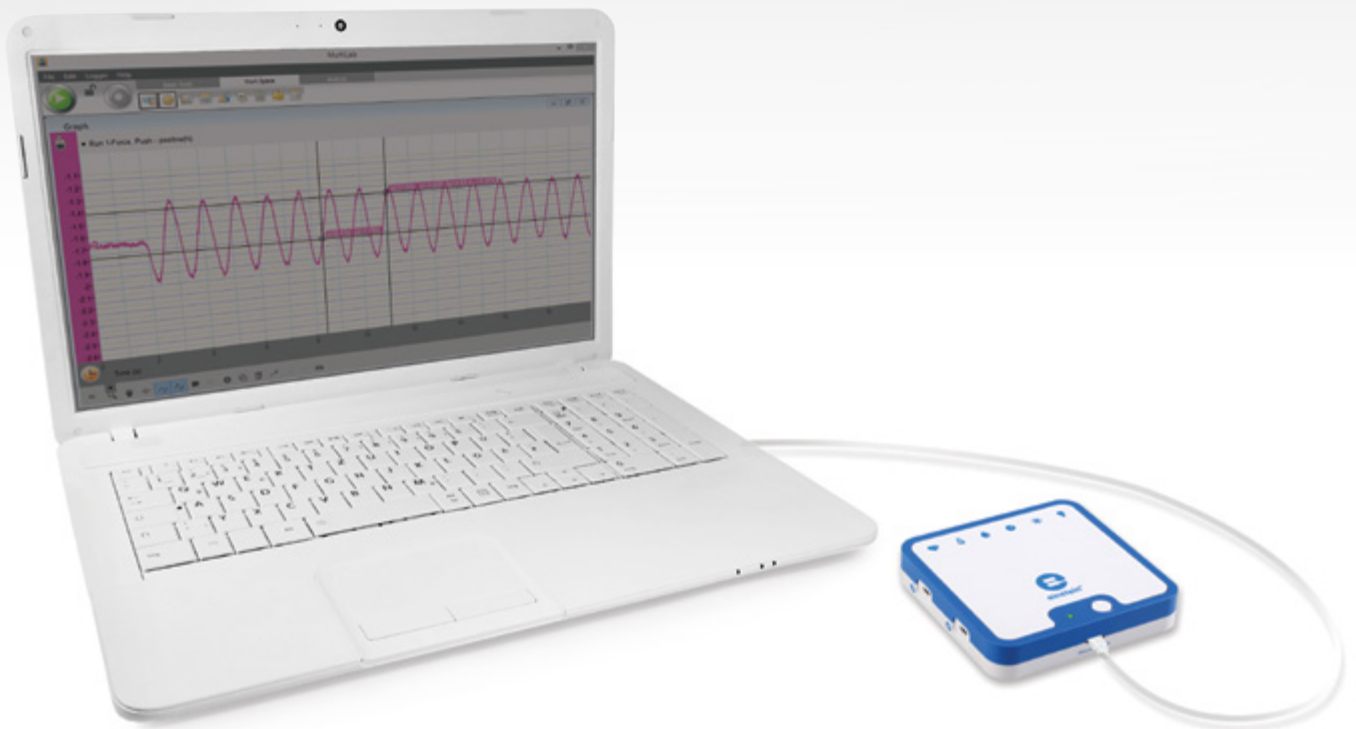


Experiments in Physics for MiLAB™ Desktop



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Preface

This book contains 48 student experiments in Physics. For your convenience we have added an index in which the experiments are sorted according to sensor (see page 2). These experiments are written for use with MiLAB Desktop and Fourier Sensors. MiLAB Desktop can be downloaded from einsteinworld.com.

einstein™LabMate

The einstein™LabMate includes the following:

6 built-in sensors:

- Heart Rate
- Temperature
- Humidity
- Pressure
- UV
- Light

+4 ports for external sensors

External sensors can be connected by inserting the sensor cable into one of the einstein™LabMate's sensor ports.

Connecting the einstein™LabMate

1. Press the Power button on the top of the device to turn it on.
2. When the einstein™LabMate+ powers up, it will display either a green, blue or red and green flashing light.
 - A blue flashing light indicates that the einstein™LabMate is on and paired with a computer
 - A green flashing light indicates that the einstein™LabMate is on but not paired with a computer
 - A red and green flashing light indicated the einstein™LabMate is low on battery and should be plugged into the USB charging cable

Note: The einstein™LabMate can also be connected to the computer via a USB cable.

Pairing the einstein™LabMate with your Windows 7 computer's Bluetooth adaptor:

Make sure that a Bluetooth adaptor is installed on your computer. If you are not sure how to do this, please consult the Microsoft Support web pages. Then, pair the einstein™LabMate to your computer.

Here's how:

Open Devices and Printers by clicking the **Start** button () and then, on the Start menu, clicking Devices and Printers.

Click Add a device, and then follow the instructions.

Click the einstein™LabMate you want to add to your computer, then click Next.

Your einstein™LabMate should appear in the list of available devices under the name "LabMate" with 3 or four digits directly after. These digits will match the last 3 or four digits of the serial number of your einstein™LabMate, located on the back of your device. If you don't see the einstein™LabMate you want to add, make sure the device is turned on. If you just turned on the device, it may take Windows several seconds to detect it.

Note: If you are using a Windows version other than Windows 7, please consult the Microsoft Support pages on how to pair a Bluetooth device to your computer.

Pairing the einstein™LabMate with your Mac via Bluetooth

1. Make sure that your computer has Bluetooth
Make sure that your computer has Bluetooth built-in or that a compatible Bluetooth adaptor is connected. Open System Preferences (from the Apple menu, choose System Preferences), then choose Bluetooth from the View menu.
2. Turn on Bluetooth
In Bluetooth preferences, select the "On" checkbox (for earlier Mac OS X versions, click the Settings tab, then click Bluetooth Power: On). Make sure to also turn on your einstein™LabMate.
3. Set up a new device
Click "Set Up New Device" (in earlier Mac OS X versions, click the Devices tab in Bluetooth, then click "Set Up New Device"). Your einstein™LabMate should appear in the list of available devices under the name "LabMate" with 3 or four digits directly after. These digits will match the last 3 or four digits of the serial number of your einstein™LabMate, located on the back of your device. If you don't see the einstein™LabMate you want to add, make sure the device is turned on. Follow the on screen instructions to finish setting up your einstein™LabMate.

MiLAB Desktop setup

When using the einstein™Labmate, select the MiLAB Desktop icon () on the application desktop.

If you are in a room where others are using einstein™LabMates, make sure you are paired with your einstein™LabMate. The serial number appearing in the lower right of the MiLAB Desktop™ screen should match that on the underside of your einstein™LabMate device.

Working with Graphs in MiLAB Desktop

The experiments in this book require the use of the MiLAB Desktop program to analyze the results.

Understanding Graphs




In general, graphs in MiLAB Desktop display the data from one or more sensors along the y- (horizontal) axis vs. time along the x- (vertical) axis.

It is also possible to display data from one sensor along the x-axis. To change what is displayed along the x-axis, click on the arrow key (▼) below the x-axis. Choose any data set from the drop down menu.

By default, graphs in MiLAB Desktop auto scale, which means you can see the entire graph displayed.

Graph Toolbar:





To zoom in on one part of the graph, use the Zoom tool () from the graph toolbar at the bottom of the graph window. Drag the cursor over the region of the graph you want to expand. Click the Zoom tool again to disable the zoom feature. Click on the Autoscale tool () to return to the original auto scale graph. You can also move the graph using the Pan tool ().

