes, we often assume that students know, or blindly accept, that a quadratic function can be used to model projectile motion. This assumption is not necessarily true. Most students, before studying quadratic functions, when asked to describe the graph of the height of a falling ball versus time, will draw a negative sloping linear function.

This experiment will show that by dropping and tossing objects, and plotting their height versus time, the general quadratic $f(x)=ax^2+bx+c$ can be developed as a model for projectile motion.

This experiment involves the collection, graphing, and analysis of two special cases of projectile motion:

1. Dropping an object from directly over a motion detector.

2. Tossing an object and allowing it to fall directly over a motion detector.

In both cases, the plot of the resulting data will appear to be quadratic.

Equipment Required

- ✓   CBL (optional power adapter recommended)
- ✓   CBL-compatible calculator with a unit-to-unit cable
- ✓   TI CBR™ (Calculator-Based Ranger™) or Vernier CBL motion detector (MD-CBL)
- ✓   Medium-weight book, playground ball, heavy hat, or some other object to drop

Program

Download or enter the BALLDROP and SELECT programs into the calculator.

Equipment Setup Procedure

To connect the equipment as shown by Figure 1:

1   Connect the CBL to the calculator with the unit-to-unit cable using the input/output ports located on the bottom edge of each unit. Press the cable ends in firmly.

2   Connect the motion detector to the SONIC port on the left side of the CBL.

3   Place the motion detector on the floor (facing up) in an open area of the classroom.

❹ Select three students to perform the experiment and identify them as the "Catcher," the "Dropper," and the "Trigger Operator."

Catcher: Sits beside the motion detector and catches the dropped object before it hits the detector.

Dropper: Holds and drops the object.

Trigger Operator: Controls the CBL.

Note: You can also construct a protective box around the motion detector.
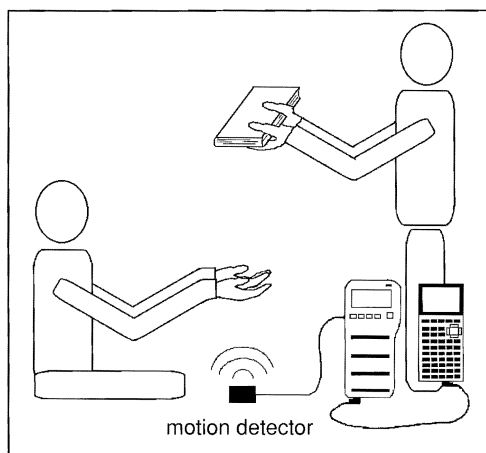
Figure 1: Equipment Setup

❺ Select an object to drop. (It is best if the object is large enough to give the motion detector a good area to detect.)

❻ Turn on the CBL and the calculator.

The CBL is now ready to receive commands from the calculator.

Experiment Procedure No. 1

Dropping an Object:

❶ Make sure the CBL is turned on. Start the program BALLDROP on the calculator. The motion detector starts clicking. This program instructs the CBL to collect data and store it internally. Data collection begins when you press TRIGGER on the CBL. When all data is collected, the program instructs the CBL to send the data to the attached calculator, which will display the data points. Do not press TRIGGER until instructed to do so.

❷ Instruct the Catcher to get in place and prepare to catch the falling object before it hits the motion detector. The Catcher's hands should be to the side of the motion detector's beam.

❸ Have the Dropper hold the object about 1.5 meters DIRECTLY ABOVE the motion detector.

Note: The motion detector cannot detect motion closer than 0.5 meters. Be sure the object is dropped from at least 1.5 meters or you might not have enough data points to develop a model for the motion.

4 When the CBL displays READY, the Trigger Operator should press ⌈TRIGGER⌉ on the CBL and tell the Dropper to release the object. Since the CBL is programmed to only record data for 1.6 seconds, the Dropper should release the object immediately after ⌈TRIGGER⌉ is pressed. When the Catcher catches it, see if the object fell directly toward the middle of the detector. If not, restart the experiment from Step 1.

5 Analyze the collected data on the calculator.

Analysis and Conclusion No. 1

Note: Refer to "Performing Data Analysis" in the *CBL System Compatible Calculators* for information about using statistical features of the calculators.

Find a function that models the height of the object at any time.

A plot of the collected data contains points before the object was dropped and after it was caught (horizontal lines). These points should be removed before using STAT CALC on the calculator to find the quadratic equation to fit the curve.

Note: The height (distance in feet) data is stored in L2 and the time data is stored in L1.

To remove points, run the program SELECT on the calculator. Move the cursor to the position where the object started in motion. Press ⌈ENTER⌉. A vertical line is drawn to mark the lower bound.

Move the cursor to the position where the object stopped its motion. Press ⌈ENTER⌉ to mark the upper bound. The program removes all points outside the bounds and plots the new data. This new subset of the collected data is stored in L3 (time) for the x-axis and L4 (distance) for the y-axis.

Use STAT CALC QuadReg L3,L4 on the calculator to find a quadratic function to model the falling ball. You can then paste the regression equation into the Y= editor to graph the equation on the same axes as the STAT PLOT.

In this example, the function $y=-15.11x^2+5.26$ was found as a model and then graphed on the data set. Each time the experiment is performed, a different function will be found. All these functions should be of the form $y=-ax^2+bx+c$, where b is very small.

Removing the points where the object was stationary before attempting to find the model usually results in a function of the form $y=-ax^2+c$. Discuss the values of a and c. The class will determine that the c values represent the height from which the object was dropped. Since other forces acting on the object are negligible compared with gravity, a must reflect the effect of gravity.
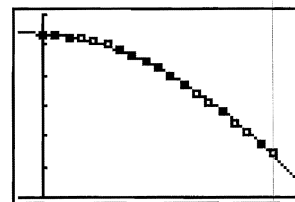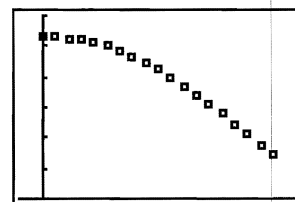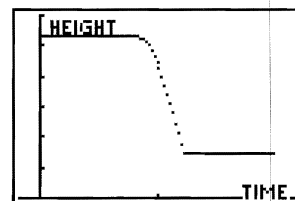
Experiment Procedure No. 2

Tossing an Object:

❶ Place the motion detector (facing up) on the seat of a chair so the motion detector can detect an object being tossed up over it.

❷ Make sure the CBL is turned on. Start the program BALLDROP on the calculator. The motion detector starts clicking.

❸ Have the Dropper hold the object over the motion detector so that his hands and arms are not sensed by the motion detector's beam. When READY is displayed on the CBL, the Trigger Operator should press TRIGGER on the CBL, and immediately tell the Dropper to toss the object directly above the motion detector.

A good toss starts directly above the motion detector and returns to the same location. Be sure the Dropper catches the tossed object before it hits the motion detector.

❹ Repeat from Step 2 until you have a good data set to analyze.

Analysis and Conclusion No. 2

A good data set for the ball being tossed up produces a parabola. Once you get a good data set, you can use three points to get a quadratic function as a model for this data set. The model should be of the form $y=ax^2+bx+c$. Discuss the values of a, b, and c. If the same object is used as in the previous experiment, and the object went directly up and down and not at an angle, the value of a should be approximately the same.
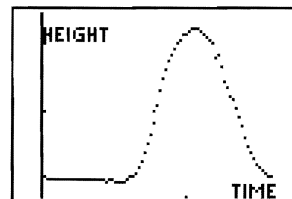
Find the vertex of the parabola and relate this value to the maximum height achieved by the object.

Fit a quadratic function to the data that was collected. Graph the function on the same axis as the data points. How good was the model? You can tell by looking. If you used the STAT CALC QuadReg option on the calculator, you will get the same model.

Another method for finding the equation of a quadratic function is to substitute points from the data set into the general quadratic equation, $f(x)=ax^2+bx+c$. The resulting system of three equations in three unknowns can be solved with matrix methods or any other method.

Variation and Extension

Based on the conclusion of the first experiment, the use of a quadratic function as a model for projectile motion can be accepted as reasonable. The class can be taken outside and different students can try to toss a ball as high as possible. Use a reasonably sized ball—one the motion detector can detect. Be sure those who participate try to throw the ball directly above the motion detector—not at an angle.

It is very difficult to toss a ball up and have it drop in the same spot. However, three points are all that is needed to find a quadratic function. Select any three points that appear to be from the ball and develop the function using these points. The maximum values of the functions can then be computed to find the student who tossed the ball the highest.

This experiment allows students to examine and develop mathematical models of oscillating objects using the square root function and a damped sine curve.

Introduction

This experiment, using various masses oscillating on a spring, is the basis of many different mathematical models.

The original data depicts a damped sine curve and allow a discussion of periodicity, amplitude, and damping factors. From a good data set, a recursive function of the form $a_n = k*a_{n-1}$, where k is a damping factor, can be developed as a model of the constantly changing maximum height of the mass' motion.

In a trigonometry class, $f(t) = a(t)sin(bt+c)+d$ can be developed as a model to determine the position of an oscillating mass at any point in time.

Another relationship that students will discover relates the period of oscillation to the oscillating mass. Stated mathematically, this relationship is:

$$T = 2\pi\sqrt{\frac{M}{k}}$$

where T = period, M = mass, k = a force constant for the spring.

This relationship is a good example of a square root function that can be developed through classroom experimentation to determine the unknown mass of an object.

Equipment Required

✓ CBL (optional power adapter recommended)

✓ CBL-compatible calculator with a unit-to-unit cable

✓ TI CBR™ (Calculator-Based Ranger™) or Vernier CBL motion detector (MD-CBL)

✓ Large C-clamp

✓ Various masses

✓ One-meter stick or a solid, heavy, wooden stick

✓ 5-in x 5-in (12.7 cm x 12.7 cm) cardboard

✓ Hook to support masses (if masses do not have built-in hooks)

✓ Tape

✓ Spring

Program

Download or enter the HOOK program into the calculator.

Equipment Setup Procedure

To connect the equipment as shown by Figure 1:

❶ Attach the spring to the end of the meter stick.

❷ Place the meter stick flat on a table and clamp it tightly to the table. Adjust the stick so that the attached spring hangs freely away from the table. Make this overhang as short as possible to prevent the experiment from being affected by any flex in the stick.

❸ Connect the CBL to the calculator with the unit-to-unit cable using the input/output ports located on the bottom edge of each unit. Press the cable ends in firmly.

❹ Connect the motion detector to the SONIC port on the left side of the CBL.

❺ Place the motion detector on the floor directly under the spring. The mass that will be attached to the spring should remain in the range of the motion detector (no closer then 0.5 meters) as the mass moves up and down. If the mass gets too close to the motion detector, pick a higher table or elevate the meter stick.

❻ Turn on the CBL and the calculator.

The CBL in now ready to receive commands from the calculator.
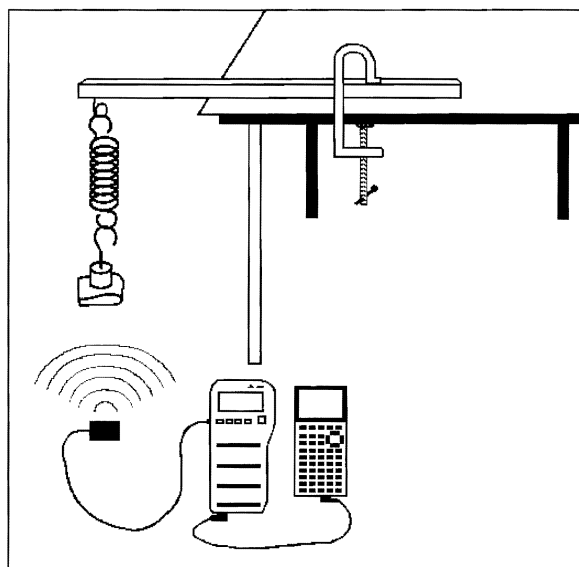
Figure 1: Equipment Setup

Note: As an alternate method to using a meter stick, you might use a stand from the science department. However, if you use a stand, make sure the vertical motion of the oscillating mass stays inside the range of the motion detector.

Experiment Procedure

❶ Make sure the CBL is turned on. Start the HOOK program on the calculator. This program instructs the CBL to collect data and store it internally. Data collection begins when you press $\boxed{\text{TRIGGER}}$ on the CBL. When all data is collected, the program instructs the CBL to send the data to the attached calculator, which displays the data points. Distance (in feet) is stored in L2 and time (in seconds) is stored in L1. Do not press $\boxed{\text{TRIGGER}}$ until instructed to do so.

❷ Attach the mass to the end of the spring. Use a support hook to hold the mass if the mass you are using does not have a built-in hook. Tape the piece of cardboard to the bottom of the mass or hook. The cardboard serves as a target for the motion detector.

❸ Record the amount of the mass on the data sheet. Be sure to include the mass of the hook (and the cardboard if you know it).

❹ Carefully pull the mass straight down, and then release it to allow it to oscillate. Once its motion is only up and down (no side motion), press $\boxed{\text{TRIGGER}}$ on the CBL.

❺ When the graph appears, press $\boxed{\text{TRACE}}$ on the calculator and find the period of the oscillation. (Refer to Step 1 of the Analysis and Conclusion section.)

❻ Record the period on the data sheet as the dependent variable, and the mass as the independent variable.

❼ Repeat Steps 1 through 6 with all except one of the masses.

❽ Determine the relationship between mass and the period of oscillation for a particular spring using the data collected in the previous steps. (Refer to Step 2 of the Analysis and Conclusion section.)

❾ Repeat Steps 1 through 6 with the last (unknown) mass. (Refer to Step 3 of the Analysis and Conclusion section.) Find the period. Use the period to approximate the object's mass.

Analysis and Conclusion

Note: Refer to "Performing Data Analysis" in the *CBL System Compatible Calculators* for information about using statistical features of the calculators.

1. The period of oscillation can be determined using any of three methods. The method actually used will be determined by the data collected.

   a) Use $\boxed{\text{TRACE}}$ on the calculator to find two consecutive maximums. Subtract the corresponding *x-values*. In this example, the period is: $0.98 - 0.38 = 0.6$
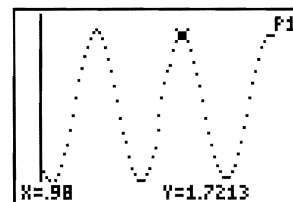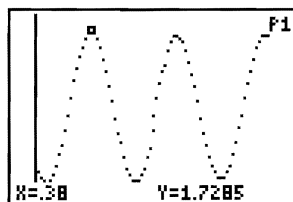
b) Use ⎡TRACE⎤ to find a maximum and the next minimum. Subtract the *x-values* and double the difference. In this example, the period is:
2(0.68 − 0.38) = 2(0.3) = 0.6
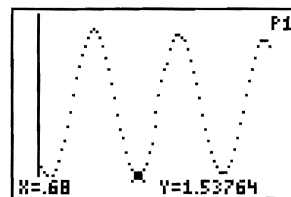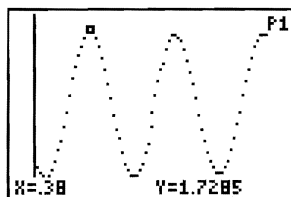
c) Use ⎡TRACE⎤ to find corresponding positions on the first and last curve in the graphing window. Subtract the corresponding *x-values* and divide by the number of complete periods between the two points.
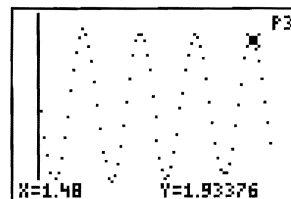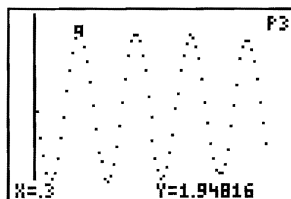
In example c), which is different from examples a) and b), there are three complete periods showing. The *x-values* for the maximums are x=0.3 and x=1.48. The period of oscillation is: (1.48 − 0.3)/3 = (1.18)/3 = 0.393.

2. Determine the relationship between the mass supported by the spring and the period of oscillation. The relationship will differ for different springs but should always be of the same form. This relationship is best modeled by the equation given in the introduction and shown below.

$$T = 2\pi\sqrt{\frac{M}{k}}$$

a) Data from the 5 masses with the same spring is shown in the table and graph on the right.

Mass (in grams)	Period (in seconds)
1015	0.60
815	0.54
715	0.50
615	0.46
515	0.42
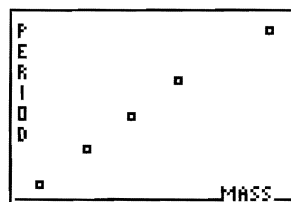
b) Store the mass and period data in L3 and L4, respectively, and then create a STAT PLOT with this data. Now find a best-fit function for the data and enter it into a Y= equation.
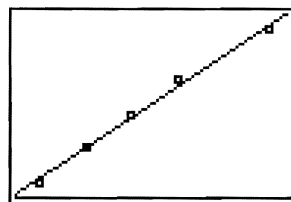
Because of the small number of data points, the data appears to be linear. Even with a large data set, many students would think a linear fit to be appropriate. It is best to collect at least 5 points, if possible. The more that can be collected in the time you have, the better.

c) The actual model is a square root function. Thus, the power function fit will do a better job. You can use the STAT CALC PwrReg option on the calculator to get a best-fit power curve for this data.

A power function for this data is:

$$f(m) = 0.015171m^{.532}$$
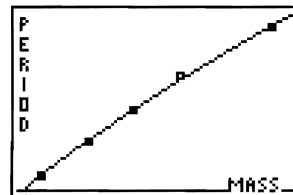
3. Apply the relationship to find the mass of an unknown object.

In Step 9 of the experiment procedure, you recorded the period of an unknown mass. Place this value in the equation $f(m) = 0.015171m^{.532}$ and solve for the mass.

For example, let's assume that the period of the unknown is 0.7 seconds. Using the relationship determined for this particular spring:

$$T = 0.015171M^{.532}$$

$$0.7 = 0.015171M^{.532}$$

$$\frac{0.7}{0.015171} = M^{.532}$$

$$46.14066 = M^{.532}$$

$$1343 = M$$

4. In a trigonometry course, if a "clean" set of data is collected, you could attempt to find a model for the position of the object at any point in time. The model is of the form:

$$f(t)=a(t)\sin(bt+c)+d \quad \text{or} \quad f(t)=a(t)\cos(bt+c)+d.$$

The most difficult part of this model is the development of the damping factor $a(t)$. First replace $a(t)$ with a constant, and then discuss the damping action and the effect this has on the function.

a) For data collected with a 550-gram mass and a different spring, the coordinates of the maximums are shown in the table. The collected data is shown in the graph to the right.

Time	Height
0.08	2.04179
0.58	2.03819
1.08	2.03459
1.58	2.03099
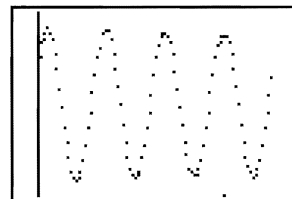
b) The function below is a model for the collected data shown in the above graph.

$$f(t) = 0.11163 \times .967^{\frac{t-.08}{.5}} \cos(12.566637t - 1.00531) + 1.93016$$

The graph of this function is shown to the right.
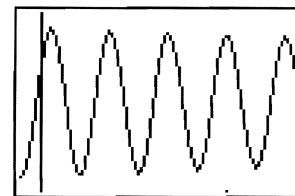
c) The collected data and the function *f(t)* are graphed together to the right. To do this, enter the function found in part 4b above into a Y= equation and graph it with the STAT PLOT of the collected data (stored in L1 and L2).
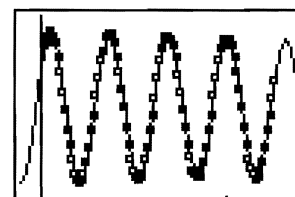
The model graphed on the same axes as the collected data points shows a reasonably good fit.

5. From a good data set, find the rate of decay of the oscillation. Using the graphs for the 1015-gram mass, we find maximums at $y = 1.7285$, $y = 1.7213$, and $y = 1.7141$. The mass is rebounding $1.7141/1.7213 = 0.9958$ of its distance each time.

A recursive function showing the height of each local maximum is $a_n = 0.9958a_{n-1}$.

An exponential function to show the height of each local maximum is $h = 1.7285 \times 0.9958^n$.

Both of these functions start with $n=0$ as the first recorded maximum.
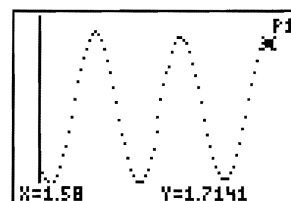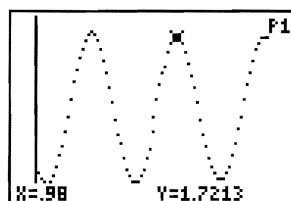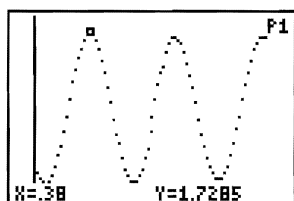
Optional Exercise

If your class has performed the other math experiments in this workbook, they could be asked to predict the graph of an object dropped on a bungee cord.

The sample data to the right was collected using a heavy rubber band as the bungee cord and a round plastic object as the jumper.