Analyzing a Graph

Analyzing the information contained in a graph is one of MiLAB Desktop's most important and powerful functions.

To analyze a graph:

- Run an Experiment.
- In order to use most of MiLAB Desktop's analysis functions, you must select at least one point on the graph – this is known as a cursor. Many functions require two cursors. Use the cursor tools to display first one  and then two  cursors.

Note: If you are using more than one sensor, both points will appear on the same plot line.

Working with Cursors

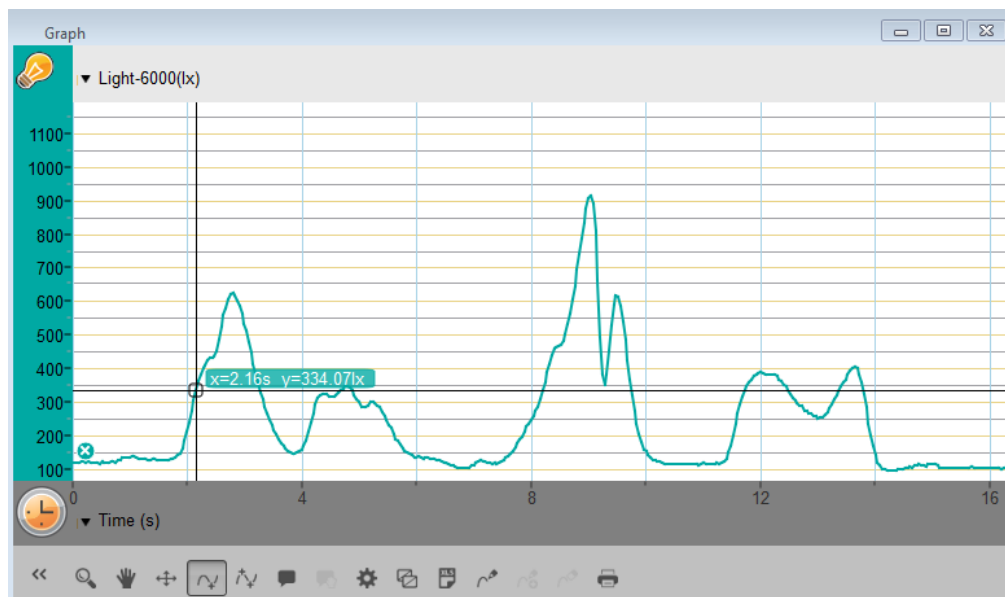
You can display up to two cursors on the graph simultaneously.

Use one cursor to display individual data recording values or to select a curve.

Use two cursors to analyze the data in the graph.

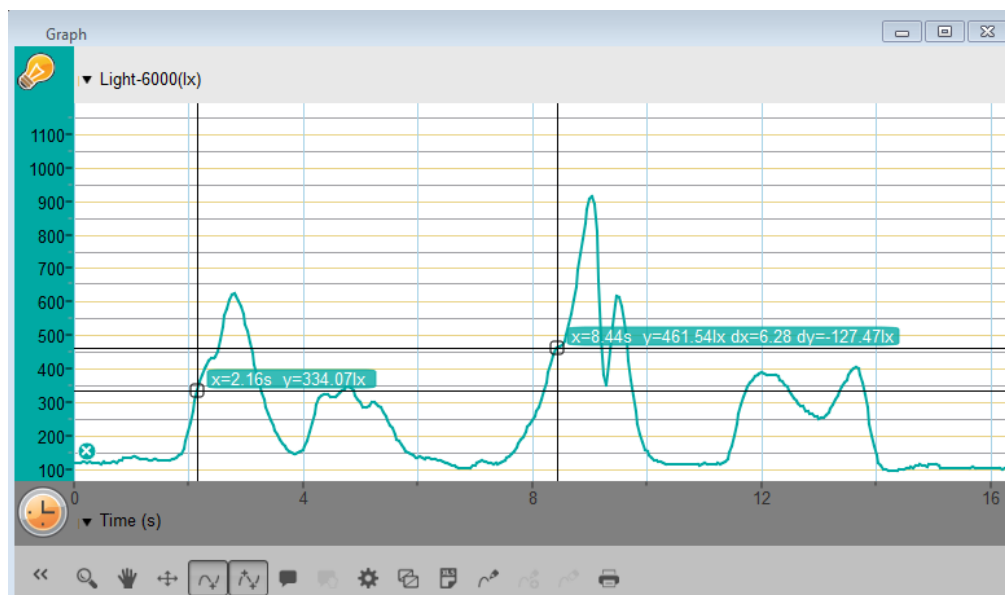
To display the first cursor:

In the graph window, click on any point on a plot line. MiLAB Desktop will now display the coordinate values.



To display the second cursor:

Once the first cursor is placed, click the second cursor tool () on the graph toolbar.



When there are two data points selected; the differences between the x and y values of the two points will appear above the second point on the graph.

- dx refers to the difference between the x values of the 2 points.
- dy refers to the difference between the y values of the 2 points.

Moving a cursor:

- Click and hold a cursor then drag it left and right along a single plot line.
- Drag the cursor up and down to move the cursor from one plot line to another on a single graph.

To remove a cursor:

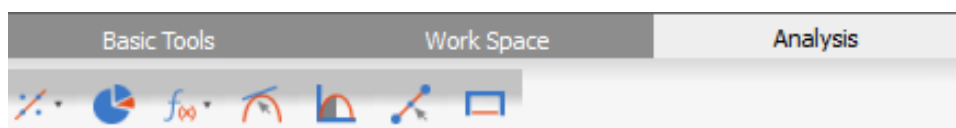
- Click on the second and then the first cursor tool on the graph toolbar.

The cursors will disappear from the plot line

Working with Functions

Once you have selected a cursor, many powerful analysis tools are available.

Select the Analysis toolbar to access the list of tools available to you.



Select one of the analysis tools to apply it to your data.

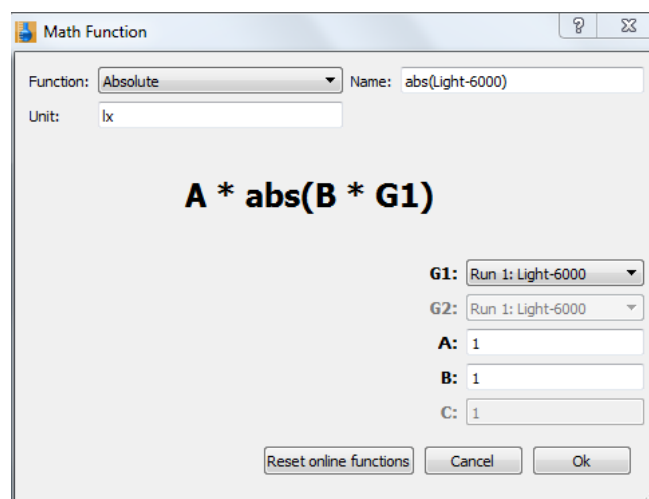
Some of the analysis tools will draw a new plot line on the graph, displaying the results.

The Math Functions tool ($f(x)$) will allow you to perform mathematical operations on your data.

Select this tool to open the Math Function window and choose the mathematical operation from the dropdown Function menu.

You can choose your data set from the dropdown menu **G1**.

An equation representing the mathematical operation will appear in bold in the Math Function window.



Some functions, such as Subtract, require you to compare 2 plot lines. To compare two plot lines:

- Use the **G1** and **G2** dropdown menus to select the plot lines you would like to compare.
- Select Ok.
- A new plot line will appear on the graph, displaying the results.


Sealing

Many of the experiments in this book, especially those involving pressure measurements, are dependent on the flasks or test tubes being tightly sealed. Following is a guide to ensure that these experiments run smoothly.

Note: To ensure a tight seal you may need to use a material such as modeling clay to seal any openings.

Note: You may want to consider purchasing the *einstein™* Pressure Kit which is specifically designed for these types of experiments.

Once you have sealed the flask or test tube, you can test the seal.

1. Select **Run** () to begin recording data.
2. (If your setup includes three-way valves) Turn the three-way valves to enable free air flow from the surrounding air (Position A – see Figure 1). The readings should now indicate the atmospheric pressure.

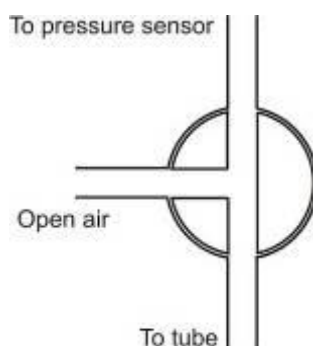


Figure 1: Three-way valve – Position A

3. (If your setup includes three-way valves) Turn the three-way valves to seal the system from the surrounding air (Position B – see Figure 2)

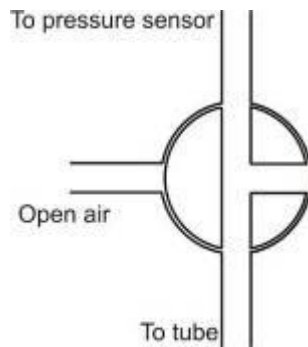


Figure 2: Three-way valve – Position B

4. Press the stoppers. The pressure should rise a little and then remain constant (see Figure 3).

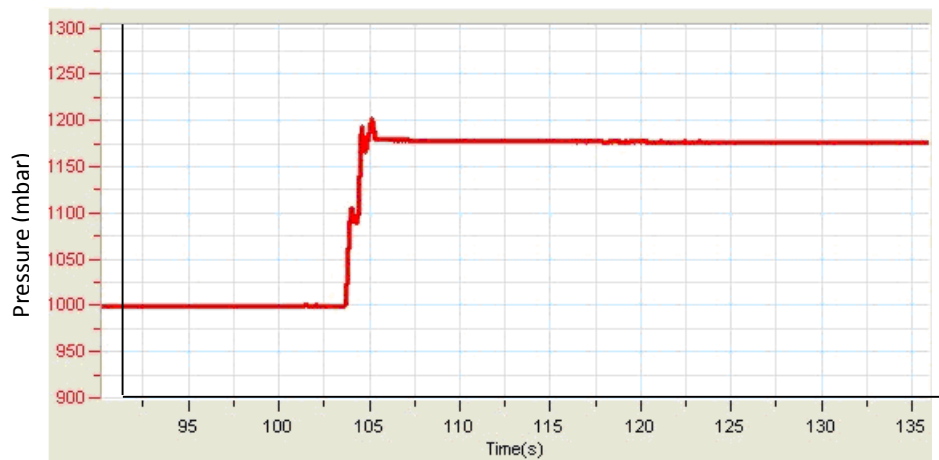


Figure 3

5. If the pressure drops (see Figure 4), there is a leak. Check your seals carefully and use a material such as modeling clay to seal off any possible openings. Repeat step 4. If that doesn't help, replace the stopper.

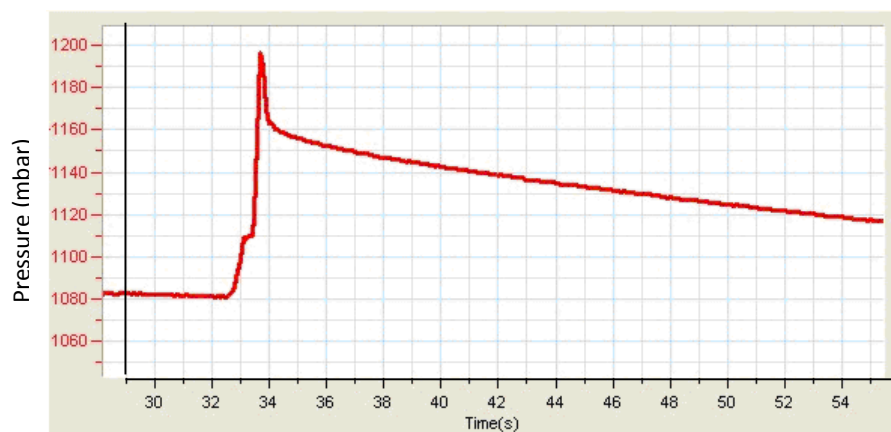



Figure 4

6. After you are satisfied that the containers are sealed, select **Stop** ().



Experimental Layout

Each experiment includes the following sections:

7. [Introduction](#): A brief description of the concept and theory
8. [Equipment](#): The equipment needed for the experiment
9. [Equipment Setup Procedure](#): Illustrated guide to assembling the experiment
10. [Current Setup Summary](#): Recommended sensor range, sampling rate and duration of the experiment
11. [Procedure](#): Step-by-step guide to executing the experiment
12. [Data Analysis](#)
13. [Questions](#)
14. [Further Suggestions](#)



Safety Precautions

- Follow standard safety procedures for laboratory activities in a science classroom.
- Proper safety precautions must be taken to protect teachers and students during the experiments described in this book.
- It is not possible to include every safety precaution or warning!
- Fourier assumes no responsibility or liability for use of the equipment, materials, or descriptions in this book.

Chapter 1

Motion Graph Matching

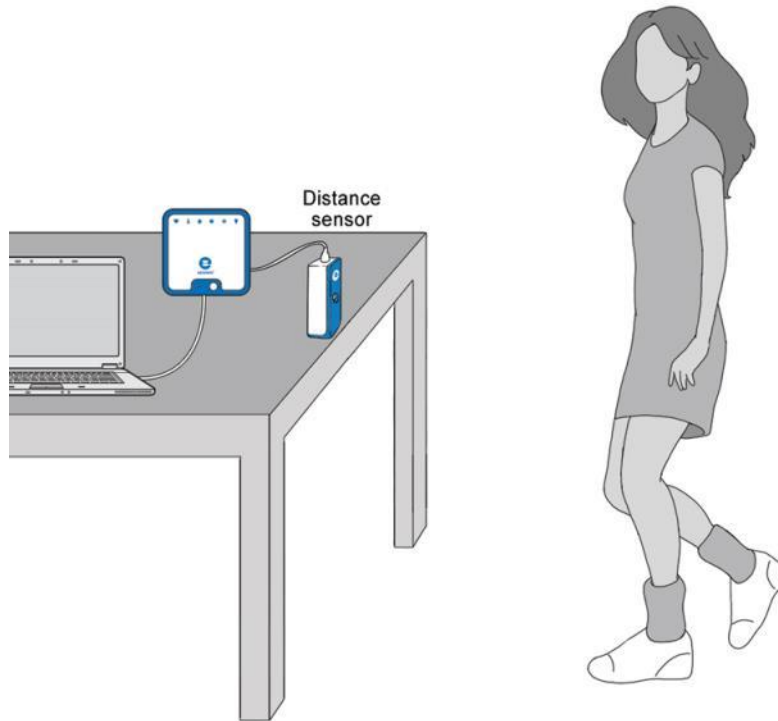


Figure 1



Introduction

In this experiment we will explore the use of the Distance sensor to create position and velocity graphs. You will walk back and forth in front of the Distance sensor and observe graphs of your motion. You will try to produce a graph that matches the graph presented to you.