The data first shows a free fall portion, and then a section of damped harmonic motion. The students could employ the techniques previously used in the other experiments to find an equation that would model this motion. This equation would be different for different parts of the domain.
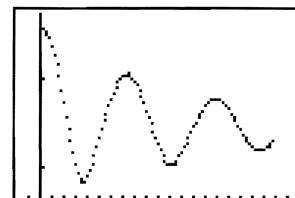
This experiment gives a starting point for studying sound by relating a musical note and its frequency to the period of the pressure (sound) wave formed by a pure sound.

Introduction

The frequency of a wave is the number of complete waves that pass a given point per unit time. Each music note has a specific frequency measured in Hertz (1 Hz = 1 cycle-per-second). Using a set of tuning forks, you will discover the relationship between the frequency (f) of a note and the period in seconds (T) of its pressure wave. This relationship is $f = 1/T$.

Most tuning forks have their frequency and musical note listed. In this experiment, the period of a sound wave is used to determine the frequency. Part of the analysis is the determination of this relationship.

Once this relationship is found, a set of water bottles is tuned by finding the period of the sound wave formed when you blow across the top of a bottle. From the period of the sound wave, the corresponding music note is determined. The tuned bottles can be used to play a simple song as a final activity.

Note	Frequency f in Hz[1]	Note	Frequency f in Hz[1]
C	262	G	392
C# or Db	277	G# or Ab	415
D	294	A	440
D# or Eb	311	A# or Bb	466
E	330	B	494
F	349	C (next octave)	524
F# or Gb	370		

Equipment Required

✓ CBL

✓ CBL-compatible calculator with a unit-to-unit cable

✓ Vernier microphone/amplifier (MCA-U) with CBL DIN adapter

✓ Set of tuning forks with rubber tuning fork hammer

✓ Sheet music for a simple song

✓ Empty 16-ounce (0.47-liter) bottles. (one bottle for each note in the song).

Program

Download or enter the TUNE program into the calculator.

---

[1] One octave from the equally tempered chromatic scale as found in: *Physics.* 3d ed., Giancoli, Douglas C., Prentice Hall

Equipment Setup Procedure

To connect the equipment as shown by Figure 1:

❶ Connect the CBL to the calculator with the unit-to-unit cable using the input/output ports located on the bottom edge of each unit. Press the cable ends in firmly.

❷ Connect the microphone to CH1 on the top edge of the CBL.

❸ Set the microphone on end so the microphone is facing up.

❹ Turn on the CBL and the calculator.

The CBL is now ready to receive commands from the calculator.
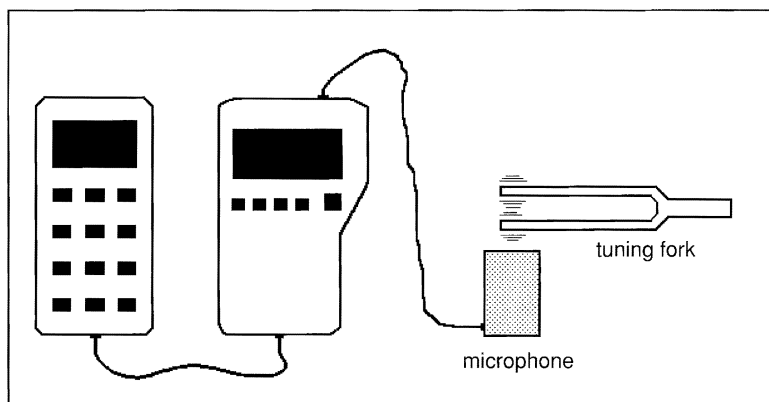
Figure 1: Equipment Setup

Experiment Procedure No. 1

❶ Make sure the CBL is turned on. Start the TUNE program on the calculator. The program will pause execution and wait for you to press ENTER on the calculator. The program TUNE collects pressure points of the sound wave over time.

❷ Select a tuning fork and record the note and its frequency on a sheet of paper. The frequency and music note are listed on most tuning forks. You will need to determine the frequency from the period of the pressure wave.

❸ Strike the tuning fork with the rubber hammer and place the vibrating fork as close as possible to the microphone. (Do not let the fork actually touch the microphone.)

❹ As soon as the tuning fork is close to the microphone, press ENTER on the calculator. Pressure is stored in L_5 and time (in seconds) is stored in L_2.

❺ Press TRACE on the calculator and find the x-coordinates of two adjacent maximums. Determine the period of the pressure wave and record this on the chart.

❻ Repeat Steps 1 through 5 with at least six different-frequency tuning forks.

Note: Steps 1 through 6 are used to determine the relationship between frequency and period of the pressure wave. This relationship ($f=1/T$) can be given to the class. If the relationship is given, use one tuning fork and Steps 1 through 5 to verify this relationship. Some classes might wish to stop at this point.

Experiment Procedure No. 2

❶ Make sure the CBL is turned on. Start the program TUNE on the calculator. Do not press [ENTER] until told to do so.

❷ Ask a student to blow across the open end of the bottle to produce a whistling sound.

❸ While the student is producing the whistling sound, bring the microphone as close as possible to the side of the bottle and press [ENTER].

microphone

❹ Press [TRACE] to determine the period of the wave.

❺ Determine the frequency of the sound.

❻ Use the chart to determine the note that corresponds to this frequency.

❼ Fill the rest of the bottles with different amounts of water and tune them for the notes needed to play the selected song. (Repeat Steps 1 through 6 for each bottle.)

❽ Play a simple song. It is difficult to produce notes of different durations.
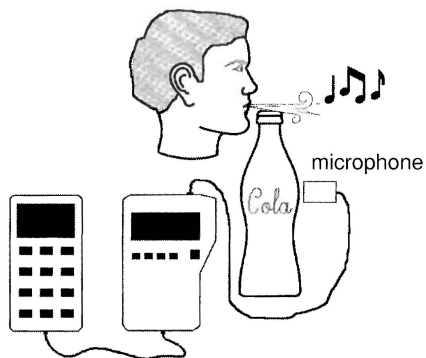
Analysis and Conclusion

Note: Refer to "Performing Data Analysis" in the *CBL System Compatible Calculators* for information about using statistical features of the calculators.

1. This experiment has many starting and stopping points.

a. Use one tuning fork and verify the relationship between frequency and period.

b. Use all the tuning forks and determine the relationship between frequency and period as a data analysis problem.

c. Using the relationship between frequency and period and the given chart, find the note made by blowing across an empty bottle.

d. Tune the bottles by adding different amounts of water and play a song.

2. The data is displayed as pressure (y-axis) versus time (in seconds on the x-axis).

The data is displayed using a Scatter plot as defined in the program. To display the graph using a xyLine plot, modify the Plot1 line in the program or go to STAT PLOT and make the change after the program runs to completion.
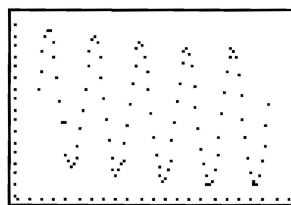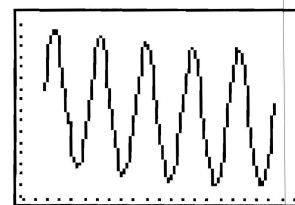
Scatter Plot   xyLine Plot

3. To calculate the period of the data from one of the tuning forks, use TRACE on the calculator to determine the x-coordinate of two adjacent maximums.
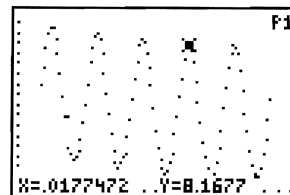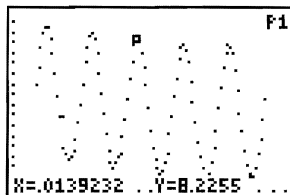
The data pictured on the right has a period of 0.0177472 seconds −0.0139232 seconds, or 0.003824 seconds.

4. To determine the relationship between frequency and period, use several tuning forks. Store the frequencies and periods for these forks in two lists, and then perform a Scatter plot on the two lists. Sample data collected with seven tuning forks is plotted below. The note and frequency are listed on each tuning fork. The period is determined in Steps 1 through 6 of the first experiment.

Frequency f in Hz[1]	Period T in seconds
262	0.0038168
277	0.0036101
330	0.0030303
392	0.0025510
440	0.0022727
494	0.0020243
524	0.0019084
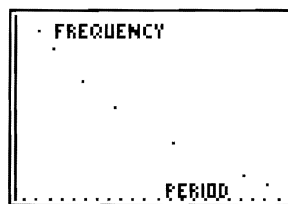
The relation $f = 1/T$ can be determined by using the STAT CALC PwrReg option on the calculator.

5. Once this relationship is determined the frequency and note on the tuning fork can be calculated.

From the data in Step 3 of this section:
frequency = 1/0.003824 seconds
frequency = 261.5 Hz

Using the table, the tuning fork is C.

6. You can tune the bottles using the same method. Place some water in the bottle and use the program TUNE and the methods above to determine the period and the frequency. If the note is lower than you need, place more water in the bottle and calculate the note again. Continue until all notes you need are found.

The graphs below were collected using TUNE with an empty 16-ounce (0.47-liter) glass bottle.
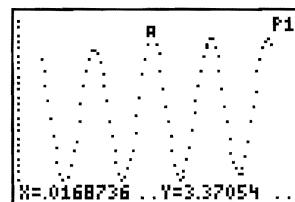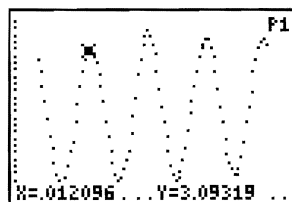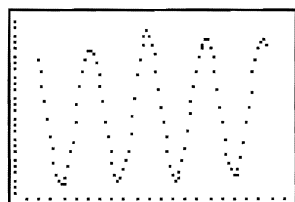
Period is 0.0168736 seconds − 0.012096 seconds = 0.0047776 seconds
Frequency = 1/0.0047776 seconds = 209 Hz

This experiment allows Algebra students to study Newton's Law of Cooling while discussing asymptotes, exponential decay, and natural logarithms.

Introduction

In this experiment, students will be working with cooling curves. A cooling curve can be expressed by two models.

Model 1:

$$T = Ae^{Bt} + C$$

where:

T = the temperature of the cooling object.

t = time (in seconds) since the first reading.

A = difference between environmental temperature and the original temperature of the cooling object.

B = a constant relating to the material being cooled and its container.

C = environmental temperature (°C).

This equation could be given to the students with all the constants explained. Or, a class could do data analysis to determine the equation and, by looking at many examples, determine the use of each constant.

Model 2:

$$T = A*B^t + C$$

Some students might prefer this model because the equation $T = A*B^t$ can be determined using the STAT CALC features on the calculator.

For either model, you will study the phenomenon of cooling by running a series of experiments, and then determine a model that relates temperature to time. You will use this model to make determinations about the best type of container that can be used to enable an object to retain it's heat.

Equipment Required

✓ CBL

✓ CBL-compatible calculator with a unit-to-unit cable

✓ TI Temperature probe

✓ Hair dryer

✓ 6-in × 10-in (15-cm × 25-cm) piece of aluminum foil

✓ Cups made from different materials

✓ Source of heated water

Program

Download or enter the HEAT program into the calculator.

Note: This program collects 36 data points and plots them in real-time. L3 contains time data and L4 contains temperature data. You select the time between readings. If you enter 1 when prompted for the time between points, data is collected every second for 36 seconds. If you enter 60 for the time between points, data is collected once each minute for 36 minutes.

Equipment Setup Procedure

To connect the equipment as shown by Figure 1:

❶ Connect the CBL to the calculator with the unit-to-unit cable using the input/output ports located on the bottom edge of each unit. Press the cable ends in firmly.

❷ Connect the temperature probe to CH1 on the top edge of the CBL.

❸ Prepare the solution or object that will be cooled.

❹ Turn on the CBL and the calculator.

The CBL in now ready to receive commands from the calculator.

temperature probe
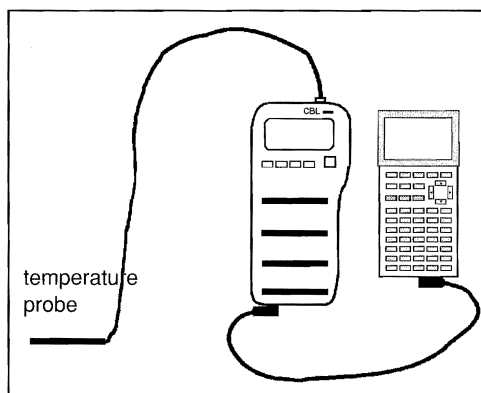
Figure 1: Equipment Setup

Experiment Procedure No. 1

Hair dryer experiment

❶ Make sure the CBL is turned on. Start the HEAT program on the calculator. Enter 5 at the HOW MUCH TIME... prompt. After you enter the time between points, wait before pressing [ENTER] again until told to do so. The program records 36 points (one point every 5 seconds for 3 minutes).

❷ Fold the 10" side of the aluminum foil in half. Place the temperature probe between the layers of the foil in the middle of one side as shown below. Flatten the foil tightly around the probe.

❸ Turn the hair dryer on high and heat the center of the foil. If the foil blows around in circles, place the nozzle of the dryer closer to the foil. Be sure to keep the hand holding the probe away from the heat.
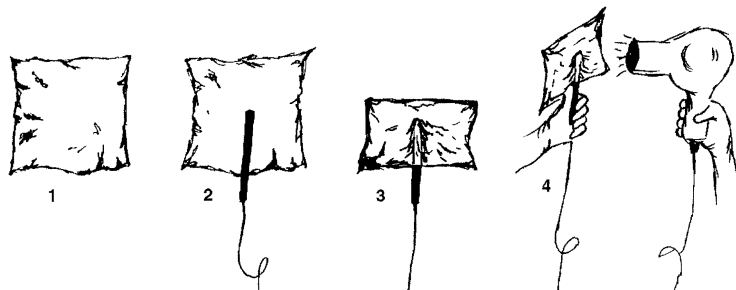
❹ When the foil is hot (about 70°C), press ENTER on the calculator to start collecting data. Turn the hair dryer off and allow the foil to cool. A collected data point is displayed in real-time once every five seconds for three minutes.

❺ Analyze the data.

Aluminum foil cools almost completely in about 3 minutes; therefore, it is a good material to use in class to collect cooling data.

Experiment Procedure No. 2

Water cooling experiment

❶ Make sure the CBL is turned on. Start the HEAT program on the calculator. Enter 60 at the HOW MUCH TIME... prompt. After you enter the time between points, wait before pressing ENTER again until told to do so.

❷ Heat the water in one of the coffee cups. When it starts to boil, remove it from the heat.

❸ Place the temperature probe in the water and press ENTER on the calculator to start collecting data. The program will run for 36 minutes.

❹ Analyze the data.

❺ Repeat Steps 1 through 4. This time heat the water to a lower temperature.

To get a good curve using hot water, you should take measurements over a longer time interval. Once the form of the curve is discovered, only a part of the curve is needed to calculate an equation.

Note: Placing a probe in hot (almost boiling) water, and then quickly placing it in ice water also produces a cooling curve over a short time interval. Although this method produces fast results, the probe itself will add heat to the water. This change in the medium surrounding the probe can create a problem. In cooling, the curve shows the temperature of the probe moving toward the temperature of its environment. To get a good cooling curve, the surrounding environment should remain constant.

Analysis and Conclusion

Note: Refer to "Performing Data Analysis" in the *CBL System Compatible Calculators* for information about using statistical features of the calculators.

Before the experiments are performed, make sure the following coordinate system is understood; temperature is in degrees Celsius (y-axis) and time is in seconds (x-axis).
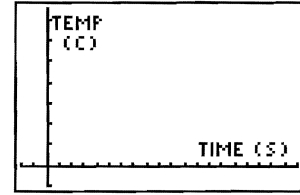
For the hair dryer experiment, the range is:
$-10 \leq y \leq 90$ (°C) and $-10 \leq x \leq 180$ (seconds)

For the water cooling experiments, the range is:
$-10 \leq y \leq 90$ (°C) and $-120 \leq x \leq 2160$ (seconds)

1.   Before the analysis is started, discuss the expected shape of the curve. Will the data points ever reach y=0 ? What is the lowest temperature that will be recorded?
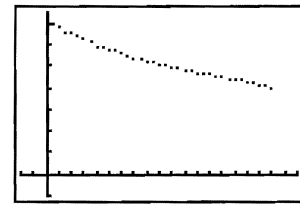
     The curve will be asymptotic to room temperature. To begin the analysis, lower all the recorded temperatures by the room temperature recorded from the classroom thermometer. This example used 24°C.

     For both the aluminum foil experiment and the water cooling experiment, the program stores the temperature data in L4 and the time data in L3 on the calculator. To lower all the temperatures by room temperature, go to STAT EDIT and place the cursor on L5. Press CLEAR ENTER to clear any existing data. Place the cursor back on L5 and enter L4 - 24 (or the recorded room temperature). This subtracts 24 from each value in L4 and places the new value in L5. Redraw the graph by creating a Scatter plot of L3 and L5.
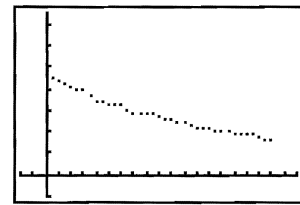
2.   Steps a and b below show two ways to find a model for the data set (L3, L5) on a calculator.

     a)   Go to STAT CALC and select ExpReg L3, L5. The resulting equation for the aluminum foil is:

          $y = 45.28 * 0.994257^x$

          Because the temperatures have been reduced by 24°C, the original data set is modeled by:

          $T = 45.28 * 0.994257^t + 24$

          To see the STAT PLOT and equation graphed together, turn off the STAT PLOT of L3 versus L5 and replot the original data set L3 versus L4. Enter the equation for *T* into the Y= editor and graph it on top of the STAT PLOT.
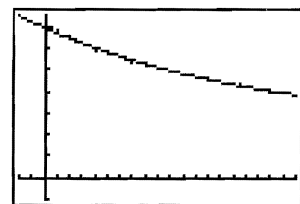
          The graph on the right shows this to be a reasonable fit.

b) If you are familiar with natural logarithms, you could do re-expression on the data set (L3, L5) to find the other model for cooling. For the hair dryer experiment the resulting model is:

$$T = 44.996e^{-0.0057073t} + 24$$
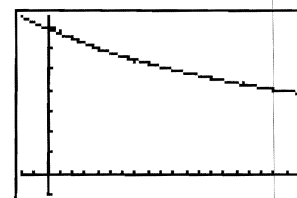
Enter this equation into the Y= editor and graph it on top of the STAT PLOT of L3 versus L4.

Again, the graph shows this to be a reasonable fit.

3. After you develop the model for Experiment No. 1 (aluminum foil), answer the following:

a) How long will it take the aluminum foil to reach room temperature? Because the model has an asymptote at room temperature, this could never happen. Mathematical models are not perfect; explain why the model says the foil will never reach room temperature. Replace this question with, "When will the foil be nominally 1°C above room temperature?"

Model 1:

It will take about 662 seconds (about 11 minutes) from when the measurement started as shown by the following computation:

$$
\begin{aligned}
T &= 45.28 * 0.994257^t + 24 \\
25 &= 45.28 * 0.994257^t + 24 \\
1 &= 45.28 * 0.994257^t \\
0.022084 &= 0.994257^t \\
662 &= t \text{ (seconds)}
\end{aligned}
$$

Model 2:

With this model it will take a little longer, but is still about 11 minutes.

$$
\begin{aligned}
T &= 44.996e^{-0.0057073t} + 24 \\
25 &= 44.996e^{-0.0057073t} + 24 \\
1 &= 44.996e^{-0.0057073t} \\
0.0222242 &= e^{-0.0057073t} \\
667 &= t \text{ (seconds)}
\end{aligned}
$$

b) At what point in time was the foil 40°C?

c) At what rate (°C/seconds) was the foil losing its heat? Using the first model, it appears to lose 0.5743% of its heat each second (therefore, it retains 99.4257% of its heat each second).

4. In Experiment No. 2, water was heated and cooled twice. Both times, the same container was used. The only difference between the two water experiments was the original temperature of the water. The first time the water was heated to 87°C, and then the mug was placed in a 20°C room. The second time the water was heated to 41°C, and then placed in the same mug in the same room.

a) The model for the first cooling is:

$$T = 66.8e^{-0.0277923t} + 20$$
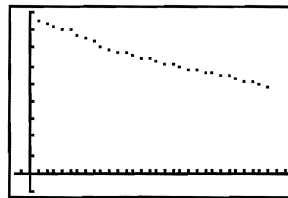
b) The model for the second cooling is:

$$T = 20.377e^{-0.0277923t} + 20$$
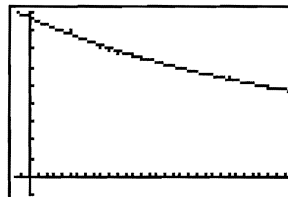
All constants in these two models remain the same except the value of A. The only difference in the experiments is the starting temperature of the water (87°C versus 41°C). The constant A should reflect the original temperature in some way. In fact A reflects the difference between the original temperature of the heated object and room temperature. Looking at the rest of the models, you should be able to see the constant 20 (in 4a and 4b) as room temperature and that the -0.027793 somehow relates to the substance water and the material of the mug.