Equipment

- einstein™ LabMate and a computer with MiLAB Desktop
- Distance sensor
- Distance adaptor
- Masking tape



123 Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect the Distance sensor with the Distance adaptor to one of the ports on the einstein™ LabMate.
3. In the Current Setup Summary window choose Full Setup and use the table below to set up the experiment. Make sure that only the Distance sensor is selected under Measurements.

Position versus Time Graph Matching:






Current Setup Summary

Program the sensor to log data according to the following setup:

Sensor:	Distance
Measurement:	Distance (m)
Rate:	10 samples per second
Samples:	1000
Duration:	1 minute 40 seconds



Procedure

1. Place the Distance sensor on a table so that it points toward an open space which is at least 4 m long (see Figure 1).
2. Use short strips of masking tape on the floor to mark the 1 m, 2 m, 3 m, and 4 m positions from the Distance sensor.
3. Produce a graph of your motion when you walk away from the Distance sensor with constant velocity. To do this, stand about 1 m from the Distance sensor and have your Lab partner select **Run** () to begin recording data. Walk slowly away from the Distance sensor.
4. When you reach the 3 m mark, ask your partner to select **Stop** ().
5. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.
6. Repeat steps 3 to 5 to match the following graph (Figure 2):

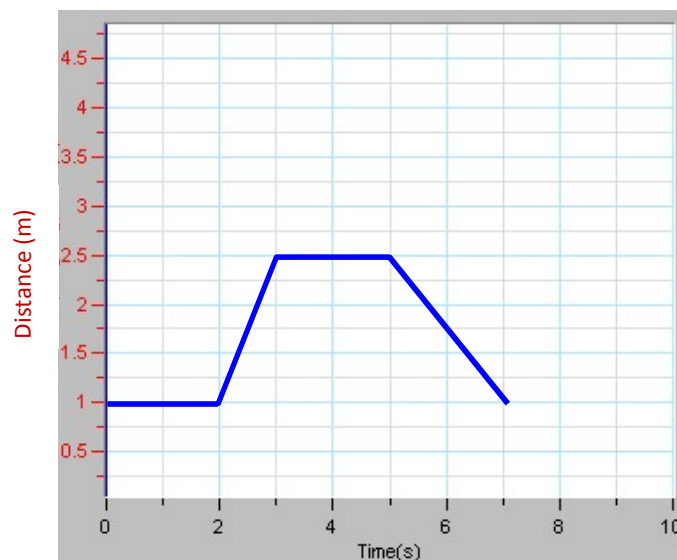


Figure 2: Position vs. Time graph

Velocity versus Time Graph Matching:






Current Setup Summary

Program the sensor to log data according to the following setup:

Sensor:	Distance
Measurement:	Velocity (Outgoing) (m/s)
Rate:	10 samples per second
Samples:	1000
Duration:	1 minute 40 seconds



Procedure

1. Place the Distance sensor on a table so that it points toward an open space which is at least 4 m long (see Figure 1).
2. Use short strips of masking tape on the floor to mark the 1 m, 2 m, 3 m, and 4 m positions from the Distance sensor.
3. Produce a graph of your motion when you walk away from the Distance sensor with constant velocity.
To do this, stand about 1 m from the Distance sensor and have your Lab partner select **Run** () to begin recording data. Walk slowly away from the Distance sensor.
4. When you reach the 3 m mark, ask your partner to select **Stop** ().
5. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.
6. Repeat steps 3 to 5 to match the following graph (Figure 3):

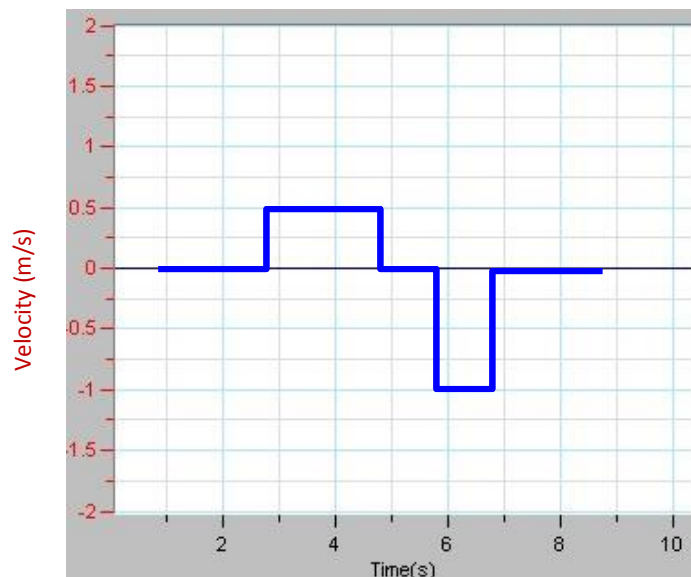


Figure 3: Velocity vs. Time graph



For more information on working with graphs see: **Working with Graphs in MiLAB Desktop.**

1. Describe how you walked to produce each of the graphs.
2. Explain the significance of the slope of a position vs. time graph. Include a discussion of positive and negative slope.
3. What type of motion is occurring when the slope of a position vs. time graph is zero?
4. What type of motion is occurring when the slope of a position vs. time graph is constant?
5. What type of motion is occurring when the slope of a position vs. time graph is changing? Test your answer to this question using the Distance sensor.
6. Describe how you walked in order to match the graph in Figure 3.
7. What type of motion is occurring when the slope of a velocity vs. time graph is zero?
8. What type of motion is occurring when the slope of a velocity vs. time graph is not zero? Test your answer using the Distance sensor.

Chapter 2

Position and Velocity Measurements

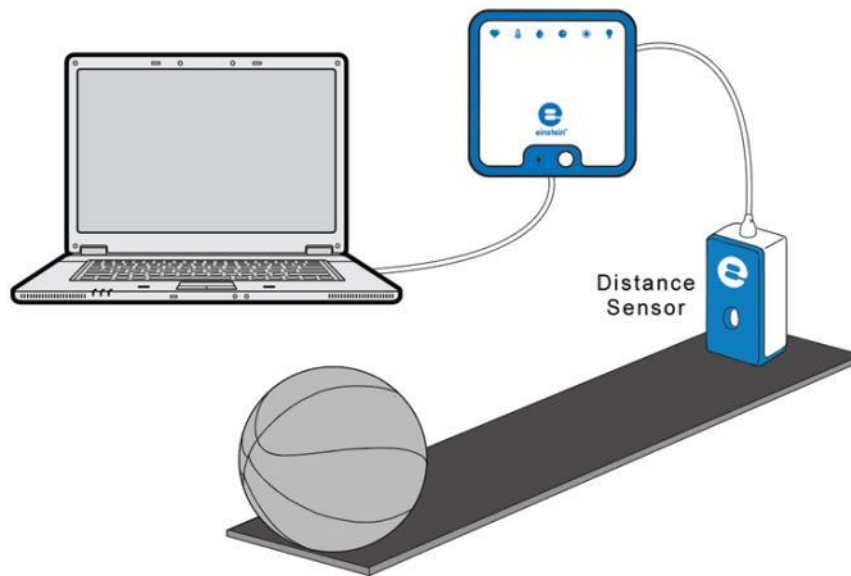


Figure 1



Introduction

Motion is best described by a position vs. time graph. From this graph one can derive velocity. Velocity, v , is defined as the rate of change of the position of an object. The average velocity, \bar{v} , can be calculated as:

$$\bar{v} = \frac{\Delta x}{\Delta t} \quad (1)$$

Where:

Δx = The displacement

Δt = The time elapsed


In this experiment we will use the Distance sensor to monitor the motion of a ball.



Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Distance sensor
- Distance adaptor
- Basketball or other round ball

123 Equipment Setup Procedure




1. Launch MiLAB Desktop ().
2. Connect the Distance sensor with the Distance adaptor to one of the ports on the einstein™ LabMate.
3. In the Current Setup Summary window choose Full Setup and use the table below to set up the experiment. Make sure that only the Distance sensor is selected under Measurements.

Current Setup Summary

Program the sensor to log data according to the following setup:

Sensor:	Distance
Measurements:	Distance (m)
Rate:	25 samples per second
Samples:	1000 samples
Duration:	40 seconds


Procedure

1. Place the Distance sensor on the floor or a smooth, flat surface where you can roll a basketball for several meters (see Figure 1).
2. Place the ball on the floor half a meter from the Distance sensor.
3. Select **Run** () to begin recording data.
4. Roll the ball across the floor, away from the Distance sensor, by giving it a gentle push.
5. When the ball reaches the end of the track or a distance of 10 m, select **Stop** ().
6. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.

Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop**.

Look at the graph in MiLAB Desktop and answer the following questions:

1. Does the slope of the graph change over time?
2. Use Equation (2) to calculate the average velocity of the ball over three different time intervals.
How does the speed change during those intervals?
3. Place a cursor on the plot line.
4. You can use MiLAB Desktop to calculate the slope at any point along the graph.
Select **Slope** () from the **Analysis** menu on the upper toolbar. MiLAB Desktop will display the slope at the current cursor position. For a position vs. time graph this slope represents the instantaneous velocity at this point.
5. Move the cursor along the graph and MiLAB Desktop will display the slope (instantaneous velocity) at each point as you move along.
6. Compare these values to the velocities you calculated using Equation (3).

Chapter 3

Velocity

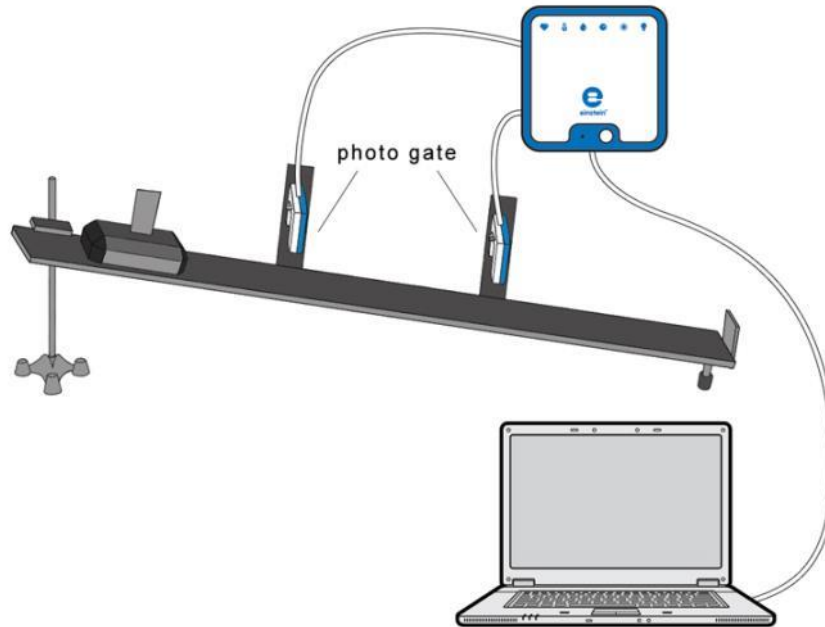


Figure 1



Introduction

In this activity we will explore the concept of average velocity using Photogate sensors. The Photogate sensor consists of two arms and a crossbeam. An infrared light source on one arm sends a narrow light beam to a light sensor on the other arm of the Photogate sensor. MiLAB Desktop uses its electronic clock to record the time when the light beam is blocked or unblocked. By using two Photogate sensors we can measure the time, Δt , it takes a cart to move from one gate to another. We will use MiLAB Desktop's analysis tools to calculate the average velocity \bar{v} according to:

$$\bar{v} = \frac{\Delta x}{\Delta t} \quad (1)$$

Where:

Δx = The displacement

Δt = The time elapsed



Equipment


- einstein™LabMate and a computer with MiLAB Desktop
- Photogate sensor (2)
- Dynamic Track
- Dynamic Cart
- Rod clamp with stand
- Bracket for Photogate sensor (2)

- Flag

123 Equipment Setup Procedure

1. Assemble the equipment as shown in Figure 1.
2. Mount the two Photogate sensors along the incline, 60cm apart, so that the cart's flag will block the Photogate sensors when passing through them.
3. Record the distance between the two Photogate sensors.
4. Mark a launching point on the track, just above the upper Photogate sensor.

Note: It is important to launch the cart from the same point at every attempt.

5. Launch MiLAB Desktop ().
6. Connect the Photogate sensors to two ports on the einstein™LabMate.
7. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Photogate sensors are selected under **Measurements**.




Current Setup Summary

Program the sensors to log data according to the following setup:

Sensor:	Photogate
Measurements:	Photogate
Rate:	100 samples per second
Samples:	10000
Duration:	1 minute 40 seconds


Note: Make sure that only the Photogate is selected and not the Smart Pulley. (make sure both Photogate sensors are selected).

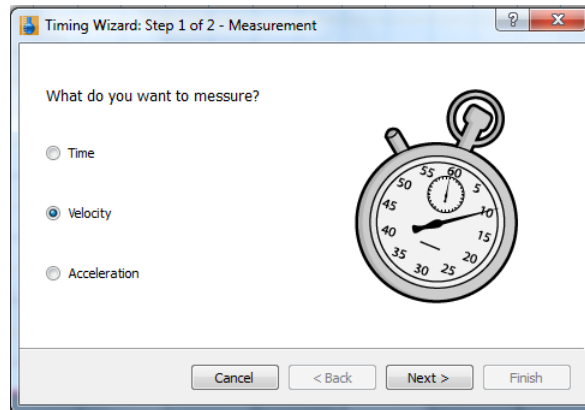
Procedure

1. Place the cart at the launching point on the Dynamic Track.
2. Select **Run** () to begin recording data and release the cart.
3. Pick the cart up off the track and return it to the launching point.
4. Repeat the measurement 2-4 more times.
5. Select **Stop** () bar to stop recording data.
6. Now move the upper Photogate sensor so that the distance between gates is 50 cm and repeat steps 2 and 5.
7. Repeat this procedure for distances of: 40 cm, 30 cm, 20 cm, 10 cm and 5 cm.
8. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.