Optional

1. If time permits, mugs (or cups) made of different material should be used and new models developed. Which material retains its heat the best—a glass cup, china cup, or plastic foam cup? Perform the cooling experiments and find out. If both containers contain the same amount of water at the same temperature, which material retains heat the best—a china soup bowl or a china pitcher? Again, a short cooling experiment could be performed to determine the answer.

2. How about a heating curve, what will it look like? Place the probe in a cup of ice water for two minutes. Start collecting data with the program HEAT as the probe is removed from the water. Get a model for the data set. How does it compare?

To get the data shown in the graph to the right, the probe was placed in ice water for five minutes and then placed in heated water. The program HEAT started to record data as soon as the probe was placed in the hot water. Measurements were taken every second for 36 seconds. The axis range is:
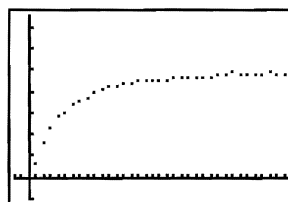
$-10 \leq y \leq 75$ (°C) and $-2 \leq x \leq 36$ (seconds)

This experiment allows students to use an inverse square function as a model for the decrease in light intensity as an object moves away from a light source.

Introduction

A common model given in mathematics textbooks as an example of inverse variation is the relation represented by:

$$I = \frac{k}{d^2}$$

where I = light intensity, d = distance between the light source and the object measuring intensity, k = a constant that depends on the physical characteristics of the light source.

In this experiment, you will derive this model from data collected while moving both a light probe and a motion sensor back-and-forth in front of a light source.

The sensors will collect data with respect to time. This provides an opportunity to introduce the concept of parametric equations. You will display the data (light intensity and distance) with respect to time, and then study the relationship that exists between light intensity and distance.

Equipment Required

- ✓ CBL (optional power adapter recommended)
- ✓ CBL-compatible calculator with a unit-to-unit cable
- ✓ TI Light probe
- ✓ TI CBR™ (Calculator-Based Ranger™) or Vernier CBL motion detector (MD-CBL)
- ✓ Standard light bulb (25W)
- ✓ Large cardboard box (all inside surfaces painted with flat black paint)
- ✓ Wooden block (approximately 2×4×12 inches; 5×10×30 centimeters)
- ✓ Tape
- ✓ Two rubber bands
- ✓ Small cart
- ✓ TI-GRAPH LINK (optional)

Program

Download or enter the LIGHTDIS and GETLIGHT programs into the calculator.

Equipment Setup Procedure

To connect the equipment as shown by Figure 1:

❶ Connect the CBL to the calculator with the unit-to-unit cable using the input/output ports located on the bottom edge of each unit. Press the cable ends in firmly.

❷ Tape the motion detector to the front of the wooden block. Be careful the tape does not cover any working part of the motion detector. Secure the light probe to the side of the wooden block with the two rubber bands. Place the CBL on top of the wooden block.

❸ Connect the light probe to CH1 on the top edge of the CBL. Connect the motion detector to the SONIC port on the left side of the CBL. Be sure all cables are firmly inserted and out of the way of the motion detector and the light probe.

❹ Place the wooden block on top of the cart.

❺ Remove the top of the box and place the box on its side, with the open side facing the cart. Place the light bulb inside the box. Make sure the box is large enough so that the motion detector's beam does not detect the sides of the box.

❻ Tape a line (about one meter long) that is perpendicular to the back of the box from the light source along the top of a table. This tape line serves as a guide for the person performing the experiment to keep the light probe and motion detector constantly perpendicular to the box when the wooden block is moved.

❼ Place the wooden block apparatus in front of the box, along the tape, about 0.6 meters away from the bulb. Align the middle of the bulb and the light probe so they are on the same level.

❽ Turn on the CBL and the calculator.

The CBL is now ready to receive commands from the calculator.
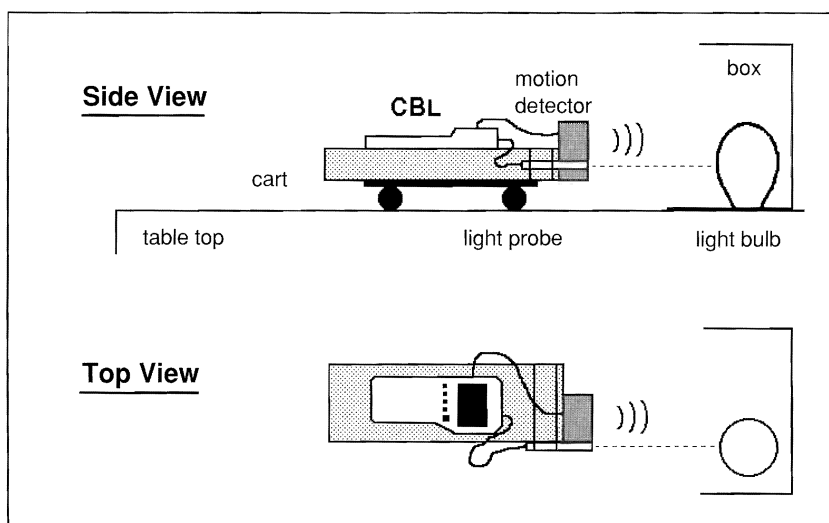
Figure 1: Equipment Setup

Experiment Procedure

❶ Make sure the CBL is turned on. Start the program LIGHTDIS on the calculator. The motion detector starts clicking. When the READY indicator is lit on the CBL display, disconnect the CBL from the calculator to allow the wooden block apparatus to roll more freely.

❷ Darken the room and turn on the light bulb.

❸ Check the alignment of the wooden block. When the light probe is directly in front of the light source and the motion detector is aimed so that its beam is detected by the back of the box, press TRIGGER and start rolling the wooden block (on its cart) back-and-forth along the tape.

The program LIGHTDIS records data from each probe every 0.1 seconds for 4 seconds. The data is stored in the CBL for later retrieval. It is best to try to move the block apparatus forward, backward, and then forward again within the 4-second period. Keep the cart between 1.2 meters and 0.5 meters from the light bulb. Roll the cart smoothly and steadily.

Note: It is important that the height and angle of the two sensors do not change while the cart is in motion. Also, be sure the cart moves in such a manner that:

a) The two sensors stay along a line perpendicular to the back of the box.

b) The motion detector's beam is always detecting the back of the box.

c) The light probe stays directly in front of the light bulb and perpendicular to the back of the box.

❹ When the data collection is complete, reconnect the CBL to the calculator with the unit-to-unit cable. Run the program GETLIGHT on the calculator to retrieve the collected data. The program retrieves the data and places it in the following:

a) Time (measured in seconds) in L_2.

b) Light intensity (measured in milliwatts per square centimeter) in L_3.

c) The distance or separation (measured in feet) between the light bulb and the sensors in L_4.

Analysis and Conclusion

Note: Refer to "Performing Data Analysis" in the *CBL System Compatible Calculators* for information about using statistical features of the calculators.

1. Until now, no data has been displayed. The purpose of the experiment is to let you work with a data set that is best modeled with an inverse square function. This data set is in L3 and L4. Before this data set is displayed, you should look at a display of distance (separation) versus time and light intensity versus time. While looking at these two displays, discuss the concept of parametric equations.

   The STAT PLOTS that are displayed as part of the analysis are shown in Figure 2.

   ▸ Light intensity versus time (L2,L3)

   ▸ Separation versus time (L2,L4)

   ▸ Light intensity versus separation (L4,L3)

Figure 2

2. Turn on the STAT PLOT of L2 versus L4 (Plot2) to display distance versus time. Press $\boxed{\text{ZOOM}}$ 9 to select the ZoomStat window. The purpose is not to fit an equation to this data but to look at the pattern formed and compare it to the graphs shown in Figures 4 and 5.
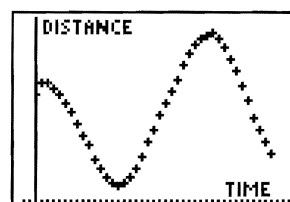
   Make a printout of this graph using TI-GRAPH LINK.

Figure 3

3. Turn off the STAT PLOT of L2 versus L4 and turn on the STAT PLOT of L2 versus L3 (Plot1). Press $\boxed{\text{ZOOM}}$ 9 to select the ZoomStat window. Compare this plot to the printout of the graph shown in Figure 3.

   The two data plots (Figures 3 and 4) show that as the distance between the light probe and the light source increases, the light intensity decreases.
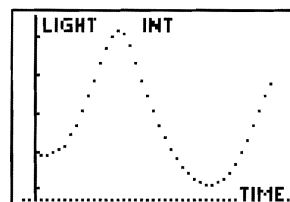
   Discuss the inverse nature of the two data plots and how the distance versus light intensity relationship is an inverse relationship.

Figure 4

4. Go to STAT EDIT to look at the actual data sets. Discuss the idea of parametric equations, and then plot a few data points that relate light intensity to distance. To do this, select a particular time, and then find the distance and the light intensity that occurred at that instance.

   You are relating distance and intensity through time. This is the same as solving one equation for t, and then plugging it into the other equation.

5. Turn off the STAT PLOT of L2 versus L3 and turn on the STAT PLOT of L4 versus L3 (Plot3) as shown in Figure 5. Press ⌈ZOOM⌋ 9 to select the ZoomStat window. Discuss how the data illustrates an inverse relationship. Find a best fit equation for the data by going to STAT CALC and computing PwrReg L4,L3.
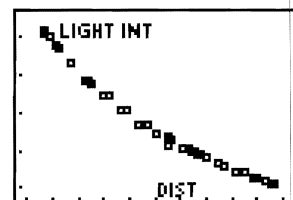
Figure 5

A best-fit equation for the data displayed is represented by the function:

$$y = \frac{1.3689}{x^{1.928}}$$

Figure 6

Figure 6 shows this function to be a reasonable approximation for the inverse square law that is found as a model in most mathematics books.
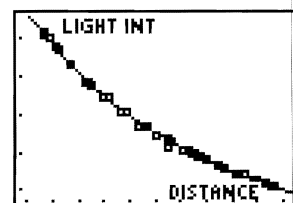
This experiment allows you to match distance versus time graphs and write equations for the represented motion.

Introduction

The equation for the motion is divided into parts. When you choose a function to represent the motion, it will be a piecewise-defined function.

Your task is to match the motion of a randomly generated graph and write a piecewise function to describe the motion. When you have written the equation, you can check your work by entering it into Y_1 on your calculator and viewing it with the data that you collected from your match.

Equipment Required

✓ CBL (optional power adapter recommended)

✓ CBL-compatible calculator with a unit-to-unit cable

✓ TI CBR™ (Calculator-Based Ranger™) or Vernier CBL motion detector (MD-CBL)

✓ Tape Measure

✓ Masking tape

✓ TI-GRAPH LINK (optional)

Program

Download or enter the DTMATCH program into the calculator.

Equipment Setup Procedure

To connect the equipment as shown by Figure 1:

❶ Connect the CBL to the calculator with the unit-to-unit cable using the input/output ports located on the bottom edge of each unit. Press the cable ends in firmly.

❷ Connect the motion detector to the SONIC port on the left side of the CBL. Position the motion detector on a flat table as shown in Figure 1.

❸ Turn on the CBL and the calculator.

The CBL is now ready to receive commands from the calculator.
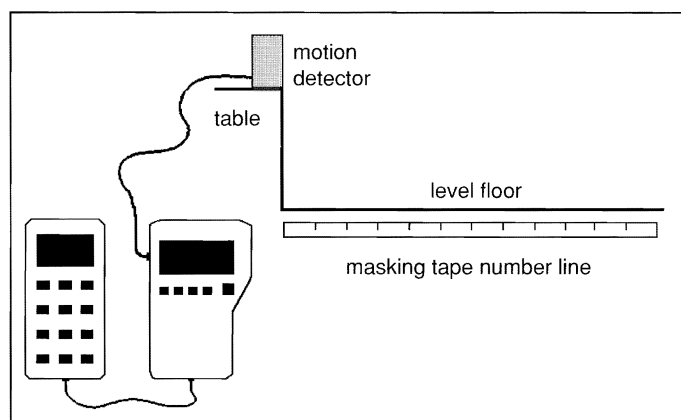
Figure 1: Equipment Setup

Experiment Procedure

❶. Make sure the CBL is turned on. Start the program DTMATCH on the calculator. A randomly generated distance (in meters) versus time (in seconds) graph is displayed. When ready, press ENTER on the calculator (the motion detector starts clicking) and "walk" the path that matches the distance versus time graph.

❷ When you are finished "walking" the graph, press ENTER on the calculator. You are given the option to repeat the distance match that you just walked (press 1), or you can try a new distance versus time graph (press 2).

If you are satisfied with the graph you walked, press 3 to quit. A STAT PLOT of your motion is displayed. Distance is in L4 and time is in L2.

Analysis and Conclusion

1. Write a piecewise-defined function for your motion.

A sample graph is shown in Figure 2. The piecewise-defined function for this graph is represented by:

$$d(t) = \begin{cases} 0.5 + t / 6 & 0 \le t \le 3 \\ 1 & 3 < t < 6 \\ -5 / 4 + 3t / 8 & 6 \le t \le 10 \end{cases}$$
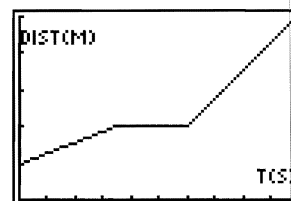
Figure 2:
Distance versus Time

2. Press Y= and enter your piecewise equation into Y1, and then press GRAPH. How well does the displayed graph match the plot of distance versus time that appears on the screen? Does this match the path that you walked? If not, try re-writing the equation until it does.

The equation for Figure 2 as entered in the calculator is shown in Figure 3.

3. Print a copy of your distance versus time match with the equation you entered into Y1 using TI-GRAPH LINK.
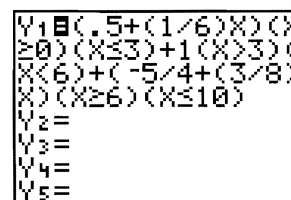
Figure 3

4. Using the information from the piecewise function that you wrote, what was your velocity during each part of the motion? How do you know?

5. Repeat the same procedure using another distance versus time match. Give the equation and print your results, and answer the question from Step 4.

6. Sketch a graph of a velocity versus time graph for each motion graph, and then write a piecewise equation for this motion. Graph the piecewise function of velocity versus time and compare it with your sketch.

Optional Exercise

Create your own distance versus time graph. Write the equation and try to match the motion. Give the equations and print your results.

This experiment allows students to investigate forces of static and kinetic friction.

Introduction

Friction is a resisting force that acts between two surfaces in contact when one object slides or attempts to slide over the other. Generally, frictional forces depend on the types of surfaces in contact and the normal forces between these surfaces.

There are two types of friction—static friction and kinetic friction. Static friction occurs when two surfaces are at rest with respect to each other but one is trying to slide over the other. The force of static friction, represented by f_s, can vary from zero to a maximum value that occurs just before the object slips. Stated mathematically,

$$f_s \leq \mu_s N$$

where N is the normal force and μ_s is a constant called the coefficient of static friction.

Kinetic friction occurs when two surfaces are actually moving with respect to each other. The force of kinetic friction, represented by f_k, is:

$$f_k = \mu_k N$$

where μ_k is the coefficient of kinetic friction.

In this experiment, the nature of the frictional forces between a variety of surface types will be investigated.

Equipment Required

- ✓ CBL
- ✓ CBL-compatible calculator with a unit-to-unit cable
- ✓ Vernier student force sensor (SFS-DIN) with CBL DIN adapter
- ✓ Rectangular wooden block and brick (mass of both together less than 1.5 kg)
- ✓ String
- ✓ Laboratory balance
- ✓ TI-GRAPH LINK (optional)

Program

Download or enter the FORCERT program into the calculator.

Equipment Setup Procedure

To connect the equipment as shown by Figure 1:

❶ Connect the CBL to the calculator with the unit-to-unit cable using the input/output ports located on the bottom edge of each unit. Press the cable ends in firmly.

❷ Connect the force probe to CH1 on the top edge of the CBL.

❸ If necessary, calibrate the force probe (refer to the front of the CBL workbook for details).

❹ Attach the force probe to the wooden block using a piece of string. Place the brick on top of the wooden block.

❺ Turn on the CBL and the calculator.

The CBL is now ready to receive commands from the calculator.
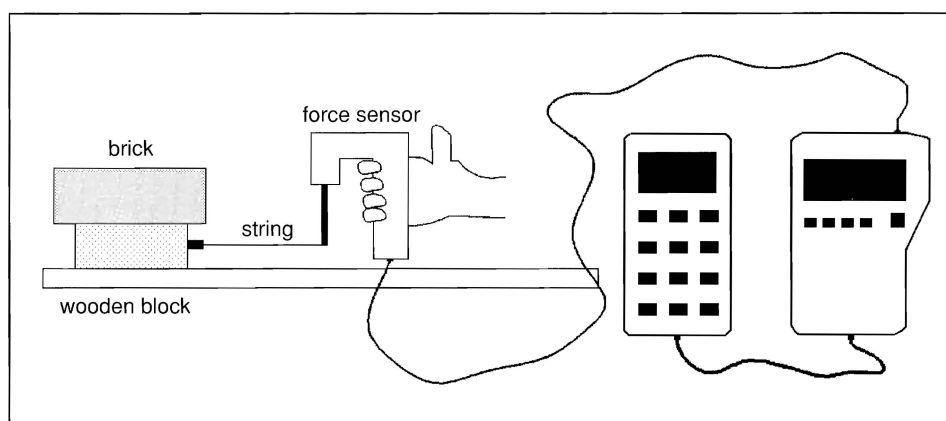
Figure 1: Equipment Setup

Experiment Procedure

❶ Make sure the CBL and the calculator are turned on. Start the FORCERT program on the calculator.

❷ When you are ready to start collecting data, press ENTER on the calculator to start the force graph.

❸ Begin pulling on the block, increasing the applied force at a slow and steady rate. Be sure that the force probe is held level and that the string is horizontal with the tabletop. When the block slips, continue pulling with a constant force so as to exactly balance the frictional force. Friction is balanced when the block moves with a constant speed.

④ A graph of force versus time is plotted on the calculator display as the data is collected. Your graph should look similar to the one shown in Figure 2. You may want to adjust *Ymax* and *Ymin* on the calculator to create an appropriate viewing window. (Press $\boxed{\text{WINDOW}}$ on the calculator to access *Ymax* and *Ymin*.) When you are satisfied with your results, save the graph to a PIC variable to print later using TI-GRAPH LINK.
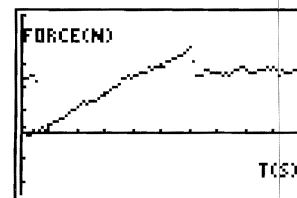
Figure 2:
Force versus Time

⑤ On the calculator, press $\boxed{\text{TRACE}}$ to move along the force versus time plot. Identify the maximum applied force (when the block is about to slip) and record this value in your lab notebook as $f_{s(max)}$.

⑥ Press $\boxed{\text{2nd}}$ [DRAW] 3 to display a horizontal line on the screen. Use the arrow keys to move the line up and down until it aligns with the portion of the force versus time plot where the applied force is approximately constant while the block was moving with constant speed. The displayed y-value gives an estimation of the average applied force acting during this interval. Record this value in your lab notebook as f_k.

Analysis and Conclusion

1. Print the PIC variable for this experiment using TI-GRAPH LINK and place it in your lab notebook. Be sure to include appropriate scales and axes labels on the printout.

2. Determine the mass of the block-brick combination, and then find the normal force acting on it (equal in magnitude to its weight). Use this information and the formulas given in the introduction section to find the coefficients of static and kinetic friction. Record these values in your lab notebook.

3. How does the normal force affect frictional coefficients? Repeat the procedure described above with an extra brick placed on the block. Record all relevant data as before.

4. Do the coefficients of friction depend on the area of the surfaces in contact? Repeat the experiment with the block turned on its side. Compare your findings with previous results.

5. Repeat the experimental procedure for at least two other surface combinations. Record the frictional coefficients for each in the form of a table.

6. Compare your findings from Steps 2 and 5 with accepted values from your textbook. Find a percentage error for each.

7. Based on the data collected in this experiment, upon what factors do frictional coefficients depend? Specifically, what factors investigated in this experiment do not affect the coefficients of friction?

This experiment allows students to investigate the rebound height variations of a bouncing ball.

Introduction

When a rubber ball is released from rest and allowed to bounce on a hard surface, the height to which the ball rebounds is typically less than its initial height. This is because some of the ball's energy is dissipated as it collides with the surface.

Generally, the ratio of the rebound height to the previous height remains constant as the ball bounces. That is, for each bounce, the rebound height is a constant percentage of the previous height. This percentage is called the rebound rate p. Accordingly, the rebound height decreases exponentially with each bounce. Stated mathematically:

$$y = y_o\, p^n$$

where y_o is the initial height and y is the rebound height after n bounces.

This activity investigates the motion of a bouncing ball using a motion detector. It shows how to develop a mathematical model relating the ball's rebound height to the number of times the ball bounces.

Equipment Required

- ✓ CBL (optional power adapter recommended)
- ✓ CBL-compatible calculator with a unit-to-unit cable
- ✓ TI CBR™ (Calculator-Based Ranger™) or Vernier CBL motion detector (MD-CBL)
- ✓ Ring stand and utility clamp
- ✓ Racquetball (small rubber ball)
- ✓ Hard, level surface
- ✓ TI-GRAPH LINK (optional)

Program

Download or enter the BOUNCE program into the calculator.

Equipment Setup Procedure

To connect the equipment as shown by Figure 1:

❶ Connect the CBL to the calculator with the unit-to-unit cable using the input/output ports located on the bottom edge of each unit. Press the cable ends in firmly.

❷ Connect the motion detector to the SONIC port on the left side of the CBL.

❸ Secure the motion detector to a ring stand, using a clamp, as shown in Figure 1. Be sure that the motion detector is level and facing a hard, level surface.

❹ Turn on the CBL and the calculator.

The CBL is now ready to receive commands from the calculator.
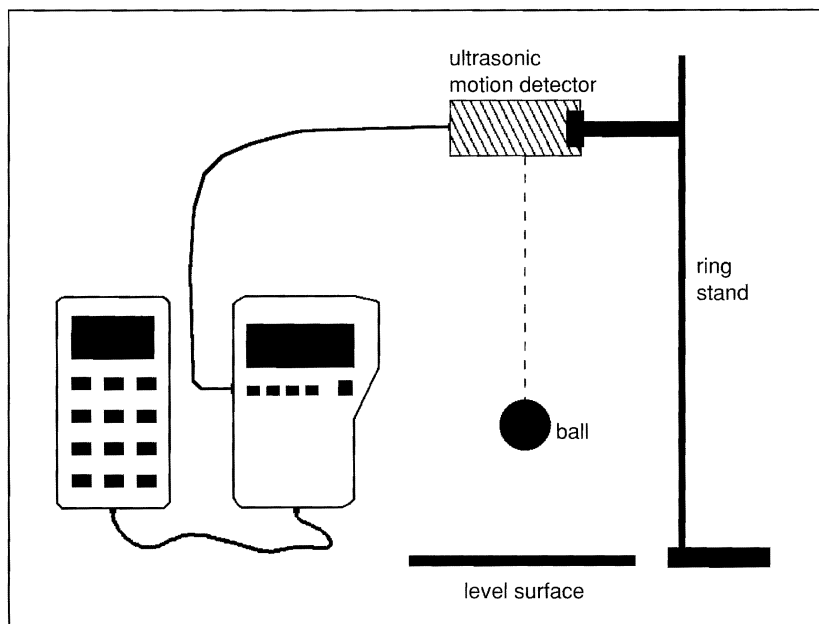
Figure 1: Equipment Setup

Experiment Procedure

❶ Make sure the CBL is turned on. Start the BOUNCE program on the calculator. (Stop at the display message, PRESS ENTER TO START COLLECTING DATA.)

❷ Hold the racquetball at least 50 cm away from the detector. When you are ready to start collecting data, press ENTER on the calculator to start the motion graph.

❸ When the motion detector starts clicking, release the ball from rest and allow it to bounce up and down directly below the detector. The distance (in meters) is stored in L4 and the time (in seconds) is stored in L2.

Note: If the ball bounces out of the detector's range, check to see if the surface on which the ball is bouncing is level, and then restart the experiment.

❹ Your graph should look similar to the one shown in Figure 2. If you are satisfied with your graph of distance versus time, save it to a PIC variable to be printed later using TI-GRAPH LINK.

Figure 2:
Distance versus Time of a
Bouncing Ball

❺ On the calculator, press ⌈2nd⌉ [DRAW] 3 to add a horizontal line to the display. Use the arrow keys to move the line up and down until it aligns with the portion of the graph corresponding to the ball's release position. The displayed *y-value* gives an estimation of the ball's initial height. Record this data in a table with the corresponding bounce number—zero.

❻ Adjust the horizontal line so that it aligns with the ball's rebound height after one bounce. Record the displayed *y-value* in your data table with the corresponding bounce number—one.

❼ Repeat Step 6 until you have collected data for at least six bounces. Each time adjust the horizontal line for the current bounce number.

Analysis and Conclusion

Note: Refer to "Performing Data Analysis" in the *CBL System Compatible Calculators* guidebook for information about using statistical features of the calculators in Steps 3, 4, and 5 below.

1. Print the PIC variable for this experiment using TI-GRAPH LINK and attach it to your lab notebook. Be sure to include appropriate scales and axis labels on the printout.

2. Press ⌈STAT⌉ and select ⟨EDIT⟩ to get to the List editor on the calculator. Use the arrow keys to move to the top of lists L_1 and L_2 and press ⌈CLEAR⌉ ⌈ENTER⌉ to clear the existing data. Enter the bounce data in list L_1 and the corresponding height data in list L_2 from the data table that you constructed earlier.

3. Perform a Scatter plot with (▫) mark on the data in L_1 and L_2 using the STAT PLOT options.

4. Perform an exponential regression (ExpReg) on L_1 and L_2 on the calculator. Record the regression equation and correlation coefficient in your lab notebook.

   • Does this equation agree with the mathematical model relating rebound height and bounce number that was described in the introduction section?

   • By what average percentage did the ball's rebound height decrease with each bounce?

5. Copy the regression equation into the Y= editor, and then graph the Scatter plot and regression curve together. Make a printout of this graph using TI-GRAPH LINK and attach it in your lab notebook.

Repeat this experiment at least two more times and record all relevant data in your lab notebook. For one of the trials, vary the ball's release height. To what extent does the initial height affect the rebound rate? Explain your answer. For another trial, use a different type of ball, such as a tennis ball or a basketball. List several physical characteristics of the balls that you suspect might have an effect on the rebound rate.

This experiment allows students to investigate the temperature variations of a cooling object.

Introduction

As soon as a hot cup of coffee is poured, it begins to cool. The cooling process is rapid at first, then levels off. After a long period of time, the temperature of the coffee eventually reaches room temperature. Temperature variations for such cooling objects were summarized by Newton. He stated that the rate at which a warm body cools is approximately proportional to the temperature difference between the temperature of the warm object and the temperature of its surroundings. Stated mathematically:

$$\frac{\Delta T}{\Delta t} = -k(T - C)$$

where ΔT represents the object's temperature change during a very small time interval Δt, T is the body's temperature at some instant, C is the surrounding temperature, and k is a proportionality constant. This equation can be solved using advanced techniques:

$$T - C = (T - T_o)e^{-kt}$$

where T_o is the body's temperature when $t = 0$.

This experiment investigates temperature variations for a cooling object and attempts to verify the mathematical model developed by Newton.

Equipment Required

- ✓ CBL
- ✓ CBL-compatible calculator with a unit-to-unit cable
- ✓ TI temperature probe
- ✓ Hot plate

- ✓ Medium beaker
- ✓ Laboratory thermometer
- ✓ Water
- ✓ Ice
- ✓ TI-GRAPH LINK (optional)

Program

Download or enter the COOLTEMP program into the calculator.

Equipment Setup Procedure

To connect the equipment as shown by Figure 1:

❶ Connect the CBL to the calculator with the unit-to-unit cable using the input/output ports located on the bottom edge of each unit. Press the cable ends in firmly.

❷ Connect the temperature probe to CH2 on the top edge of the CBL.

❸ Turn on the CBL and the calculator.

The CBL is now ready to receive commands from the calculator.
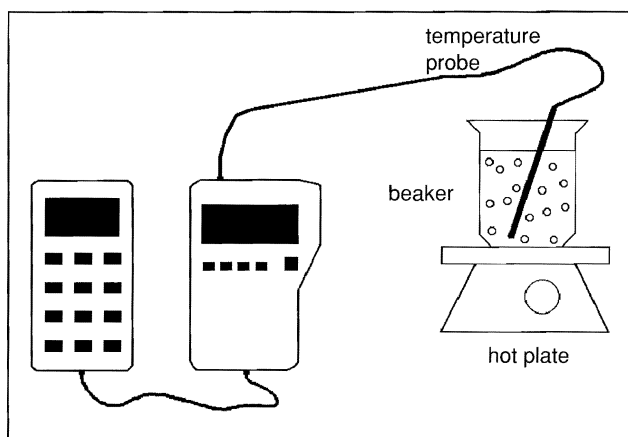
Figure 1: Equipment Setup

Experiment Procedure

❶ Read the laboratory thermometer to determine the room temperature in degrees Celsius and record this value as C in your lab notebook. Store this value in variable C on the calculator.

❷ Fill a medium beaker with water and place the beaker on a hot plate When the water begins to boil, place the temperature probe in the beaker for several seconds.

❸ Make sure the CBL is turned on. Start the COOLTEMP program on the calculator. Remove the temperature probe from the boiling water and press ENTER on the calculator to start collecting data.

The probe should remain exposed to the air while the CBL and calculator collect the temperature data. To avoid conduction and evaporation effects on the temperature probe, do not place the probe directly on the tabletop or expose it to any drafts.

Figure 2:
Temperature versus Time

❹ Observe the resulting variations in temperature on the calculator display as the data is collected. Data is collected at a rate of 1 point per second for approximately 1.5 minutes. Temperature (in °C) is stored in L4 and time (in seconds) is store in L2.

Your graph should look similar to the one shown in Figure 2. After the CBL has finished collecting data, you may want to adjust *Ymax* and *Ymin* on the calculator to create an appropriate viewing window. (Press [WINDOW] on the calculator to access *Ymax* and *Ymin*.) When you are satisfied with the graph, save it to a PIC variable to be printed later using TI-GRAPH LINK.

Analysis and Conclusion

Note: Refer to "Performing Data Analysis" in the CBL *System Compatible Calculators* for information about using statistical features of the calculators.

1. Print the PIC variable for this experiment using TI-GRAPH LINK and attach it to your lab notebook. Be sure to include appropriate scales and axis labels on the printout.

2. According to Newton's law of cooling, the quantity $y=T-C$ varies exponentially with time. To create a model of this relationship, you should first subtract room temperature from the collected temperature values. To do this on the calculator, press [2nd] [L4] [−] [ALPHA] C [STO▶] [2nd] [L4] [ENTER] on the home screen, where C is the room temperature value that you previously stored in the calculator.

3. Perform an exponential regression (ExpReg) on the collected data on the calculator. Remember that the time data is stored in list L2 and the temperature data is stored in list L4. Record the regression equation and correlation coefficient in your lab notebook.

   Does the equation obtained using the calculator match the mathematical model relating temperature and time described in the introduction, i.e., do temperature and time appear to vary exponentially?

Repeat this experiment at least two more times and record all relevant data in your lab notebook. For one of the trials, start with the temperature probe in an ice bath and allow it to warm up when removed from the bath. Is this relationship exponential? If it is, use the calculator to find an appropriate regression equation for this data.

This experiment allows students to verify Newton's well-known expression relating force, mass, and acceleration.

Introduction

Newton's Second Law of Motion gives the relationship between the mass of a body and the resultant force required to produce a certain acceleration. Stated mathematically:

$$F = ma$$

where F is the net force, m is the body's mass and a is its acceleration.

In this experiment, hanging masses are used to apply different forces to a dynamics cart, which is allowed to accelerate along a level table top. The applied forces are measured using a force probe. The acceleration produced by these forces is measured using a motion detector. Based on the data collected, the relationship predicted by Newton is tested.

Equipment Required

- ✓ CBL (optional power adapter recommended)
- ✓ CBL-compatible calculator with a unit-to-unit cable
- ✓ TI CBR™ (Calculator-Based Ranger™) or Vernier CBL motion detector (MD-CBL)
- ✓ Vernier student force sensor (SFS-DIN) with CBL DIN adapter

- ✓ Dynamics cart
- ✓ String
- ✓ Calibrated masses and holder
- ✓ Pulley
- ✓ TI-GRAPH LINK (optional)

Program

Download or enter the PLOTS and SECOND programs into the calculator.

Equipment Setup Procedure

To connect the equipment as shown by Figure 1:

❶ Connect the CBL to the calculator with the unit-to-unit cable using the input/output ports located on the bottom edge of each unit. Press the cable ends in firmly.

❷ Connect the force probe to CH1 on the top edge of the CBL.

❸ If necessary, calibrate the force probe (refer to the front of the CBL workbook for details).

❹ Connect the motion detector to the SONIC port on the left side of the CBL.

❺ Secure the force probe to the dynamics cart as shown in Figure 1. Face the motion detector toward the back end of the cart. Make sure that the motion detector has a large enough target to detect. If necessary, tape a square piece of cardboard to the side of the force probe facing the motion detector.

❻ Attach the force probe to the hanging mass using a piece of string and place the string over the pulley. Adjust the string length so that when it is pulled back and released, the hanging mass hits the floor just before the cart reaches the edge of the table.

❼ Turn on the CBL and the calculator.

The CBL is now ready to receive commands from the calculator.

Figure 1: Equipment Setup

Experiment Procedure

❶ Determine the mass required to exactly balance the frictional force acting on the cart. To do this, add enough small masses to the end of the string to cause the cart to move at a constant speed across the table top when given a small push. Record the value of the mass required to offset friction as m_f, in grams. If you are using a very low friction cart, record zero for m_f.

❷ Add some mass to the hanger (about 50 g to start) and place a 1.0 kg mass on the cart. Record the total cart mass in kilograms as M. This value remains constant throughout the experiment.

❸ Make sure the CBL is turned on. Start the SECOND program on the calculator, and enter m_f when prompted for the mass required to balance friction.

❹ Pull the cart straight back, making sure that the string that connects the cart and the hanging mass is level with the table. The distance between the cart and motion detector should be at least 50 cm. Press ENTER on the calculator to start collecting data. Release the cart from rest as soon as you hear the "clicking" sound, which indicates that the motion detector is collecting data. The force probe measures any variations in the applied force, while the motion detector simultaneously measures the cart's velocity.

❺ To see a plot of net force versus time, select 2 from the PLOT OPTIONS menu on the calculator. Your force versus time graph should look similar to Figure 2. Force (in Newtons) is stored in L4 and time (in seconds) is stored in L2.
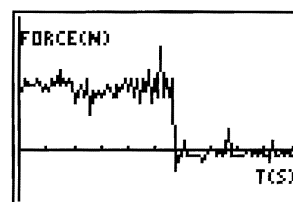
Figure 2:
Net Force versus Time

❻ Press 2nd [DRAW] 3 to display a horizontal line on the screen. Use the arrow keys to move the line up and down until it aligns with the portion of the force versus time plot where the applied force was approximately constant while the cart was accelerating along the table top. The displayed y-value gives an estimation of the average applied force acting during this interval. Record this value in your lab notebook as the net force F acting on the cart.

❼ Start the PLOTS program. Press 1 at the PLOT OPTIONS menu to see a graph of velocity versus time for the accelerating cart. The velocity versus time plot that appears on the calculator screen should look similar to the one displayed in Figure 3, showing a speed that increases at a constant rate. Velocity (in meters/second) is stored in L5 and time (in seconds) is stored in L2.
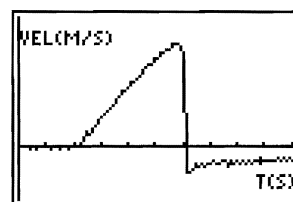
Figure 3:
Velocity versus Time

8 Press ⟦TRACE⟧ to move along the velocity versus time plot. Identify the coordinates of two points that lie on the sloping straight-line portion of the velocity versus time plot, and record them in you lab notebook as (t_1, v_1) and (t_2, v_2).

9 Use the coordinates recorded in Step 8 to determine the slope of the velocity versus time plot:

$$slope = (v_2 - v_1)/(t_2 - t_1)$$

The velocity-time slope found above represents the average acceleration a of the dynamics cart. Record this value in your lab notebook.

10 The applied force is changed by varying the hanging mass. Repeat this procedure (Steps 1 through 9) for at least five different applied force values, keeping the dynamics cart mass M constant. For each trial, record all relevant data including the net force F and the average acceleration a. Organize this data in a table.

Analysis and Conclusion

Note: Refer to "Performing Data Analysis" in the *CBL System Compatible Calculators* for information about using statistical features of the calculators.

1. Press ⟦STAT⟧ ⟦ENTER⟧ on the calculator to access the list editor. Clear any existing data from lists L1 and L2 by moving to the top of each list and pressing ⟦CLEAR⟧ ⟦ENTER⟧. Based on the data table you constructed earlier, enter the acceleration values in list L1 and the corresponding forces in list L2.

2. Perform a Scatter plot with (▫) mark on the data in L1 and L2 using the STAT PLOT options and the ZoomStat window. Be sure to turn off all other statistic plots.

3. Perform a linear regression (LinReg) on L1 and L2 on the calculator. Record the regression equation and correlation coefficient in your lab notebook.

   The slope of the regression line on the force versus acceleration graph represents cart mass M in kilograms. Compare this value to the value of M recorded at the beginning of the experiment and find the percentage difference.

4. Press ⟦Y=⟧ and move the cursor to the first available function. Press ⟦VARS⟧ 5 ⟦▶⟧ ⟦▶⟧ 7 to copy the regression equation to the cursor position. Press ⟦GRAPH⟧ to see the Scatter plot and regression curve together. Print this graph using TI-GRAPH LINK and attach it to your lab notebook.

5. Do your results agree with the expression relating force, mass and acceleration suggested by Newton? Comment on any discrepancies.

This experiment allows students to investigate the characteristics of sound waves.

Introduction

When a tuning fork vibrates, it disturbs nearby air molecules, creating regions of higher-than-normal pressure (called compressions) and regions of lower-than-normal pressure (called rarefactions). It is possible to digitize these pressure variations using a microphone. The resulting signal can then be transferred to the calculator and displayed on its screen as a sinusoidal curve. Characteristics of the sound wave, such as its period T can be determined from this curve. Knowing the wave's period, its frequency f is easily computed using the formula:

$f = 1/T$

In the following exercises, you collect sound data using a microphone. This data will be used to investigate acoustical phenomena.

Equipment Required

✓ CBL

✓ CBL-compatible calculator with a unit-to-unit cable

✓ Vernier microphone/amplifier (MCA-U) with CBL DIN adapter

✓ Tuning forks

✓ Rubber tuning fork hammer

✓ TI-GRAPH LINK (optional)

Program

Download or enter the BEATS and SOUND programs into the calculator.

Equipment Setup Procedure

To connect the equipment as shown by Figure 1:

❶ Connect the CBL to the calculator with the unit-to-unit cable using the input/output ports located on the bottom edge of each unit. Press the cable ends in firmly.

❷ Connect the microphone to CH1 on the top edge of the CBL.

❸ Turn on the CBL and the calculator.

The CBL is now ready to receive commands from the calculator.

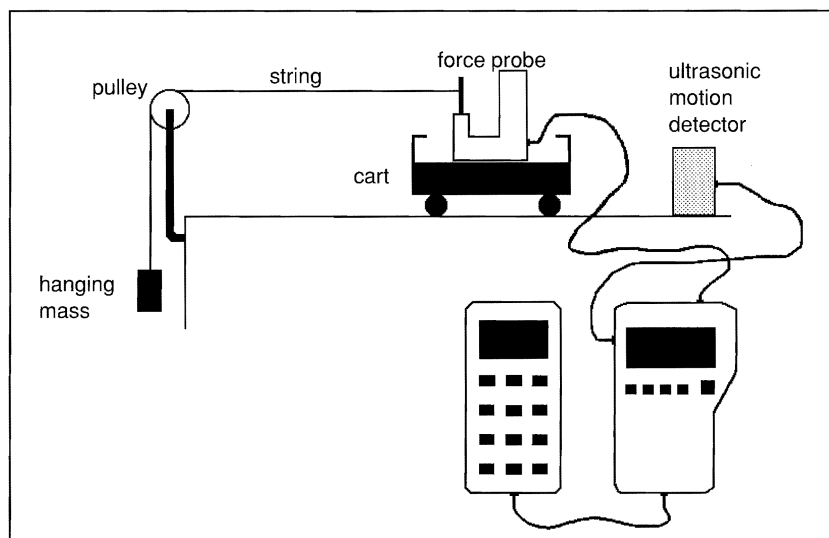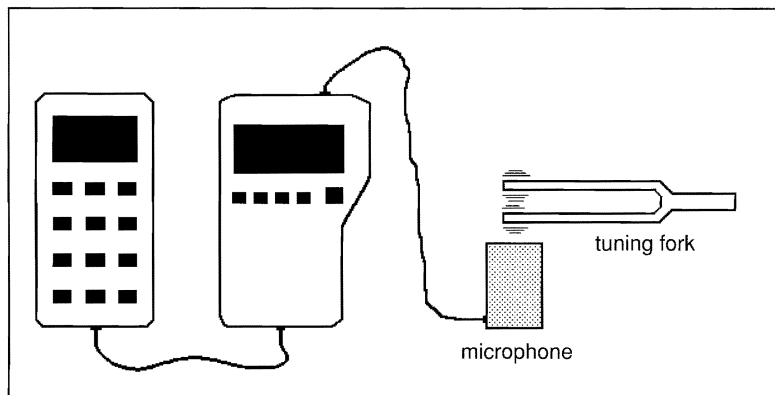**Figure 1:** Equipment Setup

Experiment Procedure and Analysis No. 1

Sound experiment

❶ Make sure the CBL is turned on. Start the SOUND program on the calculator. The program pauses execution and waits for you to press ENTER on the calculator.

❷ Select a tuning fork whose frequency is between 200 and 300 Hz.

❸ Strike the tuning fork with the rubber hammer and place the vibrating fork as close as possible to the microphone. (Do not let the fork actually touch the microphone.)