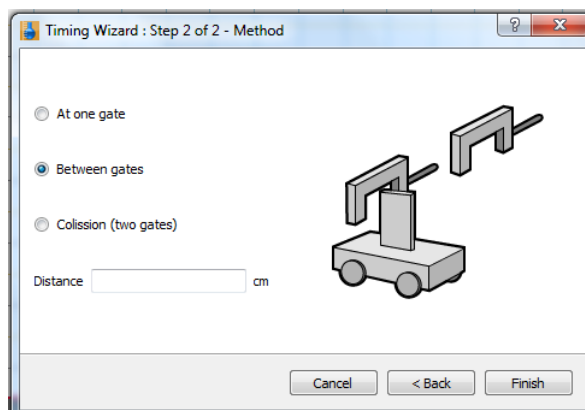
Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop.**

1. Select **Photogate** () from the **Analysis** menu on the upper toolbar to open the **Timing wizard** window:



2. Select **Velocity** and click **Next**.



3. Select **Between gates**.
4. Enter the distance between the two Photogate sensors in cm.
5. Select **Finish** and the **Timing Wizard** will display a list of the average velocities for the 3-5 runs of the cart on the track.
6. Repeat the analysis for each of the trials.
7. Describe the pattern of the graph.
8. What is the average velocity of the cart for each trial?
9. Does the average velocity change as the distance over which it is measured (Δx) changes? If so, when is the velocity greatest?
10. What would happen if you repeated the experiment but instead moved the position of the lower gate? What would be the same and what would be different?

Chapter 4

Motion on an Inclined Plane

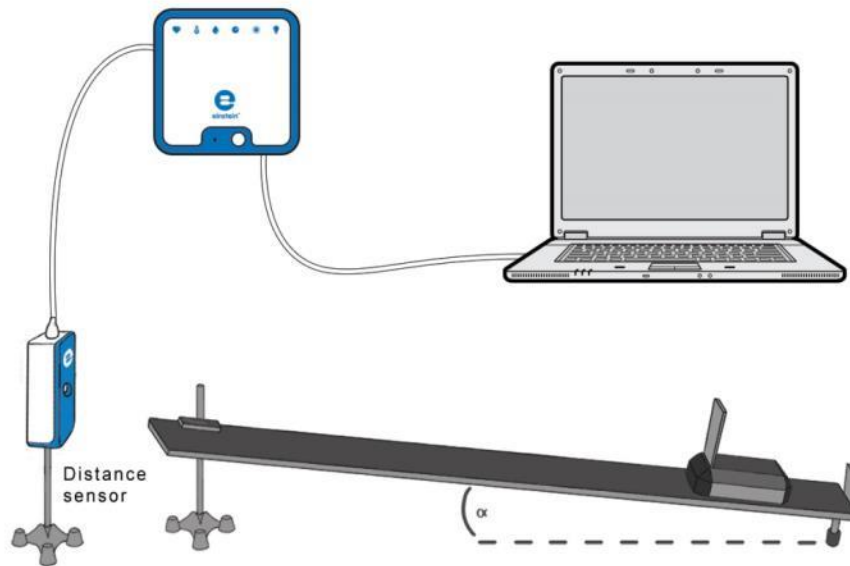


Figure 1

Introduction


When a body is placed on an inclined plane it will move down the slope with constant acceleration. If the body rebounds back up the plane when it reaches the bottom and the plane is friction free, the acceleration of the body up the plane will be equal to the acceleration down.

In this experiment we place a cart on an inclined plane and explore the properties of the motion.

Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Distance sensor
- Distance adaptor
- Cart
- Square piece of cardboard 10 x 10 cm (*flag*)
- Inclined plane (as friction free as possible)
- Laboratory stand with clamp OR books to vary height of inclined plane

123 Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect the Distance sensor with the Distance adaptor to one of the ports on the einstein™LabMate.
3. Assemble the equipment as shown in Figure 1.
4. Place the Distance sensor at the upper end of the inclined plane.

- Place a stopper at the bottom of the plane.
- The starting distance between the cart and the Distance sensor should be at least 50 cm.
- In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Distance sensor is selected under **Measurements**.



Current Setup Summary

Program the sensor to log data according to the following setup:

Sensor:	Distance
Measurements:	Distance (m)
Rate:	10 samples per second
Samples:	100
Duration:	10 seconds



Procedure

- Set the height of the inclined plane at ~5 cm. Record the height in your data table.
- Hold the cart at the top of the inclined plane.
- Select **Run** () to begin recording data.
- Release the cart when you hear the clicking of the sensor.
- When the cart reaches the bottom of the inclined plane, select **Stop** (). The cart may jump several times before the end of the measurement as it bounces away from the stopper.
- Repeat steps 3 to 5 two more times. Record all data in the data table.
- Change the height of the incline to 15 cm and repeat steps 3 to 5. Record all data in the data table.
- Change the height of the incline to 20 cm and repeat steps 3 to 5. Record all data in the data table.
- Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.

Data Table

Height of Inclined Plane (cm)	Acceleration (m/s^2)			Average Acceleration (m/s^2)
	Trial 1	Trial 2	Trial 3	

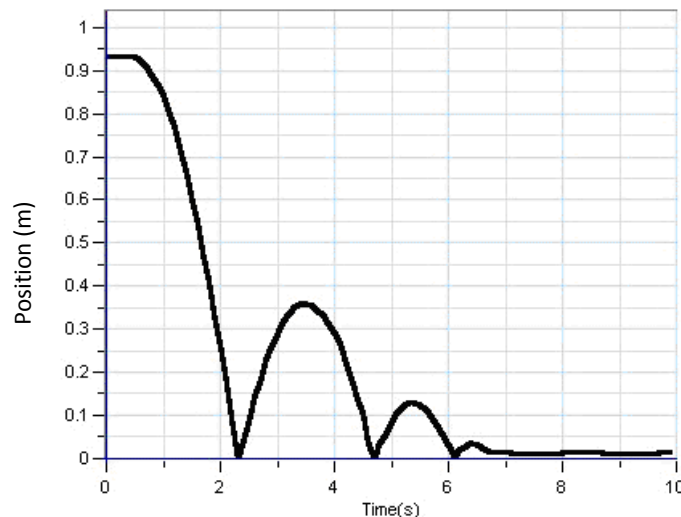


Figure 2



Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop.**

1. Use two cursors () to mark the downward slope of the graph. If the cart bounced up one or more times, choose the first (and biggest) downward slope on the graph.
2. Select **Math functions** () from the **Analysis** window on the upper menu bar.
3. In the **Math function** window which opens, choose **Derivative** from the **Function** drop down menu.
4. In the **G1** drop down menu select the Distance data.
5. The line which is drawn on the graph represents the velocity of the cart.
6. Use two cursors () to select two well separated points on the derived velocity line.
7. Select **Curve fit** () from the **Analysis** window on the upper menu bar.
8. In the **Curve fit** window which opens, choose **Linear** from the **Curve fit** drop down menu.
9. The graph of the linear fit will appear on the velocity graph and the fit equation will be displayed below the x-axis. The value of the slope of this graph is the acceleration. Record the acceleration in the data table.
10. Repeat this analysis for each height of the inclined plane.
What is the relationship between the height of the incline and acceleration?



Further Suggestions

1. You may want to check that the graph of the distance is parabolic:
 - a. Use two cursors () to select only one *jump*.
 - b. Select **Curve fit** () from the **Analysis** window on the upper menu bar.
 - c. In the **Curve fit** window which opens, choose **Polynomial** from the **Curve fit** drop down menu. and **2** from the **Order** drop down menu. The fit equation will be displayed in the information bar at the bottom of the graph window.
2. If there is significant friction between the cart and the plane, the cart will move up and down the plane with different accelerations. Measure α the angle of inclination of the plane (see Figure 1) and the acceleration when the cart is moving downwards in order to calculate the friction coefficient between

the cart and the plane:

$$\mu = \frac{g \sin \alpha - a_{down}}{g \cos \alpha}$$

3. Start the motion of the cart at different points on the plane and in different directions and try to predict the shapes of the distance and velocity graphs.
4. Place the sensor at the upper end of the inclined plane and try to predict in advance the form of the graphs of distance and velocity.