❹ As soon as the tuning fork is close to the microphone, press ENTER on the calculator.

The resulting pressure versus time plot should look similar to Figure 2. If the resulting plot is not sinusoidal, press CLEAR ENTER on the calculator and record the sound again. When you are satisfied with the graph, save it to a PIC variable to be printed later using TI-GRAPH LINK. Pressure is stored in L5 and time (in seconds) is stored in L2.
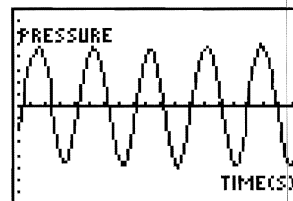
Figure 2:
Pressure versus Time

❺ Press TRACE and move along the pressure versus time plot. To find the period T, determine the time required for several complete oscillations, and then divide by that number of oscillations. Record this value in your lab notebook.

❻ Determine the frequency of the sound wave produced by the tuning fork using the formula given in the introduction section and the calculated period from Step 5. Record this value as f in your lab notebook. How does this value compare to the frequency value printed on the tuning fork? Calculate a percentage error.

❼ Press [2nd] [DRAW] 3 to display a horizontal line on the screen. Use the arrow keys to move the line up and down until it aligns with the top portion of the sound wave. The displayed *y-value* gives an estimate of the wave's amplitude. Record this value in your lab notebook as *A*.

❽ Store your computed amplitude and frequency values to the variables *A* and *F* respectively on the calculator. Also, store zero to the variable *D* on the calculator.

❾ Press [Y=] and move the cursor to the first available function. Enter the equation $Y = A \sin(2\pi F(X + D))$, and then press [GRAPH]. How well does the displayed graph match the plot of position versus time that appears on the screen? Try storing different values for the horizontal shift variable *D* until the Y= graph and the pressure versus time plot exactly overlap. Copy the resulting equation into your lab notebook, using the numerical values for *A*, *F*, and *D*. Save the resulting screen image to a PIC variable to be printed later using TI-GRAPH LINK.

❿ Repeat this procedure (Steps 1 through 9) at least twice, using different tuning forks for each trial. Record all relevant data in your lab notebook.

Experiment Procedure and Analysis No. 2

Beats experiment

When two tones of slightly different frequencies are sounded simultaneously, the loudness of the resulting sound wave fluctuates periodically. This phenomenon is called *beats*. This portion of the activity investigates beat patterns produced using pairs of tuning forks.

❶ Make sure the CBL is turned on. Start the BEATS program on the calculator. Select two tuning forks whose frequencies differ by less than 50 Hz. When prompted by the program, enter the tuning fork frequencies. This allows the program to select an appropriate data collection rate and viewing window. The program then pauses execution and waits for you to press [ENTER] on the calculator.

❷ Strike the tuning forks with the rubber hammer. Bring the tuning forks as close as possible to the microphone.

❸ When the tuning forks are close to the microphone, press [ENTER] on the calculator. (It may be easier to have someone else press [ENTER] for you.)

The resulting pressure versus time plot should look similar to Figure 3. If you are not satisfied with your plot, press [CLEAR] [ENTER] and start again. When you obtain an acceptable graph, save it to a PIC variable to be printed later using TI-GRAPH LINK. Pressure is stored in L5 and time (in seconds) is stored in L2.
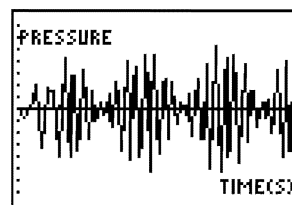
Figure 3:
Pressure versus Time

❹ Press [2nd] [DRAW] 4 to display a vertical line on the screen. Use the arrow keys to move the line back and forth. Determine the time required for one complete beat pattern and record this value as the beat period T_b in your lab notebook.

❺ Determine the beat frequency of the sound wave produced by the tuning forks using the formula $f=1/T$ (given in the introduction section) and the calculated period from Step 4. Record this value as the beat frequency f_b in your lab notebook. How does this value compare to the difference between the frequency values printed on the tuning forks? What do you suspect is the general relationship between the frequency of the beat pattern produced and the frequencies of the individual tones producing this pattern?

❻ Repeat this procedure (Steps 1 through 5) at least twice, using a different pair of tuning forks for each trial. Record all relevant data in your lab notebook.

This experiment lets you investigate the intensity decay of a light bulb.

Introduction

We generally refer to light intensity as "brightness." More precisely, intensity is defined as the rate at which energy is transferred per unit area, measured in watts per square meter.

As light propagates away from its source, the energy associated with it tends to spread out. Consequently, the intensity of the light *I* decreases as the distance from the source *r* increases. This relationship is expressed in terms of an inverse square law:

$$I = k/r^2$$

where *k* is a constant that depends on the physical characteristics of the light source.

This experiment uses a light intensity sensor to verify the relationship stated above.

Equipment Required

- ✓ CBL
- ✓ CBL-compatible calculator with a unit-to-unit cable
- ✓ TI Light probe
- ✓ Standard light bulb (15W or 25W)
- ✓ Wooden block
- ✓ Tape
- ✓ Meter stick
- ✓ TI-GRAPH LINK (optional)

Program

Download or enter the LIGHT program into the calculator.

Equipment Setup Procedure

To connect the equipment as shown by Figure 1:

❶ Connect the CBL to the calculator with the unit-to-unit cable using the input/output ports located on the bottom edge of each unit. Press the cable ends in firmly.

❷ Connect the TI light probe to CH1 on the top edge of the CBL.

❸ Secure the light sensor to a wooden block with tape. Position the sensor so that it is facing the light bulb as shown in Figure 1.

❹ Turn on the CBL and the calculator.

The CBL is now ready to receive commands from the calculator.

Figure 1: Equipment Setup

Experiment Procedure

❶ Make sure the CBL is turned on. Start the LIGHT program on the calculator. Darken the room and turn off the light bulb. Press [ENTER] to zero the probe. Enter 15 when prompted by the program for the number of data points to collect.

❷ Position the light sensor so that separation between it and the center of the bulb is 30 cm. Turn on the light bulb. Enter 30 when prompted for the separation. Press [ENTER] to collect the corresponding light intensity for this position. Move the sensor 35 cm away from the center of the bulb. Enter 35 for the separation. Press [ENTER] to record the corresponding intensity. Continue in this fashion until 15 data points are collected.

❸ After the data is collected, a plot of light intensity (in mW/cm^2) versus separation (in centimeters) appears on the calculator screen. The plot should look similar to the one shown in Figure 2. Make a printout of this graph using TI-GRAPH LINK or save it as a PIC variable to be printed later. Attach this printout to your lab notebook. Be sure to include appropriate scales and axis labels on the printout.
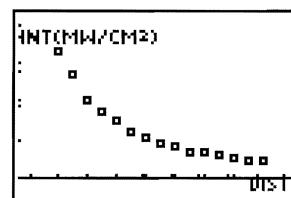
Figure 2:
Intensity versus Distance

Analysis and Conclusion

Note: Refer to "Performing Data Analysis" in the *CBL System Compatible Calculators* for information about using statistical features of the calculators.

1. The separation data is stored in list L$_2$ and the light intensity data is stored in list L$_4$. To determine the relationship between these variables, select PwrReg from the STAT CALC menu. Enter the appropriate regression command on the home screen, PwrReg L$_2$, L$_4$.

2. Record the regression equation and correlation coefficient in your lab notebook. Does this equation agree with the mathematical model relating intensity and separation that was described in the introduction section?

3. Press Y= and move the cursor to the first available function. Press VARS 5 ▶ ▶ 7 to copy the regression equation to the cursor position. Press GRAPH to see the scatter plot and regression curve together. Make a printout of this graph using TI-GRAPH LINK and attach it to your lab notebook.

4. Repeat this experiment using a different type of light source. If the source is significantly brighter, you may need to start at a separation greater than 30 cm. Record all relevant data in your lab notebook, as before.

5. List several physical characteristics of a light source that you suspect might have an effect on its intensity at a fixed distance from the source.

Experiment P7 — The Pendulum and Mechanical Energy

This experiment allows students to examine and possibly verify the conservation of mechanical energy principle for a swinging pendulum.

Introduction

If a pendulum is pulled to one side and held in place, there is no motion and no kinetic energy, but there is potential energy. When the pendulum is released, the potential energy lost as it descends is equal to the kinetic energy that is gained. This is consistent with the conservation of mechanical energy principle, which states that the total energy of a conservative system, kinetic plus potential, remains constant while the system is in motion. Stated mathematically:

$$K_i + U_i = K_f + U_f$$

where kinetic energy is given by the formula $K = (1/2)mv^2$ and potential energy is given by the formula $U = mgy$.

In the preceding expressions, m and v are the mass and speed of the pendulum respectively, g is gravitational acceleration (9.8 m/sec^2), and y represents the pendulum's vertical position.

This experiment determines whether or not mechanical energy is conserved as a pendulum swings.

Equipment Required

- ✓ CBL
- ✓ CBL-compatible calculator with a unit-to-unit cable
- ✓ TI Light probe
- ✓ Infrared source*
- ✓ String

- ✓ 20 g mass
- ✓ Cardboard strip (about 5x5 cm)
- ✓ Binder clip
- ✓ Support blocks
- ✓ 2 Ring stands and utility clamps
- ✓ Meter stick

Program

Download or enter the GATE and STATUS programs into the calculator.

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* An IR LED such as a Radio Shack #276-143 connected in series with a 390-ohm resistor and a 9-volt battery works nicely as an infrared source. It is also possible to trigger with a visible light source such as a low-power laser. However, this would require an adjustment in the trigger threshold value in CMD3 in the STATUS and GATE programs. (Refer to the CBL guidebook for details regarding the syntax of CMD3.)

Equipment Setup Procedure

To connect the equipment as shown by Figure 1:

❶ Connect the CBL to the calculator with the unit-to-unit cable using the input/output ports located on the bottom edge of each unit. Press the cable ends in firmly.

❷ Connect the TI light probe to CH1 on the top edge of the CBL.

❸ Support the meter stick with two ring stands so that the meter stick is about 0.5 meters above and horizontal to a flat surface.

❹ Assemble the pendulum, which consists of a 20 g mass and about a 5 cm-wide cardboard strip held together with a binder clip. A string passing through the clip handles supports the pendulum (refer to Figure 1).

❺ Find the mass of the pendulum and record this value as *m* in your lab notebook.

❻ Attach the string to support the pendulum to the meter stick at two points, and adjust the height so that the cardboard target falls between the light sensor and infrared source.

❼ Secure the light sensor and infrared source to support blocks as shown in Figure 1, and position them directly in line with the resting pendulum about 4 or 5 centimeters apart.

❽ Turn on the CBL and the calculator.

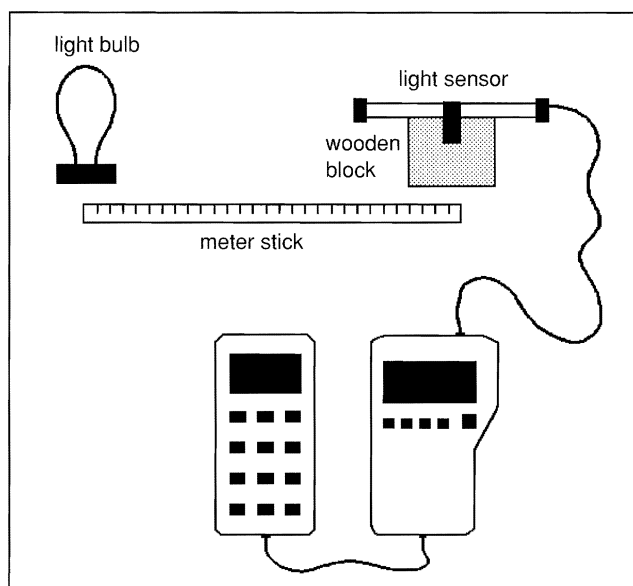The CBL is now ready to receive commands from the calculator.
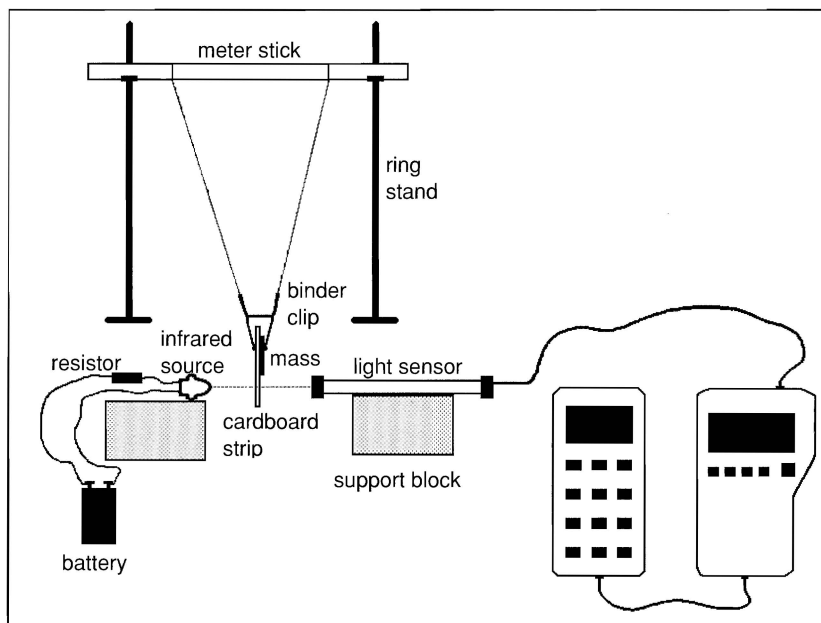
Figure 1: Equipment Setup

Experiment Procedure

❶ Make sure the CBL is turned on. Start the STATUS program on the calculator. Press ENTER to check the photogate system for alignment. Pull the pendulum to one side and adjust the positions of the light sensor and infrared source until the status shows "unblocked." Press ON 2 to interrupt and quit the program.

❷ With the pendulum at rest, measure and record the distance of the pendulum from the surface of the table and record this value as y_f. Also, measure the width of the cardboard strip that passes through the photogate as it swings. Record this value in your lab notebook as Δd.

❸ Start the GATE program on the calculator. Pull the pendulum to one side making sure there is no slack in the string. Measure the height of the pendulum from the surface of the table and record this value as y_i in your lab notebook.

❹ Press ENTER to arm the photogate and then release the pendulum. Let the pendulum swing through the photogate, and then catch it. The time during which the cardboard strip blocked the beam as the pendulum passed through the photogate appears at the top of the calculator screen as Δt (refer to Figure 2).

ΔT=.0380448 SEC

Figure 2

❺ Record this value in your lab notebook. Repeat this measurement at least three times, starting the pendulum from the same height each time. Take the average of your measured times and record this value in your lab notebook as Δt_{ave}.

❻ Change the starting height of the pendulum and repeat this procedure (Steps 1 through 6). Do this for at least five different starting heights.

Analysis and Conclusion

1. For each trial, calculate the initial and final potential energy values, U_i and U_f, using the data collected during the experiment and the formula $U=mgy$ (given in the introduction section). Record these values in your lab notebook using a table format.

2. Find the speed of the pendulum at its lowest position, using the measured width of the cardboard strip, the average time value supplied by the photogate system, and the formula $v=\Delta d/\Delta t_{ave}$. Record this value in a data table.

3. Calculate and record the final kinetic energy K_f of the pendulum using the data obtained in Step 2 above along with the formula $K=(1/2)mv^2$ (given in the introduction section). Since the pendulum was released from rest, K_i is zero.

4. Determine the total initial energy K_i+U_i, and the total final energy K_f+U_f for each trial. Compare the magnitudes of these quantities and find the percentage difference. To what extent do your findings verify the conservation of mechanical energy principle?

IMPORTANT **UK**	Proper safety precautions must be taken to protect teachers and students during demonstrations and experiments described in this workbook. In addition to the instructions provided here, it is important that you follow safety procedures and precautions defined by your lab, teacher, or other expert concerning the particular activity. It is the teacher's responsibility to ensure that proper laboratory safety procedures are identified and followed, and that chemicals and other items are properly disposed of.
WICHTIG **D**	Bei den Vorführungen und Experimenten, die im vorliegenden Arbeitsbuch beschrieben werden, sind angemessene Sicherheitsvorkehrungen zum Schutz von Lehrern und Schülern zu treffen. Zusätzlich zu den hier aufgeführten Anweisungen ist die Befolgung der Sicherheitsmaßnahmen und -vorkehrungen wichtig, die vom Labor, vom Lehrer oder anderen Fachleuten für die bestimmte Tätigkeit festgelegt wurden. Es liegt in der Verantwortung des Lehrers sicherzustellen, daß angemessene Sicherheitsmaßnahmen für das Labor festgestellt und befolgt werden, und daß Chemikalien und andere Materialien entsprechend entsorgt werden.
IMPORTANT **F**	Des mesures de sécurité adéquates doivent être adoptées pour protéger les professeurs et les étudiants au cours des démonstrations et expériences décrites dans le présent manuel. Outre les instructions fournies ici, il importe que vous adoptiez les procédures et mesures de sécurité définies par votre labo, votre professeur ou tout autre spécialiste concernant l'activité particulière. Il relève de la responsabilité du professeur de veiller à ce que des mesures de sécurité de laboratoire adéquates soient définies et adoptées et à ce que les produits chimiques et autres articles soient correctement évacués.
IMPORTANTE **I**	E' necessario assumere adeguate misure di sicurezza nei confronti di insegnanti e studenti durante le dimostrazioni e gli esperimenti descritti in questo testo di esercitazioni. Oltre alle istruzioni qui riportate, è importante adottare le precauzioni e le misure di sicurezza stabilite dal tecnico di laboratorio, dall'insegnante o da una persona esperta di questo tipo di operazioni. Gli insegnanti hanno la responsabilità di controllare che vengano stabilite e adottate le misure di sicurezza adeguate e che le sostanze chimiche o di altra natura siano smaltite correttamente.
BELANGRIJK **NL**	Neem de geëigende voorzorgsmaatregelen om leraars en studenten te beschermen tijdens de demonstraties en experimenten die in deze documentatie worden voorgesteld. Naast de hierna vermelde instructies moet u ook de veiligheidsvoorschriften en voorzorgsmaatregelen naleven die door uw laboratorium, leraar of andere deskundige werden opgesteld in het kader van de activiteiten in kwestie. Het is de verantwoordelijkheid van de leraar ervoor te zorgen dat de geëigende veiligheidsvoorschriften worden afgebakend en opgevolgd, en dat de chemicaliën en andere voorwerpen oordeelkundig worden weggedaan.
IMPORTANTE **E**	Se deben adoptar las precauciones de seguridad apropiadas para proteger a los profesores y estudiantes durante las demostraciones y experimentos descritos en este libro de trabajo. Además de las instrucciones que aquí se ofrecen, es importante que se sigan los procedimientos y precauciones de seguridad definidos por el laboratorio, profesor o cualquier otro experto y relativos a una actividad en concreto. Es responsabilidad del profesor comprobar que se identifican y siguen los procedimientos de seguridad de laboratorio apropiados, y que los productos químicos y demás elementos se eliminan de forma adecuada.
IMPORTANTE **P**	Devem ser tomadas precauções de segurança adequadas para proteger professores e alunos durante as demonstrações e experiências descritas neste manual. Além das instruções aqui fornecidas, é importante que siga os procedimentos e precauções de segurança definidos pelo seu laboratório, professor(a) ou outro perito relacionado com a actividade em questão. O professor(a) é responsável pela identificação e prosecução dos procedimentos de segurança laboratorial mais adequados e pela eliminação apropriada de produtos químicos e outros artigos.
VIGTIGT **DK**	Der skal træffes de fornødne sikkerhedsforanstaltninger for at beskytte lærere og elever under demonstrationerne og forsøgene, der er beskrevet i denne arbejdsbog. Ud over instruktionerne heri, er det vigtigt at følge sikkerhedsprocedurer og -forholdsregler i forbindelse med den enkelte aktivitet, som er oplyst af laboratoriet, læreren eller andre eksperter. Det er lærerens ansvar at sikre, at sikkerhedsprocedurerne for arbejdet i laboratoriet er kendt og følges, samt at kemikalier og andre artikler bortskaffes på korrekt vis.
VIKTIGT **S**	Se till att nödvändiga säkerhetsföreskrifter följs för att skydda lärare och elever under de demonstrationer och experiment som beskrivs i denna arbetsbok. Utöver de instruktioner som ges här är det viktigt att också följa de säkerhetsföreskrifter som gäller för laboratoriet eller ges av lärare eller någon annan expert på området. Läraren ansvarar för laboratoriets säkerhet, information om riskmoment, att säkerhetsföreskrifterna följs och att kemikalier och annat avfall hanteras korrekt.
VIKTIG **N**	Under de eksperimentene som beskrives i denne arbeidsboken er det av stor betydning å treffe de nødvendige sikkerhetstiltak for å beskytte lærere og elever. I tillegg til instruksjonene er det viktig at du følger de sikkerhetsforskriftene og tiltakene for den aktuelle aktiviteten som er fastlagt av laboratoriet, læreren din eller andre eksperter. Det er lærerens ansvar å å sørge for at de gjeldene sikkerhetstiltak klarlegges og overholdes,og at kjemikalier og andre ting blir tatt hånd på en forskriftsmessig måte.
TÄRKEÄÄ **SF**	Opettajien ja oppilaiden turvallisuuden varmistamiseksi on demonstraatioiden ja kokeiden aikana noudatettava tässä kirjassa mainittuja turvamääräyksiä. Näiden ohjeiden lisäksi on noudatettava laboratorion, opettajan ja muiden asiantuntijoiden antamia kyseistä toimintaa koskevia turvaohjeita ja varovaisuussääntöjä. Opettajan vastuulla on antaa asianmukaiset turvaohjeet, valvoa turvaohjeiden noudattamista ja huolehtia kemikaalien ja muiden aineiden tai esineiden asianmukaisesta hävittämisestä.
ΣHMANTIKO **GR**	Θα πρέπει να ληφθούν οι κατάλληλες προφυλάξεις ασφαλείας για να προστατευτούν οι καθηγητές και οι μαθητές κατά τη διάρκεια των επιδείξεων και των πειραμάτων που περιγράφονται σε αυτό το βιβλίο εργασιών. Εκτός από τις οδηγίες που παρέχονται στο παρόν, είναι σημαντικό να ακολουθήσετε τις διαδικασίες ασφαλείας και τα μέτρα προφύλαξης που καθορίζουν το εργαστήριό σας, οι καθηγητές σας ή άλλοι αρμόδιοι σχετικά με τη συγκεκριμένη δραστηριότητα. Είναι ευθύνη του καθηγητή να βεβαιωθεί ότι έχουν κοινοποιηθεί και τηρούνται οι σωστές διαδικασίες ασφάλειας εργαστηρίου και ότι η απόρριψη χημικών και άλλων υλικών γίνεται σωστά.

This experiment lets you compare and measure the effectiveness of over-the-counter gastrointestinal products to neutralize excess stomach acid.

Introduction

There are many commercial products available that are used to combat acid indigestion and/or upset stomach caused by excessive amounts of stomach acid. All of these products claim to be effective in neutralizing excess stomach acid and providing fast, safe relief. Some products, however, may be more effective than others. In this experiment, we will see how well several brands of antacid tablets take care of our gastrointestinal ailments.

Most of these products contain additional ingredients: flavoring and substances that soothe the stomach walls, binders to hold the tablet together, and lubricants to keep the tablets from sticking to each other in the container. The active ingredients, however, are similar. Among the most common acid-neutralizing substances are magnesium hydroxide, sodium bicarbonate, calcium carbonate, magnesium carbonate, aluminum hydroxide, and dihydroxyaluminum sodium carbonate.

In this experiment, you will create a high-acidity situation, and then add a carefully measured amount of an antacid tablet. In a titration, a solution of known concentration is reacted with a second solution to determine the concentration of the second solution. By titrating the mixture with a strong acid (HCl), you will be able to determine how much acid your product can neutralize. Your test results will be used to rank several products by their effectiveness.

⚠️**WARNING: Wear goggles, gloves, and an apron at all times!**

The acids and bases you will use are harmful to your skin and eyes. Wash all spills immediately with generous amounts of tap water.

Equipment Required

- ✓ CBL
- ✓ CBL-compatible calculator with a unit-to-unit cable
- ✓ Vernier pH probe (PHA-DIN amplifier and 7120B electrode) with CBL DIN adapter
- ✓ Mortar and pestle
- ✓ Antacid tablet samples
- ✓ Plastic weigh dishes
- ✓ 250-mL beaker

- ✓ 0.5 M HCl solution
- ✓ 0.1 M HCl solution
- ✓ Distilled water
- ✓ 50-mL or 100-mL graduated cylinder
- ✓ Ring stand and utility clamp
- ✓ Buret and buret clamp
- ✓ TI-GRAPH LINK (optional)
- ✓ Indicator solution (optional)
- ✓ Magnetic stirrer and stir bar (optional)

Program

Download or enter the PH programinto the calculator.

To perform the alternate experiment procedure at the end of this experiment, which collects data in real-time, download or enter the PHRT program into the calculator.

Equipment Setup Procedure

To connect the equipment as shown by Figure 1:

❶ Connect the CBL to the calculator with the unit-to-unit cable using the input/output ports located on the bottom edge of each unit. Press the cable ends in firmly.

❷ Assemble the buret clamp to a ring stand and attach a buret to the clamp.

❸ Attach the pH probe to the ring stand (below the buret assembly) with a utility clamp.

❹ Connect the pH probe to CH1 on the top edge of the CBL.

❺ Turn on the CBL and the calculator.

❻ If necessary, calibrate the pH probe (refer to the front of the CBL workbook for details).

The CBL in now ready to receive commands from the calculator.

Figure 1: Equipment Setup

Experiment Procedure

❶ Obtain an antacid tablet and record (on your data sheet) the brand that you are testing. Measure and record the mass of the tablet, and then use a mortar and pestle to grind the tablet into a powder.

❷ Carefully transfer the powder to a 250-mL beaker. Add 50 mL of distilled water to the beaker and swirl the mixture to dissolve the powder.

Note: Depending on the ingredients in your product, all the powder may not dissolve. Swirl for a minute or two, and do not worry about undissolved particles.

❸ Pre-rinse the buret and tip with a small amount of HCl, and then fill it to the 0.0 mL mark with 0.5 M HCl. (Refill the buret as needed.)

❹ If an indicator solution is used for visual effect, add 2 or 3 drops of it to the beaker at this time.

❺ Place the beaker under the buret. If a magnetic stirrer is used, place the beaker on the stirrer and place a stirring bar into the mixture.

❻ Place the pH probe into the antacid mixture. If a magnetic stirrer is used, begin stirring. Position the pH probe so that it does not interfere with the stirring bar.

❼ Make sure the CBL is turned on. Start the PH program on the calculator. When prompted, enter the number of the channel to which the probe is connected, and enter 40 for the number of samples to collect.

❽ Start the titration and take an initial pH reading of the antacid mixture. At the ML? prompt, enter zero (0 mL volume).

Note: To take pH readings, press TRIGGER on the CBL. At the ML? prompt, enter the volume of HCl that you are adding. The data point is plotted on the calculator display, and the program pauses until you press TRIGGER again. Wait a few seconds between each TRIGGER keypress to allow the reading to stabilize.

❾ When prompted by the program, add 0.5 M HCl in increments of 5.0 mL for the first 15 mL of acid, and then add HCl in increments of one or two milliliters until a consistent pH reading of 3.00 is achieved. At a pH of 3.00, the antacid is considered ineffective. After all samples are taken, a STAT PLOT of the collected data (volume in L5 and pH in L4) is displayed. Press TRIGGER on the CBL one more time to complete data collection.

❿ Clean up by rinsing the contents of the beaker down the sink. Repeat the titration with another antacid tablet. Be sure to rinse the pH probe with tap water before each titration.

Analysis and Conclusion

Compile the results of each test by printing the titration plot and the data lists using TI-GRAPH LINK. Collect all the test data for the other antacid tablets and include this information in your lab report Data section. Include the following items in your report:

• A chart that lists the products in order of effectiveness.

• A chart that lists the chemical substances (active ingredients) in order of effectiveness. (These two charts can be combined, if you wish.)

• A discussion of the economy of each product.

• A general discussion of antacids, referencing magazine articles and/or books that you have reviewed. (The topic is your choice.)

Analysis of Three Antacid Tablet Products

1. Titration of Brand A versus 0.50 M HCl.

mL	pH	
0	8.58	
5	7.85	
10	5.99	
15	5.56	
20	5.37	
25	5.21	
30	5.08	
35	4.68	**Figure 2**
40	4.39	
45	3.18	
50	2.90	
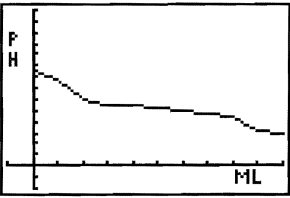
2. Titration of Brand B versus 0.50 M HCl.

mL	pH	
0	9.14	
5	9.01	
10	3.08	
15	2.62	
20	2.73	
25	2.83	
30	2.73	
35	2.74	**Figure 3**
40	2.38	
45	2.64	
50	2.54	
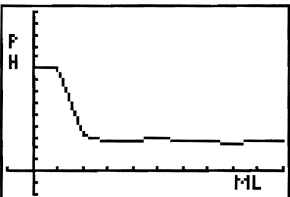
3. Titration of Brand C versus 0.50 M HCl.

mL	pH	
0	9.60	
5	8.99	
10	4.57	
15	3.22	
20	4.00	
25	3.03	
30	2.73	
35	2.74	**Figure 4**
40	2.54	
45	2.64	
50	2.54	
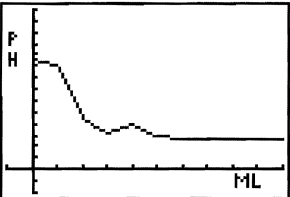
Alternate Experiment Procedure

The following procedure describes how to display collected data in real-time, which simulates the activity of an antacid in the stomach over a 30-minute period. This procedure mimics the method used by consumer testing laboratories when various antacid products are compared to each other. Note that 0.1 M HCl is added initially to simulate conditions in the stomach.

❶ Obtain an antacid tablet and record (on your data sheet) the brand that you are testing. Measure and record the mass of the tablet, and then use a mortar and pestle to grind the tablet into a powder.

❷ Carefully transfer the powder to a 250-mL beaker. Add 50 mL of distilled water to the beaker and swirl the mixture to dissolve the powder.

Note: Depending on the ingredients in your product, all the powder may not dissolve. Swirl for a minute or two, and don't worry about undissolved particles.

❸ Pre-rinse the buret and tip with a small amount of HCl, and then fill it to the 0.0 mL mark with 0.5 M HCl. (Refill the buret as needed.)

❹ Add exactly 50 mL of 0.1 M HCl to the beaker of the antacid mixture to simulate conditions in a human stomach. At this point, more of the suspended ingredients should dissolve. Ignore any particles that do not dissolve— they will not affect the testing. If an indicator solution is used for visual effect, add 2 or 3 drops of it to the beaker at this time.

❺ Place the beaker under the buret. If a magnetic stirrer is used, place the beaker on the stirrer and place a stirring bar into the mixture.

❻ Place the pH probe into the antacid mixture. If a magnetic stirrer is used, begin stirring. Position the pH probe so that it does not interfere with the stirring bar.

❼ Make sure the CBL is turned on. Start the PHRT program on the calculator. A sample will be collected once every 20 seconds for 30-minutes. When prompted, enter the number of the channel to which the probe is connected.

❽ Begin adding 0.5 M HCl dropwise, very slowly and press ENTER on the calculator to start collecting data. Let the HCl drip at a rate of one drop per second. This rate should correspond closely to the CBL sampling so that a sample will be collected for every mL of HCl added. Also, the buret should be refilled when about 25 mL of HCl has been used.

The display on your calculator should look similar to the graph shown in Figure 5. The data for pH is stored in L4 and time (in seconds) is stored in L5.
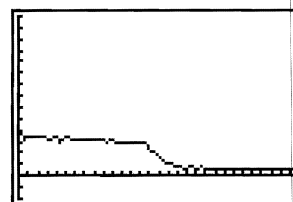
Figure 5:
pH (y-axis) versus
Time (x-axis)

Introduction

Many interesting chemical phenomena can be easily studied with common household products. Reactions between acids (substances with pH below 7.0) and bases (pH above 7.0) are well illustrated by testing vinegar by a process called titration. In a titration, a solution of known concentration is reacted with a second solution to determine the concentration of the second solution.

Vinegar contains acetic acid, which is a weak acid with a distinctive odor. Sodium hydroxide (NaOH), a strong base, neutralizes acetic acid. By measuring the amount of NaOH needed to neutralize all the acetic acid in a sample of vinegar, which is indicated by the solution having a pH between 8.0 and 9.0, the concentration of acetic acid can be determined. The acetic acid content of household vinegar can vary significantly, either by the age of the product or by its brand name.

The objectives in this experiment are to:

▸ Determine the concentration of acetic acid in three brands of vinegar.

▸ Verify or refute the description on the product labels.

▸ Practice the chemical testing technique of titration.

⚠ WARNING: Wear goggles, gloves, and an apron at all times!

Sodium hydroxide is a strong irritant and is harmful to your skin and eyes. Wash all spills immediately with generous amounts of tap water.

Equipment Required

✓ CBL

✓ CBL-compatible calculator with a unit-to-unit cable

✓ Vernier pH probe (PHA-DIN amplifier and 7120B electrode) with CBL DIN adapter

✓ Three different brands of white vinegar

✓ 1.0 M NaOH solution (40.0 grams of NaOH per liter of solution)

✓ 50-mL buret and buret clamp

✓ Ring stand and utility clamp

✓ 250-mL beaker

✓ 50-mL graduated cylinder

✓ Magnetic stirrer and stirring bar (optional) or glass stirring rod

✓ TI-GRAPH LINK (optional)

✓ Indicator solution (optional)

Program

Download or enter the PH program into the calculator.

Equipment Setup

To connect the equipment as shown by Figure 1:

❶ Connect the CBL to the calculator calculator with the unit-to-unit cable using the input/output ports located on the bottom edge of each unit. Press the cable ends in firmly.

❷ Assemble the buret clamp to a ring stand and attach a buret to the clamp.

❸ Attach the pH probe to the ring stand (below the buret assembly) with a utility clamp.

❹ Connect the pH probe to CH1 on the top edge of the CBL.

❺ Turn on the CBL and the calculator.

❻ If necessary, calibrate the pH probe (refer to the front of the CBL workbook for details).

The CBL in now ready to receive commands from the calculator.

Figure 1: Equipment Setup

Experiment Procedure

❶ Pre-rinse the buret and tip with a small amount of NaOH, and then fill it to the 0.0 mL mark with 1.0 M of the NaOH solution.

❷ Using a 50-mL graduated cylinder, carefully measure 35 mL of vinegar and transfer it into a 250-mL beaker. Record the brand of vinegar and the volume used in your data table. (If a visual aid is desired, add a few drops of an indicator solution to the vinegar.)

❸ If a magnetic stirrer is used, place the beaker on the magnetic stirrer. Position the pH probe so that it is deep into the vinegar solution and does not touch the rotating stirring bar.

❹ Position the beaker, pH probe, and buret so that the NaOH solution can be easily added to the vinegar.

❺ Make sure the CBL and calculator are turned on. Start the PH program on the calculator. When prompted, enter the number of the channel to which the probe is connected, and enter 30 for the number of samples to collect.

❻ Start the titration and take an initial pH reading of the vinegar. At the ML? prompt, enter zero (0 mL volume).

Note: To take pH readings, press TRIGGER on the CBL. At the ML? prompt, enter the volume of NaOH that you are adding. The data point is plotted on the calculator display, and the program pauses until you press TRIGGER again. Wait a few seconds between each TRIGGER keypress to allow the reading to stabilize.

❼ When prompted by the program, add the NaOH solution in 3- to 5-mL increments until about 18–20 mL have been added to the vinegar, or a pH of about 5 has been reached. Carefully add NaOH in 1- or 2-mL increments as you near the equivalence point (pH=9). Once the equivalence point is reached, add several more mL of the NaOH solution, and then collect three or four data points beyond pH=9. After all samples are taken, a STAT PLOT of the collected data is displayed. Press TRIGGER on the CBL one more time to complete data collection.

❽ Save the test results by sending the data lists L4 (pH) and L5 (mL of NaOH) to a computer using TI-GRAPH LINK, or store the data in two new lists in the calculator.

❾ Discard the solution in the beaker and clean up. Prepare another 35-mL vinegar sample. Rinse and refill the buret with 1.0 M NaOH.

Return to Step 3 and conduct a second titration. Be sure to rinse the pH probe with tap water before each titration.

❿ Repeat Steps 1 through 9 for all three brands of vinegar.

Note: Before you complete the work, you must have two sets of tests that compare within 1.0 mL for each brand of vinegar that you test. Unless something unusual occurs, it is not necessary to run more than three tests per brand of vinegar.

Analysis

1. Examine the graphs of pH versus mL of NaOH added. Read the amount of NaOH used to reach a pH of 9. Prepare a paper copy of your graphs for the lab report. Review the graphs to select the most reliable data for the following calculations.

2. To determine the molar concentration of acetic acid in the vinegar, use the equation: $M_1V_1 = M_2V_2$.

M_1 = 1.00 M NaOH
V_1 = volume (in mL) of NaOH used in a given titration to reach a pH of 9
M_2 = molar concentration of acetic acid
V_2 = 35.0 mL of vinegar solution used in each titration

3. To determine the percent concentration of acetic acid in vinegar, use the molarity calculated above to determine the molar amount of acetic acid (CH_3COOH), and then convert moles of acetic acid to grams. Convert mass of acetic acid to volume by using its density. The density of vinegar is considered to be 1.001 gram/mL.

The calculation for percent concentration by mass is:

$$\% \ concentration = \frac{volume \ of \ acetic \ acid}{35 \ mL \ of \ vinegar \ tested}$$

Conclusion

Compare the strengths of the various brands of vinegar tested. Which brand is strongest? Does each brand provide the stated percentage of acetic acid? Which product is a best buy (more acetic acid for the money)?

Typical data for this experiment is shown by Figure 2. Each mark on the x-axis is equal to 5.0 mL, and each mark on the y-axis is equal to 1 pH unit.

The endpoint of the titration (pH=9) occurs at a point between the addition of 29.9 mL and 30.3 mL of 1.0 M NaOH. A reasonable estimate of the endpoint lies at 30.0 mL of NaOH added. By using the equation provided in the Analysis section, the concentration of this vinegar sample is 0.857 M. In percent concentration, as a product label would show, 0.857 M is equal to 5.13%, which is very close to the stated concentration for this product.

Figure 2: Vinegar Titration

This graph shows a relatively rough titration, which in a chemistry experiment would be used solely to define the parameters of the test. A second and third run would be made, with increments of 0.05 mL to 0.1 mL of NaOH added from about 26.5 mL to 30.5 mL, to more clearly identify the point at which pH equals 9.

This experiment lets you determine the equilibrium constant, represented by K_{eq} (or K_c), for a complex ion of iron thiocyanate.

Introduction

This experiment explores the reaction of iron (III) nitrate [$Fe(NO_3)_3$] and potassium thiocyanate (KSCN), which produces iron thiocyanate ions. An equilibrium is established as shown below:

$$Fe^{3+} + SCN^- \leftrightarrow FeSCN^{2+}$$
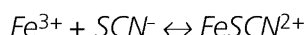
The color of this mixture is reddish-amber, which varies in intensity as the equilibrium and the concentration of iron thiocyanate ions change. You can take advantage of this color variation by monitoring the equilibrium using a colorimeter. The colorimeter passes green light through samples of the equilibrium mixture. The mixture absorbs some of this green light, and a photocell detects the amount of light that passes through unchanged. The amount of green light that is absorbed is proportional to the concentration of $FeSCN^{2+}$. This relationship is known as Beer's Law, and is the basis for all spectrophotometric analyses.

⚠ **WARNING: Wear goggles, gloves, and an apron at all times!**

Nitric acid is harmful to your skin and eyes. Wash all spills immediately with generous amounts of tap water. Also, we recommend that you wear a lab apron to prevent iron (III) nitrate from staining your clothes.

Equipment Required

- ✓ CBL
- ✓ CBL-compatible calculator with a unit-to-unit cable
- ✓ Vernier Colorimeter (COL-DIN) with CBL DIN adapter and cuvettes
- ✓ Six test tubes, 18 mm × 150 mm
- ✓ Test tube rack
- ✓ Rubber stoppers (size no. 1)

- ✓ 10-mL graduated cylinders or 10-mL pipette
- ✓ 50-mL beaker
- ✓ Eye dropper
- ✓ 0.00100 M KSCN[1]
- ✓ 0.100 M $Fe(NO_3)_3$, acidified[2]
- ✓ 0.30 M HNO_3 (18 mL of concentrated HNO_3 per liter)
- ✓ TI-GRAPH LINK (optional)

Program

Download or enter the COLOR program into the calculator.

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[1] Make an aqueous stock solution by adding 0.972 g of KSCN per 100 mL of solution. Measure out 10.0 mL of the stock solution and dilute to 1.00 liter with distilled water.

[2] For 1.00 liter of solution, mix 80.80 g of $Fe(NO_3)_3 \cdot 9H_2O$ to 600 mL of distilled water. Add 20.0 mL of concentrated HNO_3, and then dilute the solution to 1.00 liter.

Equipment Setup Procedure

To connect the equipment as shown by Figure 1:

1 Connect the CBL to the calculator with the unit-to-unit cable using the input/output ports located on the bottom edge of each unit. Press the cable ends in firmly.

2 Connect the colorimeter to CH1 on the top edge of the CBL.

3 Turn on the CBL and the calculator.

4 Calibrate the colorimeter. (This step is **required** to run COLOR program. Refer to the front of the CBL workbook for details.)