Chapter 5

Gravity

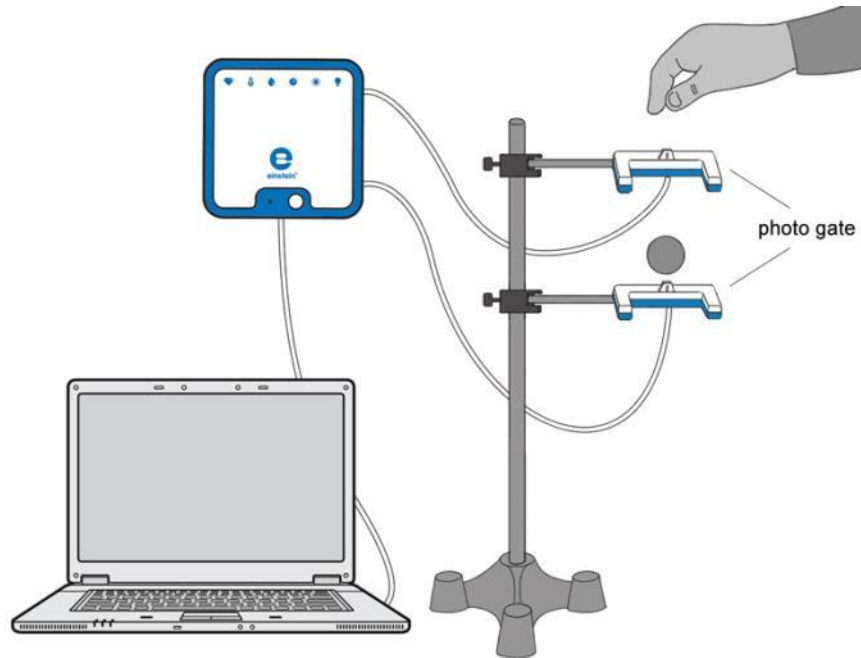


Figure 1

Introduction


In this activity we will explore the motion of objects falling due to gravity. We will use two Photogate sensors.

A Photogate sensor has an infrared light source on one of its two arms which sends a narrow light beam to a light sensor on its second arm. The data logger uses its electronic clock to record the time when the light beam is blocked or unblocked. By using the two Photogate sensors we can measure the velocity of a falling body at each gate and the time it takes the body to move from one gate to the other – thus enabling the data logger to calculate the acceleration due to gravity.

Equipment

- einstein™ LabMate and a computer with MiLAB Desktop
- Photogate sensor (2)
- Various small balls
- Stand
- Right angle clamp (2)
- Caliper or ruler
- Balance for weighing the balls

123 Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Assemble the equipment as shown in Figure 1.
3. Mount the two Photogate sensors one above the other, about 20 cm apart, so that a ball can fall freely through the arms of the Photogate sensors.
4. Measure the balls' diameters and record the data in your notebook.
5. Weigh the balls and record the data in your notebook.
6. Connect the two Photogate sensors to two of the ports of the einstein™ LabMate.
7. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Photogate sensors are selected under **Measurements**.

Current Setup Summary




Program the sensors to log data according to the following setup:

Sensor:	Photogate
Measurements:	Photogate
Rate:	100 samples per second
Samples:	5000
Duration:	50 seconds

Note: Make sure that only the Photogate is selected and not the Smart Pulley. Make sure both Photogate sensors are selected.

Procedure

Hints: Take care to drop the ball vertically to limit interference with the fall. Center the ball so its core diameter crosses the Photogates' beams.

1. Select **Run** () to begin recording data.
2. Drop the ball through the two gates.
3. Repeat this procedure several times and with different balls.
4. After several trials, select **Stop** ().
5. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.

Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop**.

The data from the two Photogate sensors should give a graph such as the one seen below in Figure 2:

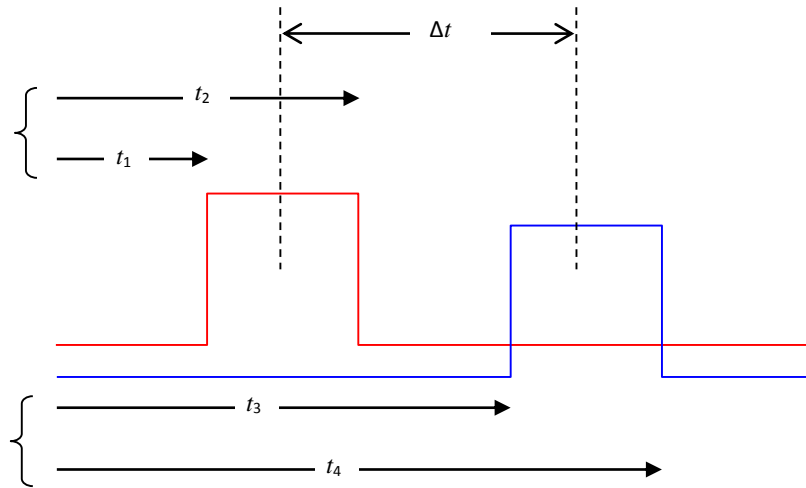


Figure 2

We can use the two Photogate sensors to measure the instantaneous velocities, v_1 and v_2 , of the falling balls at each Photogate sensor.

$$v_1 = \frac{w}{t_2 - t_1} \quad (1)$$

$$v_2 = \frac{w}{t_4 - t_3} \quad (2)$$

Where


w = The width (diameter) of the ball

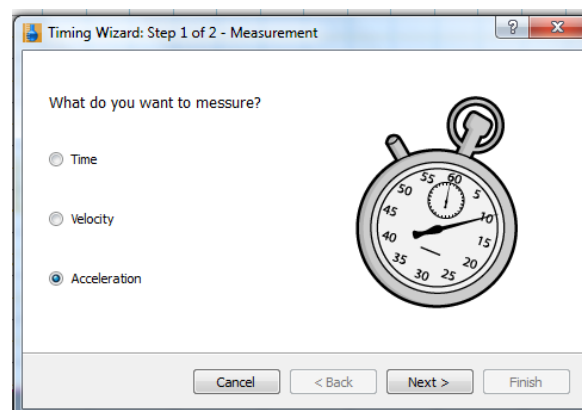
We can then calculate the acceleration a of each falling ball using these two instantaneous velocities and the time elapsed between passing through the two Photogate sensors (Δt) as follows:

$$\Delta t = \frac{t_4 + t_3 - t_2 - t_1}{2} \quad (3)$$

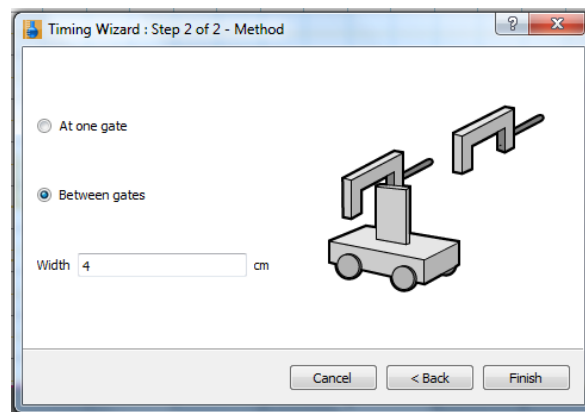
$$a = \frac{v_2 - v_1}{\Delta t} \quad (4)$$

We can use the MiLAB Desktop analysis tools to do these calculations and determine the acceleration of the balls.