The CBL is now ready to receive commands from the calculator.
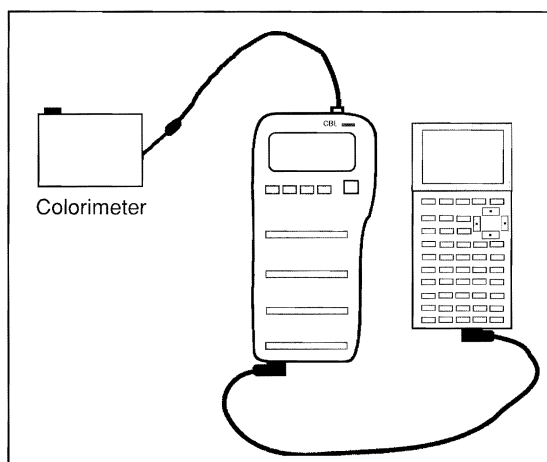
Figure 1: Equipment Setup

Experiment Procedure

1 Label six clean and dry test tubes from 1 to 6.

2 Add 5.0 mL of the acidified 0.100 M iron (III) nitrate solution to test tube 1.

3 Add 5.0 mL of the acidified 0.100 M iron (III) nitrate solution and 5.0 mL of 0.3 M HNO_3 to a 50-mL beaker and mix the solution.

4 Transfer 5.0 mL of the mixture to test tube 2.

5 Add 5.0 mL of 0.3 M HNO_3 to the beaker and mix well. Transfer 5.0 mL of the mixture to test tube 3.

6 Repeat Step 5 for test tubes 4, 5, and 6.

7 Pour any remaining solution in the 50-mL beaker down the sink. Rinse out the beaker with tap water and let it air dry.

❽ To each of the six test tubes, add 5.0 mL of 0.001 M KSCN solution. A color change should occur after each addition of KSCN. Seal each test tube with a rubber stopper and gently shake the test tubes (one at a time) to mix the substances.

❾ Rinse the curvette with a portion of the liquid from the test tube being used. Transfer a portion of the solution from test tube 1 to a cuvette. Fill the cuvette about three-fourths full, and then place the cuvette in the colorimeter.

❿ Make sure the CBL is turned on. Start the COLOR program on the calculator. At the prompt, enter the number of the channel to which the probe is connected. Test the solution with a green light. When the CBL has recorded a transmittance reading for the sample, remove and rinse out the cuvette with tap water.

Note: To take transmittance readings, press TRIGGER on the CBL. At the prompt "SAMPLE NUMBER?", enter the test tube number from 1 to 6. The data point is plotted on the calculator display, and the program pauses until you press TRIGGER again.

⓫ Repeat Steps 9 and 10 for the mixtures in test tubes 2 to 6. After all samples are taken, a STAT PLOT of the collected data (sample number in L5 and percent transmittance in L4) is displayed as shown in the graph to the right. Press TRIGGER on the CBL one more time to complete data collection.
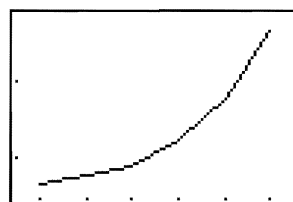
⓬ Rinse out the cuvette thoroughly after testing the mixture from test tube 6. Save the mixtures in the six test tubes for repeated testing.

Analysis

1. The following data are typical for this reaction, determined at equilibrium.

Test Tube	Fe^{3+}	SCN^-	$FeSCN^{2+}$	% Trans.	Absorbance	K_{eq}
1	0.0500	0.00	5.00×10^{-4}	12.28	0.9108	-
2	0.0246	9.7×10^{-5}	4.03×10^{-4}	18.45	0.7340	169
3	0.0122	1.74×10^{-5}	3.26×10^{-4}	25.48	0.5938	154
4	0.00600	2.45×10^{-5}	2.55×10^{-4}	34.52	0.4645	173
5	0.00296	3.32×10^{-4}	1.68×10^{-4}	49.34	0.3068	171
6	0.00146	4.04×10^{-4}	9.65×10^{-4}	66.72	0.1757	164

2. Test tube #1 is used as the reference standard for [$FeSCN^{2+}$]. It is presumed that all the SCN^- ions react to form $FeSCN^{2+}$ in test tube #1, providing a percent transmittance value for a known concentration of $FeSCN^{2+}$. This can be presumed for two reasons: 1) iron (III) nitrate is added in large excess to test tube #1; 2) the K_{eq} of this reaction heavily favors the production of $FeSCN^{2+}$.

3. The initial concentration for test tube #1 of each reactant is determined as shown by:

$[Fe^{3+}]$: $(0.005L)(0.10M) = 0.0005$ mol/$0.01L = 0.05M$

Each succeeding test tube has an initial Fe^{3+} concentration that is one-half of the preceding test tube. Thus, for test tube #2:

$[Fe^{3+}] = 0.025M$ $[SCN^-]$: $(0.005L)(0.001M) = 5 \times 10^{-6}$ mol/$0.01L = 5 \times 10^{-4}M$

The initial concentration of SCN^- is the same for each test tube.

4. Absorbance (A) is related to percent transmittance (%T) by the following equation:

$A = 2 - log\%T$

As stated in the introduction, the absorbance value for each test is directly related to the molar concentration of $FeSCN^{2+}$. For example, the absorbance value for test tube #2 is determined by the following:

$A = 2 - log\ 18.45 = 0.7340$

5. From test tubes #2 through #6, the $FeSCN^{2+}$ concentration decreases because the Fe^{3+} concentration is decreased. The molar concentration of $FeSCN^{2+}$ is directly proportional to the absorbance values calculated above, and can be determined by using the reference standard:

$[FeSCN^{2+}]_{eq} = (A_{eq}/A_{std})([FeSCN^{2+}])$

This calculation for test tube #2 is shown below:

$[FeSCN^{2+}]_{eq} = (0.7340/0.9108)(5.00 \times 10^{-4}M) = 4.03 \times 10^{-4}M$

6. The concentration of the reactants, Fe^{3+} and SCN^-, can be determined by subtracting the $FeSCN^{2+}$ concentration at equilibrium from the initial concentrations of Fe^{3+} and SCN^-, as shown below:

$[Fe3^+]_{eq} = [Fe3^+]_i - [FeSCN^{2+}]_{eq}$
$[SCN^-]_{eq} = [SCN^-]_i - [FeSCN^{2+}]_{eq}$

For test tube #2, the calculations are:

$[Fe3^+]_{eq} = 0.025M - 4.03 \times 10^{-4}M = 0.0246M$
$[SCN^-]_{eq} = 5.00 \times 10^{-4}M - 4.03 \times 10^{-4}M = 9.7 \times 10^{-5}M$

7. The K_{eq} for each test is calculated by evaluating the following expression:

$K_{eq} = [FeSCN^{2+}]_{eq} / \{[Fe^{3+}]_{eq} \times [SCN^-]_{eq}\}$

For test tube #2:

$K_{eq} = 4.03 \times 10^{-4}M / (0.0246M \times 9.7 \times 10^{-5}M) = 169$

This experiment lets you observe how buffers, made from common substances, are able to resist the invasion of a strong acid and a strong base.

Introduction

Powdered fruit-drink mixes, certain types of aspirin products, and human blood all have something in common: each of these items contains a buffer. So, what is a buffer? In chemical terms, a buffer is a solution that maintains a relatively stable pH when moderate amounts of acids or bases are added to it. This pH stability is critical in the human body, where the pH of blood *must* be between 7.35 and 7.45. It is valuable, but not critical, in a powdered drink mix because the flavor of the drink will be reasonably similar regardless of the pH of the drinking water that is used.

What is a buffer composed of and how does it work? We make use of the Bronsted/Lowry definition of acids and bases to define the composition of buffers. A buffer is made up of either a weak acid and a salt of the weak acid, or a weak base and its salt. According to Bronsted/Lowry, this mixture is termed a "conjugate acid-base pair." In human blood, the buffer is composed of carbonic acid and a bicarbonate ion (H_2CO_3/HCO_3^-). A package of a lemonade-flavored, powdered-drink mix may contain the buffer citric acid and sodium citrate. The clever design of a buffer contains a component that neutralizes small amounts of OH^- ions, and a component that neutralizes small amounts of H^+ ions.

In this experiment, one buffer will be made by mixing equal amounts of acetic acid and sodium acetate. If a strong acid, such as HCl (H_3O^+), is added to this mixture, the acetate ion reacts with the acid as shown by: $H_3O^+ + CH_3COO^- \rightarrow CH_3COOH + H_2O$.

In this reaction, the product is acetic acid, which is already a part of the buffer mixture. If a strong base, such as NaOH (OH^-) is added to the buffer, the acetic acid reacts with the base shown by:
$OH^- + CH_3COOH \rightarrow CH_3COO^- + H_2O$
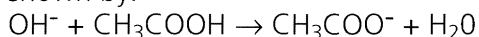
A product of this reaction is the acetate ion. A buffer can neutralize acid and a base in this way as long as the amounts of the acid or the base are small.

Your objective in this experiment is to observe this phenomenon of buffer activity. A quantitative analysis of buffers will be left for future experiments.

⚠ **WARNING: Wear goggles, gloves, and an apron at all times!**

The acids and bases you will use are harmful to your skin, eyes, and nose. Wash all spills immediately with generous amounts of tap water.

Equipment Required

- ✓ CBL
- ✓ CBL-compatible calculator with a unit-to-unit cable
- ✓ Vernier pH probe (PHA-DIN amplifier and 7120B electrode) with CBL DIN adapter
- ✓ 1.0 M acetic acid (CH_3COOH)
- ✓ 1.0 M sodium acetate ($NaCH_3COO$)
- ✓ 1.0 M ammonia (NH_3 or NH_4OH)
- ✓ 1.0 M ammonium chloride (NH_4Cl)

- ✓ 1.0 M HCl and 1.0 M NaOH
- ✓ 0.1 M HCl and 0.1 M NaOH
- ✓ Fruit drink prepared from powdered mix
- ✓ Universal indicator solution (optional)
- ✓ Two 50-mL burets
- ✓ Two 25-mL graduated cylinders
- ✓ Ring stand, buret clamp, and utility clamp
- ✓ Several 250-mL beakers
- ✓ TI-GRAPH LINK (optional)
- ✓ Magnetic stirrer and stir bar (optional, but preferred) or glass stir rod

Program

Download or enter the PH program into the calculator.

Equipment Setup Procedure

To connect the equipment as shown by Figure 1:

1 Connect the CBL to the calculator with the unit-to-unit cable using the input/output ports located on the bottom edge of each unit. Press the cable ends in firmly.

2 Assemble the buret clamp to a ring stand, and attach two burets to the clamp.

3 Attach the pH probe to the ring stand (below the buret assembly) with a utility clamp.

4 Connect the pH probe to CH1 on the top edge of the CBL.

5 Turn on the CBL and the calculator.

6 If necessary, calibrate the pH probe (refer to the front of the CBL workbook for details).

The CBL in now ready to receive commands from the calculator.
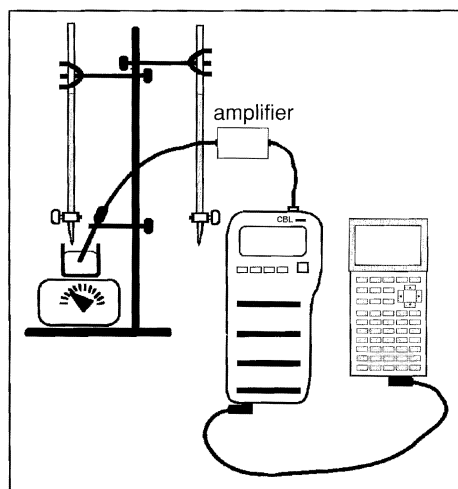
Figure 1: Equipment Setup

Experiment Procedure

❶ Rinse each buret with a small amount of acid or base. Fill one buret with 1.0 M HCl and the other buret with 1.0 M NaOH solution.

❷ Use 25-mL graduated cylinders to measure out 15-mL of acetic acid and 15-mL of sodium acetate. Transfer these solutions to a clean 250-mL beaker. (Optional: a few drops of universal indicator may be added as a visual aid.)

❸ Place the pH probe into the buffer solution. If a magnetic stirrer is used, place the beaker on the stirrer and begin stirring. Position the pH probe so that it does not interfere with the stirring bar.

❹ Position the beaker, pH probe, and buret so that the 1.0 M NaOH can be easily added to the buffer solution.

❺ Make sure the CBL is turned on. Start the PH program on the calculator. When prompted, enter the number of the channel to which the probe is connected, and enter 35 for the number of samples to collect.

❻ Start the titration and take an initial pH reading of the buffer solution. At the ML? prompt, enter zero (0 mL volume).

Note: To take pH readings, press ⌗TRIGGER⌗ on the CBL. At the ML? prompt, enter the volume of NaOH that you are adding. The data point is plotted on the calculator display, and the program pauses until you press ⌗TRIGGER⌗ again. Wait a few seconds between each ⌗TRIGGER⌗ keypress to allow the reading to stabilize.

❼ When prompted by the program, add 1.0 M NaOH in increments of 1.0 mL until 10 mL have been added. After 10 mL of NaOH have been added, add base in 0.5 mL increments until a large change in pH is observed. This is the point at which the buffer has failed. Take a few more pH readings beyond this point to develop the curve. After all samples are taken, a STAT PLOT of the collected data (volume in L5 and pH in L4) is displayed. Press ⌗TRIGGER⌗ on the CBL one more time to complete data collection.

8 Clean up by rinsing the contents of the beaker down the sink.

9 Prepare a second acetic acid/acetate buffer and test this solution with 1.0 M HCl (Steps 2 through 8). Be sure to rinse the pH probe with tap water before each titration.

10 Prepare ammonia/ammonium chloride buffer solutions and test this buffer the same way that you tested the acetic acid/acetate buffer (Steps 1 through 9).

11 Replace the burets of acid and base with 0.1 M HCl and 0.1 M NaOH. Measure 50-mL of Kool-Aid lemonade drink and test it with 0.1 M NaOH (Steps 3 through 8).

12 Test a second 50-mL sample of Kool-Aid drink with 0.1 M HCl (Steps 3 through 8).

Analysis and Conclusion

1. Compare the effectiveness of the acetic acid/acetate buffer with the ammonia/ammonium chloride buffer.

2. Write reaction equations that describe how the ammonia/ammonium chloride buffer neutralizes HCl and NaOH.

3. Suggest other mixtures that could work as buffers, including substances that are commercially available.

4. Discuss the effectiveness of the drink sample as a buffer. Why is the citric acid/sodium citrate buffer less effective than the other mixtures?

Optional Exercise for Further Experimentation

Prepare a 1.0 M solution of baking soda ($NaHCO_3$). Test a 30-mL sample of this solution as you did with the buffers. Is it an effective buffer? If so, write reaction equations that may explain why.

Typical Data for this Experiment

1. Titration of Acetic Acid/ Acetate Buffer versus 1.0 M NaOH

mL	pH	mL	pH
0	5.63	14.1	6.81
1	5.72	14.2	6.89
2	5.65	14.3	6.77
3	5.72	14.4	6.97
4	5.70	14.5	6.98
5	5.86	14.6	7.12
6	5.97	14.7	7.17
7	5.90	14.8	7.23
8	5.97	14.9	7.28
9	6.16	15	7.52
10	6.22	15.2	10.31
11	6.16	16	11.22
12	6.20	17	11.41
13	6.41	18	11.41
14	6.77	19	11.46
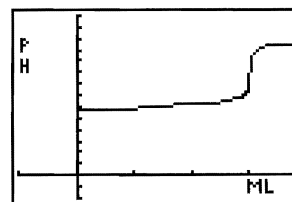
Figure 2:
pH versus mL of NaOH

2. Titration of Acetic Acid/ Acetate Buffer versus 1.0 M HCl

mL	pH	mL	pH
0	5.65	11.5	4.68
1	5.54	12	4.58
2	5.40	12.5	4.52
3	5.49	13	4.53
4	5.43	13.5	4.50
5	5.20	14	4.43
7	5.06	14.5	4.10
8	5.04	15	3.68
9	4.89	16	3.40
10	4.81	17	3.15
10.5	4.91	18	2.97
11	4.74	19	2.90
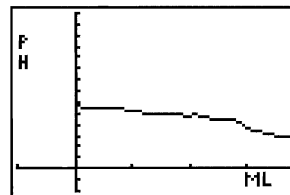
Figure 3:
pH versus mL of HCl

3. Titration of Ammonia/Ammonium Chloride Buffer versus 1.0 M HCl

mL	pH	mL	pH
0	9.38	11	8.54
1	9.38	11.5	8.52
2	9.38	12	8.39
3	9.29	12.5	8.69
4	9.20	13	7.92
5	9.09	13.5	3.94
6	8.99	14	3.33
7	9.08	14.5	3.24
8	9.01	15	3.08
9	8.91	16	2.97
10	8.77	17	2.77
10.5	8.71	18	2.69
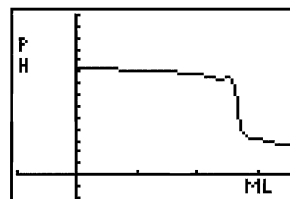
Figure 4:
pH versus mL of HCl

4. Titration of Ammonia/Ammonium Chloride Buffer versus 1.0 M NaOH

mL	pH	mL	pH
0	9.22	11.5	9.94
1	9.31	12	10.16
2	9.45	12.5	10.14
3	9.43	13	10.27
4	9.53	13.5	10.54
5	9.43	14	10.74
6	9.54	14.5	11.21
7	9.65	15	11.48
8	9.68	15.5	11.56
9	9.75	16	11.72
10	9.77	16.5	11.67
10.5	9.97	17	11.76
11	9.99	18	11.73
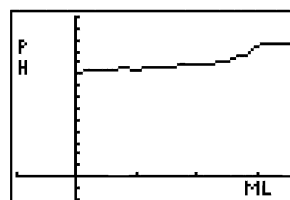
Figure 5:
pH versus mL of NaOH

Experiment C5 — An Acid/Base Titration—The Acidity of Cola Drinks

This experiment lets you investigate and compare the acidity differences between a cola drink and its diet counterpart.

Introduction

We commonly presume that the only significant difference between a carbonated cola and the diet version of the cola is the substitution of an artificial sweetener for high-fructose corn syrup. In this experiment, two samples of a cola beverage are titrated with sodium hydroxide to determine if the acid concentration of regular cola is different from diet cola.

Carbonated beverages contain several acidic substances that include citric acid, carbonic acid, phosphoric acid, and caffeine. Phosphoric acid is the strongest of the lot, and will be considered the major contributor to the acidity of these beverages. Because carbonic acid concentration can vary from container to container, it will be eliminated from the testing by gently boiling the cola samples before the titration is conducted.

⚠ **WARNING: Wear goggles, gloves, and an apron at all times!**

The bases you will use are harmful to your skin, eyes, and nose. Wash all spills immediately with generous amounts of tap water.


Equipment Required

- ✓ CBL
- ✓ CBL-compatible calculator with a unit-to-unit cable
- ✓ Vernier pH probe (PHA-DIN amplifier and 7120B electrode) with CBL DIN adapter
- ✓ 0.1 M NaOH
- ✓ 50-mL buret
- ✓ 50-mL graduated cylinder
- ✓ Ring stand, buret clamp, and utility clamp

- ✓ Several 250-mL beakers
- ✓ Lab burner with separate ring stand, ring and wire gauze (or hot plate)
- ✓ Flint striker or electric sparker (if a lab burner is used)
- ✓ Regular and diet cola soft drink beverages
- ✓ TI-GRAPH LINK (optional)
- ✓ Magnetic stirrer and stir bar (optional)

Program

Download or enter the PH program into the calculator.

Equipment Setup Procedure

To connect the equipment as shown by Figure 1:

❶ Connect the CBL to the calculator with the unit-to-unit cable using the input/output ports located on the bottom edge of each unit. Press the cable ends in firmly.

❷ Assemble the buret clamp to a ring stand and attach a 50-mL buret to the clamp.

❸ Attach the pH probe to the ring stand (below the buret assembly) with a utility clamp.

❹ Connect the pH probe to CH1 on the top edge of the CBL.

❺ Turn on the CBL and the calculator.

❻ If necessary, calibrate the pH probe (refer to the front of the CBL workbook for details).

The CBL in now ready to receive commands from the calculator.

Figure 1: Equipment Setup

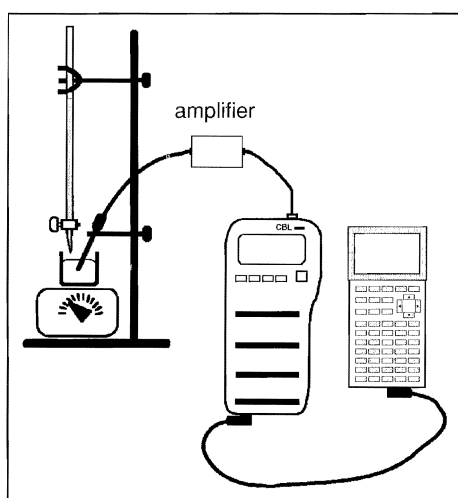## Experiment Procedure

❶ Rinse and fill the buret with 0.1 M NaOH.

❷ Measure about 50-mL of a carbonated cola beverage into a 250-mL beaker.

❸ Gently boil the container of cola, using a hot plate or a lab burner, for ten minutes. Allow the liquid to cool to near room temperature before proceeding.

❹ Measure 30-mL of the cola in a graduated cylinder and transfer the liquid to a clean 250-mL beaker.

⑤ Place the pH probe into the solution. If a magnetic stirrer is used, place the beaker on the stirrer and begin stirring. Position the pH probe so that it does not interfere with the stirring bar.

⑥ Position the beaker, probe, and buret so you can easily add the 0.1 M NaOH to the cola.

⑦ Make sure the CBL is turned on. Start the PH program on the calculator. At the prompt, enter the number of the channel to which the probe is connected, and enter 30 for the number of samples to collect.

⑧ Start the titration and take an initial pH reading of the cola. At the ML? prompt, enter zero (0 mL volume).

Note: To take pH readings, press TRIGGER on the CBL. At the ML? prompt, enter the volume of NaOH that you are adding. The data point is plotted on the calculator display, and the program pauses until you press TRIGGER again. Wait a few seconds between each TRIGGER keypress to allow the reading to stabilize.

⑨ When prompted by the program, add the NaOH in 1- to 2-mL increments until you observe a sharp increase in pH. Carefully add the base in 0.1- to 0.2-mL increments to more clearly define the equivalence point of the titration. Once the equivalence point is reached, add more NaOH in 1- to 2-mL increments and take several pH readings to develop the titration plot. After all samples are taken, a STAT PLOT of the collected data (volume in L5 and pH in L4) is displayed. Press TRIGGER on the CBL one more time to complete data collection.

⑩ Discard the solution in the beaker and clean up. Prepare another 50-mL cola sample. Rinse and refill the buret with 0.1 M NaOH.

Return to Step 5 and conduct a second titration. Be sure to rinse the pH probe with tap water before each titration.

⑪ Repeat the procedure (Steps 1 through 10) with a second sample. However, this time use the diet cola beverage in Step 2.

Note: You must conduct at least two tests per product sample if you want to perform a quantitative analysis of the data.

Analysis and Conclusion

1. Review the titration plots for the two types of cola. Note any differences or similarities.

2. If you want to perform a quantitative analysis, determine the exact endpoint of the titration to calculate the phosphoric acid concentration in each beverage. Even though phosphoric acid is triprotic, only the first endpoint will be easily discerned.

Optional Exercises for Further Experimentation

1. Select three different brands of cola and diet cola to test for acidity.

2. Select one brand of cola whose products include regular, diet, caffeine-free, and diet caffeine-free colas. Compare the acidities of each type.

3. Compare the acidity of cola beverages with other carbonated drinks.

Typical Data for this Experiment

1. Titration of 30-mL Cola versus 0.1 M NaOH

mL	pH	mL	pH
0	3.75	18.5	7.06
2	3.77	19.5	7.17
4	3.87	20.5	7.28
6	4.06	22	7.34
8	4.10	23	7.42
10	5.25	24	7.58
11	5.65	25	7.68
11.5	6.39	26	7.85
12	6.41	28	8.01
12.5	6.57	29	8.54
13	6.60	30	8.73
14.5	6.60	32	8.85
15.5	6.81	34	9.08
16	6.83	36	9.14
16.5	6.85	38	9.27
17.5	7.04	40	9.40
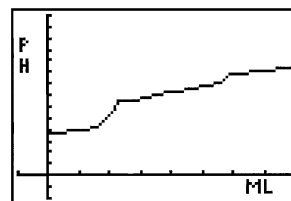
Figure 2:
pH of Cola versus 0.1 M NaOH

2. Titration of 30-mL Diet Cola versus 0.1 M NaOH

mL	pH	mL	pH
0	3.61	20	6.62
2	3.62	22	6.72
4	4.15	22.5	6.91
6	4.15	23.5	7.06
8	4.25	24	7.12
10	4.84	24.5	7.14
13	4.91	25.5	7.34
14	5.21	28	7.58
14.5	5.21	30	7.60
15	5.42	31	7.95
15.5	5.49	32	7.99
16	5.63	33	8.30
16.5	5.79	34	8.36
17.5	6.12	35	8.60
18	6.16	36	8.77
19	6.41	37	9.01
19.5	6.35	39	9.29
		40	9.64
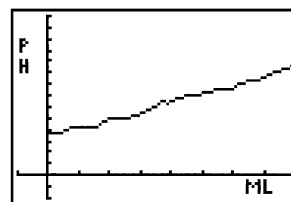
Figure 3:
pH of Diet Cola versus 0.1 M NaOH

This experiment let you use the Clausius-Clapeyron equation to investigate changes in vapor pressure of a liquid versus changes in temperature (of the liquid).

Introduction

The Clausius-Clapeyron equation is used by chemists to describe the change in vapor pressure of a liquid as temperature changes. Stated mathematically:

$$\ln P = \frac{\Delta H_{vap}}{R}\left(\frac{1}{T}\right) + C$$

You can use Clausius-Clapeyron to calculate the enthalpy (heat) of vaporization. In this laboratory exercise you will collect data on the vapor pressure and temperature effects of water.

In this experiment, you will saturate an air sample with water vapor by trapping a sample of air in an inverted graduated cylinder and heating it in a water bath. As the gas is cooled, the amount of water vapor in the air decreases while the molar quantity of gas remains constant.

By calculating the moles of air in the cylinder, you can calculate the partial pressure of air at each temperature. Then you can obtain the vapor pressure of water by referring to the room barometric pressure and doing some basic math.

You determine the moles of air at a temperature near 0°C where the water vapor in air is less than one percent. Although this amount is negligible, it will affect the accuracy of your calculations. Your objective is to manipulate the data that you gather in the fashion described by Clausius and Clapeyron to determine the enthalpy of vaporization for water.

Note: There is a methodological error that you cannot avoid—the inverted meniscus in the cylinder leads to inaccurate volume measurements. For a 10-mL graduated cylinder, the error is 0.2 mL. For best results, this quantity must be subtracted from each volume reading.

Equipment Required

- ✓ CBL
- ✓ CBL-compatible calculator with a unit-to-unit cable
- ✓ TI Temperature probe
- ✓ 10-mL graduated cylinder
- ✓ 1-L beaker
- ✓ Distilled water
- ✓ Ring stand and ring

- ✓ Lab burner, separate ring stand, ring and wire gauze (or hot plate)
- ✓ Flint striker or electric sparker (if a lab burner is used)
- ✓ Plastic tray
- ✓ TI-GRAPH LINK (optional)
- ✓ Magnetic stirrer and stir bar (optional)

Program

Download or enter the CLAUSIUS program into the calculator.

Equipment Setup Procedure

To connect the equipment as shown by Figure 1:

❶ Connect the CBL to the calculator with the unit-to-unit cable using the input/output ports located on the bottom edge of each unit. Press the cable ends in firmly.

❷ Connect the temperature probe to CH1 on the top edge of the CBL.

❸ Attach the temperature probe to the ring stand with a utility clamp.

❹ Turn on the CBL and the calculator.

The CBL in now ready to receive commands from the calculator.
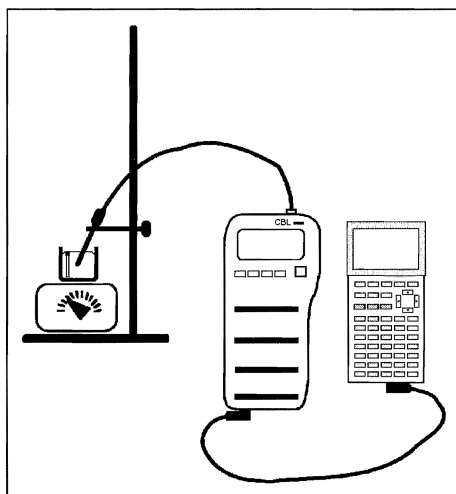
Figure 1: Equipment Setup

Experiment Procedure

❶ Fill a 10-mL graduated cylinder with 6 to 7 mL of distilled water. Fill a 1-Liter beaker nearly full with tap water. (Leave some room for the inverted graduated cylinder.)

❷ Cover the top of the graduated cylinder with your fingers (or hand) and quickly invert it, and then lower it into the beaker of water. For best results you want to trap 4 or 5 mL of water in the cylinder.

❸ Add more water, if necessary, so that the trapped air in the graduated cylinder is completely covered by the water in the beaker.

❹ Place the beaker on a piece of wire mesh that is setting on the ring of a ring stand (or place it on a hot plate).

❺ Heat the beaker of water until the water is about 80°C.

6 Carefully observe the volume of trapped air. Regardless of the water temperature, when the air level expands just beyond the scale on the graduated cylinder, remove the beaker from the burner and place it on a plastic tray on the magnetic stirrer. Place a stirring bar in the beaker and stir the water very slowly to maintain an even temperature throughout the system.

7 Lower and secure the clamp, with the temperature probe attached, so that the probe is immersed and alongside the graduated cylinder as shown in Figure 1.

8 When the gas contracts to a volume that can be read (10 mL or slightly less), make sure the CBL is turned on, and start the CLAUSIUS program on the calculator. At the prompt, enter the number of the channel to which the probe is connected, and enter 20 for the number of samples to collect. For each temperature reading, determine the gas volume to the nearest 0.1 mL and enter this at the ML? prompt.

Note: To take temperature readings, press TRIGGER on the CBL. At the ML? prompt, enter the gas volume to the nearest 0.1 mL. The data point is plotted on the calculator display, and the program pauses until you press TRIGGER again.

9 As the water cools and the volume in the cylinder changes, make additional readings at approximately 0.2 mL intervals until the water reaches about 50°C. Ice may be added to speed the cooling. However, add very small amounts of ice because the gas volume will not change as quickly as the water temperature, thus adding error to your data. (If ice is added, the plastic tray will catch any overflow.)

10 After the temperature has reached 50°C, cool the water rapidly to 5°C or less by adding large amounts of ice. Enter the gas volume at this temperature at the ML? prompt. After all samples are taken, a STAT PLOT of the data is displayed. Press TRIGGER on the CBL one more time to complete data collection.

11 Obtain a reading of the barometric pressure from the classroom barometer and record it in your lab notes.

Analysis

1. Prepare a data table similar to Table 1 by manipulating the temperature data in L4 as necessary. The gas volumes are in L5.

2. Use the volume and temperature readings at the lowest temperature, and the room barometric pressure, to calculate the molar quantity of air in the cylinder. Remember that you are considering the vapor pressure of water to be negligible at this low temperature, thus the lower your temperature, the more accurate your calculation. Use the equations in the conclusion section to compute P_{air} and P_{H_2O}.

3. Store the 1/T values in L1 and vapor pressure ($\ln P_{H_2O}$) in L2. Prepare a STAT PLOT of L1 versus L2 as shown in Figure 2 using Scatter plot with (□) mark. This plot can be used with the Clausius-Clapeyron equation to determine the enthalpy of vaporization of water. Prepare a print-out of the graph by sending your data to a computer using TI-GRAPH LINK.

> **Note:** Refer to "Performing Data Analysis" in the *CBL System Compatible Calculators* for information about using statistical features of the calculators.

4. Test the accuracy of your data. Two suggestions: (1) Use $\boxed{\text{TRACE}}$ on the calculator to read the vapor pressure of water at some temperature, 65°C or so, from your STAT PLOT that describes your data and compare it to the results of your experiment; (2) extrapolate the boiling point of water from your graph and compare it to the normal boiling point of water.

Conclusions

Note: Refer to "Performing Data Analysis" in the *CBL System Compatible Calculators* for information about using statistical features of the calculators.

The actual heat of vaporization value (40.6 kJ/mol) can be referred to in discussing the accuracy of your experiment. Your concluding remarks should include factors that influenced your results.

1. You can find the molar quantity of air in the cylinder from the equation:

$$PV = nRT$$

> where: P = barometric pressure of the room, V = volume, R = Ideal Gas Law Constant, and   T = temperature.

$$n = \frac{PV}{RT} = \frac{(1.0188\,atm)\,(0.0065\,L)}{(0.08206\,L\,atm\,/\,K\,mol)\,(318K)}$$

$$= 0.000227 \; mol \; air$$

2. P_{air} and P_{H_2O} for a column of air at 318 Kelvin, whose volume is 6.5 mL, are represented by:

$$P_{air} = \frac{nRT}{V} \qquad P_{H_2O} = P_{room} - P_{air}$$

$$P_{air} = \frac{(0.000227 \text{ mol air}) (0.08206 \text{ L atm} / \text{K mol}) (318 \text{ K})}{0.0065 \text{ L}} = 0.9113 \text{ atm}$$

$$P_{H_2O} \quad = 1.0188 \text{ atm room pressure} - 0.9113 \quad = 0.1075 \text{ atm}$$

Table 1 shows typical data for this lab. Manipulation of the collected data is efficient with the TI-82, which helps you to see the relationships inherent in the Clausius-Clapeyron equation.

Vol(mL)	Temp. K	1/T	P_{air} (atm)	P_{H2O}(atm)	lnP_{H2O}
6.5	318	0.00314	0.9113	0.1075	-2.230
6.8	323	0.00310	0.8848	0.1340	-2.010
7.2	328	0.00305	0.8486	0.1702	-1.771
7.6	333	0.00300	0.8162	0.2026	-1.597
8.3	338	0.00296	0.7586	0.2602	-1.346
9.8	344	0.00291	0.6539	0.3649	-1.008

Table 1

3. To compute the linear regression equation for the data in L_1 and L_2 go to the STAT CALC menu and enter LinReg L_1,L_2.

4. The plot of $1/T$ (x-axis) versus $\ln P_{H2O}$ (y-axis) is a linear regression with:

   slope (a)   = -5103
   y-intercept (b) =   13.785
            r   = -0.9949

5. The enthalpy of vaporization of water (ΔH_{vap}) can be calculated by recognizing that the slope of this line is related to ΔH_{vap} as shown below:

   slope = ΔH_{vap}/R   (where R = 8.3145J/K mol)

   -5103 = ΔH_{vap}/8.3145J/K mol

   ΔH_{vap} = 42,429 J/mol

   ΔH_{vap} $\cong$ 42.4 kJ/mol

Figure 2 shows a STAT PLOT of vapor pressure of a liquid, lnP_{H2O} (y-axis) versus 1/temperature (x-axis). Enter the linear regression equation computed in Step 3 above into the Y= editor and graph it with the STAT PLOT. Use the ZoomStat window. The graph describes a line, the slope of which is equal to the heat of vaporization/R (ΔH_{vap}/R), where R is the gas law constant 8.3145J/K mol.
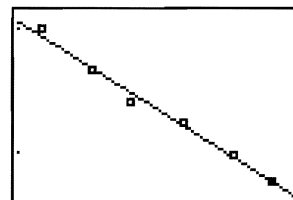

Figure 2: Ln Vapor Pressure versus 1/Temperature

6. The published value for the enthalpy of vaporization of water is 40.6 kJ/mol compared to 42.4 kJ/mol from Step 5 above; therefore, the experimental results compare well with the accepted value.

This experiment lets you determine the heat of solution of various common substances as they affect the temperature of 100 mL of water.

Introduction

Many solid substances exhibit a thermal change when they are dissolved, either cooling (endotherm) or heating (exotherm) the liquid in which they are dissolved. This rather interesting property of matter is used in some types of instant cold packs and hot packs.

It is suggested that this experiment be set up so that each group of students has samples of differing masses. In this manner, multiple runs can be made for each sample with minimum waste. This technique gives students the opportunity to deal with more data per compound, as well as deal with bad data.

Equipment Required

✓ CBL

✓ CBL-compatible calculator with a unit-to-unit cable

✓ TI temperature probe

✓ 100-mL graduated cylinder

✓ Several 150-mL or 250-mL beakers

✓ Ring stand and utility clamp

✓ Balance

✓ Several premeasured samples (up to 10 g/100 mL water) of:

 • KI (used to iodize table salt)

 • CaCl2 (road salt or sidewalk de-icing salt)

 • CaO (lime or quicklime)

✓ TI-GRAPH LINK (optional)

✓ Magnetic stirrer and stir bar (optional, but preferred) or glass stir rod

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⚠ **WARNING: Wear goggles, gloves, and an apron at all times!**

The chemicals you will use are harmful to your skin, eyes, and nose. Wash all spills immediately with generous amounts of tap water.

Program

Download or enter the TEMP program into the calculator.

Equipment Setup Procedure

To connect the equipment as shown by Figure 1:

❶ Connect the CBL to the calculator with the unit-to-unit cable using the input/output ports located on the bottom edge of each unit. Press the cable ends in firmly.

❷ Attach the temperature probe to the ring stand with a utility clamp.

❸ Connect the temperature probe to CH1 on the top edge of the CBL.

❹ Turn on the CBL and the calculator.

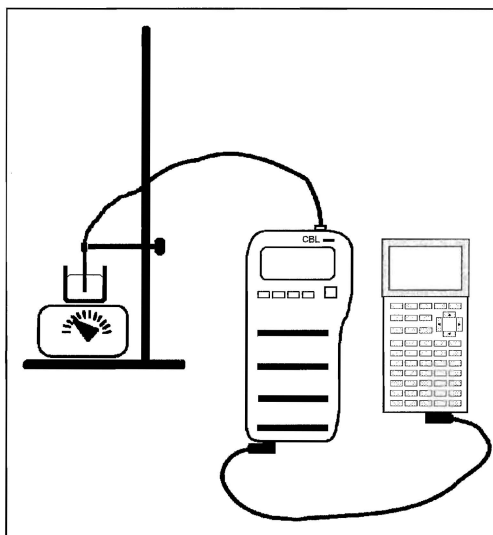The CBL is now ready to receive commands from the calculator.

Figure 1: Equipment Setup

Experiment Procedure

❶ Record the pre-measured sample compounds and their masses in a data table.

❷ Measure 100-mL of tap water in a graduated cylinder and transfer the water to a small beaker.

❸ Place the temperature probe into the water. If a magnetic stirrer is used, place the beaker of water on the stirrer and begin stirring. Position the temperature probe so that it does not interfere with the stirring bar.

❹ Make sure the CBL is turned on and start the TEMP program on the calculator. At the prompt, enter the channel number to which the probe is connected. A sample will be taken once every four seconds. At the prompt, enter a value for the number of samples to provide sufficient time for the solution to reach a maximum or minimum temperature.

⑤ When ready, press ENTER to start collecting data.

⑥ Record one temperature reading before the solid is added. Quickly add one of the samples to the water and stir to dissolve. For best results, stir the solution moderately and constantly.

⑦ Observe the endotherm or exotherm as the solid dissolves. When all samples are taken, a STAT PLOT of temperature (in °C) versus time (in seconds) is displayed.

⑧ Press TRACE on the STAT PLOT to find the initial and final temperature values for the sample. Record these values in the data table. Save the collected temperature data in L4 and the time data in L5 to a computer using TI-GRAPH LINK.

⑨ Repeat Steps 2 through 8 with the remaining samples.

⑩ Clean up by disposing each solution down the sink, followed by large amounts of tap water.

Analysis and Conclusion

Calculate and record the change in temperature (ΔT) of the solution for each sample to complete the data table. Share your results with other groups and record the results from others. (The mass of each sample is different and the collaborative data can provide a more accurate picture of each compound.)

Questions for This Experiment

Note: Refer to "Performing Data Analysis" in the *CBL System Compatible Calculators* for information about using statistical features of the calculators.

1. Calculate the ΔT for 1.00 gram of each solute per 100-mL of water using the data from your table.

   $CaCl_2$: _____ KI: _____ CaO: _____

2. Store the ΔT values for $CaCl_2$ in L2 and the mass of each $CaCl_2$ sample in L1. Perform a Scatter plot with (▫) mark of L1 (mass) versus L2 (ΔT). Press ZOOM 9 to select the ZoomStat window.

   Go to STAT CALC and select LinReg L1,L2 to compute the regression equation for the points. Store this equation in Y1 and graph it with the STAT PLOT. Turn off the STAT PLOT and press TRACE on the calculator to read the y-value at the point where x = 1 from the equation. This is the graphed value of the heat of solution for 1.00 gram of $CaCl_2$. Compare it to your answer in question number 1 above and suggest why these values are different from each other.

3. Calculate the molality for each solution, using 1.00 gram of the solute and 100 mL of the solvent (water).

   $CaCl_2$: _____ KI: _____ CaO _____

4. Which solute shows the greatest temperature change per molal concentration?

Typical Data for This Experiment

1. Substance: $CaCl_2$

Mass (g)	Initial Temp. (°C)	Final Temp. (°C)	DT	
2.95	23.0	26.9	3.9	
3.72	21.6	26.7	5.1	
4.83	22.8	29.0	6.2	
2.24	24.0	27.0	3.0	
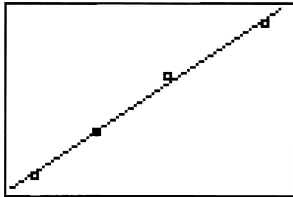
Figure 2:
DT versus Mass of $CaCl_2$

ΔT per gram $CaCl_2$ = 1.3°C

2. Substance: KI

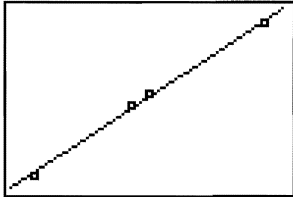| Mass (g)	Initial Temp. (°C)	Final Temp. (°C)	ΔT	
1.64	24.0	23.0	1.0	
0.81	21.6	21.1	0.5	
1.79	22.3	21.2	1.1	
2.76	22.9	21.3	1.6	

Figure 2:
DT versus Mass of KI

ΔT per gram of KI = 0.6°C

Optional

Some types of commercial hot packs and cold packs use heat of solution as their source of heat or cold. Find examples of these products and identify the substances that are used. You will notice something quite different about the solutions in these products, which illustrates another property of compounds dissolved in liquids.

CE

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