1. Select **Photogate** () from the **Analysis** menu on the upper toolbar to open the **Timing wizard** window:



2. Select **Acceleration** and click **Next**.



3. Select **Between gates**.
4. Enter the diameter of the ball in cm in the Width field.
5. Calculate the average acceleration for each ball.
6. Do the results agree with the accepted value for acceleration due to gravity?
7. Does the free fall acceleration depend on the body's mass?
8. Does the free fall acceleration depend on the body's shape?
9. Explain how it is that all bodies fall with the same acceleration, 9.8 m/s^2 ?

Chapter 6

Momentum Conservation in Collisions

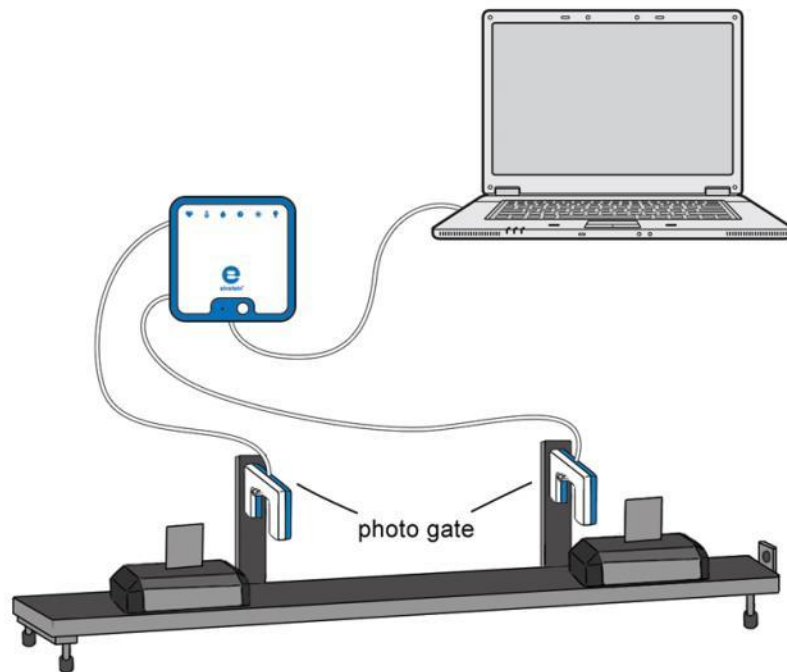


Figure 1



Introduction

The total momentum is conserved in collisions between two carts as long as there are no external forces acting upon them.


In this experiment we will use two Photogate sensors to examine conservation of momentum in collisions.



Equipment

- einstein™ LabMate and a computer with MiLAB Desktop
- Photogate sensor (2)
- Dynamic Track
- Dynamic cart (2)
- Flag (2)
- Two stands
- Bracket for Photogate sensor (2)

123 Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect the two Photogate sensors to ports on the einstein™LabMate.
3. Assemble the equipment as shown in Figure 1.
4. Attach a flag to each cart (see Figure 1).
5. Mount the Photogate sensors on the Dynamic Track using the brackets. Position the two Photogate sensors about 20 to 25 cm apart along the track (see Figure 1) so that the flags block the sensors while passing through them.
6. Align the track so that it is horizontal. Test this by releasing a cart on the track from rest. The cart should not move.
7. In the **Current Setup Summary** window, choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Photogate sensors are selected under **Measurements**.

Current Setup Summary

Program the sensors to log data according to the following setup:




Sensor:	Photogate
Measurements:	Photogate
Rate:	100 samples per second
Samples:	10000
Duration:	1 minute 40 seconds

Note: Make sure that only the Photogate is selected and not the Smart Pulley. Make sure both Photogate sensors are selected.




Procedure

1. Measure the mass of your carts and record the measurements in your data table. Label the carts as cart 1 and cart 2.
2. Practice creating gentle collisions: place one cart at rest between the Photogate sensors. Release the other cart from outside the Photogate sensors' zone so that it rolls toward the first cart, magnetic bumper toward magnetic bumper. The carts should smoothly repel one another without physically touching.

Elastic collisions:


1. Set the magnetic plugs in the two carts to repel each other upon contact.
2. Position the carts so the magnetic bumpers are facing one another.
3. Select **Run** () to begin recording data.
4. Reproduce a collision like the one you practiced in step 332 of the Procedure.
5. After the second cart leaves the Photogate sensor's zone, select **Stop** ().
6. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.
7. Repeat steps 12 to 6 for two more collisions, each time with different initial velocities.

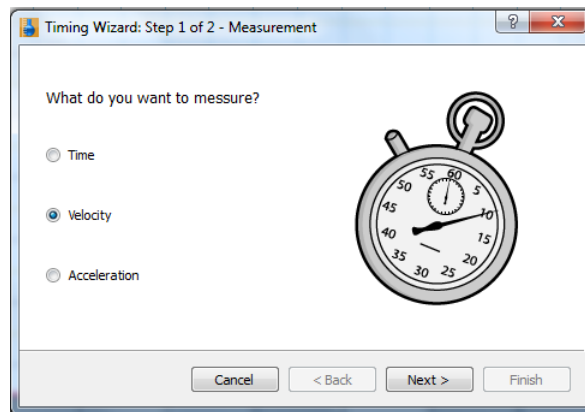
Inelastic collisions:

1. Set the magnetic plugs in the two carts to attract each other upon contact.
2. Position the carts so the magnetic bumpers are facing one another.
3. Select **Run** () to begin recording data.
4. Reproduce a collision like the one you practiced in step 2 of the Procedure. This time the carts should stick together.
5. After the second cart leaves the Photogate sensor's zone, select **Stop** ().
6. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.
7. Repeat steps 1 to 6 for two more collisions, each time with different initial velocities.

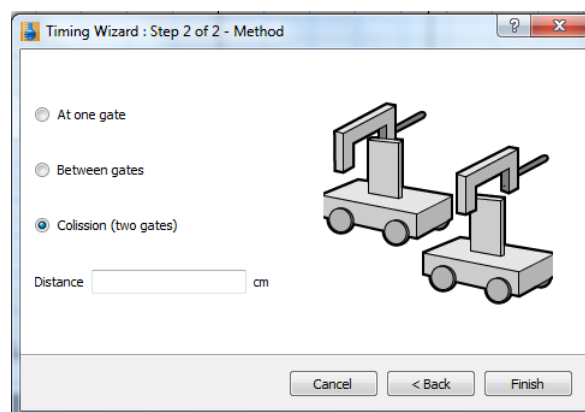
Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop.**

1. Select **Photogate** () from the **Analysis** menu on the upper toolbar to open the **Timing wizard** window:



2. Select **Velocity** and click **Next**.



3. Select **Collision** and enter the distance between the two Photogate sensors then select **Finish**.
4. Record the results in the data table.
5. Determine the momentum (mv) for each cart before and after the collision. Calculate the ratio of the total momentum after the collision to the total momentum before the collision. Enter the values in your data table.
6. Discuss the six trials in terms of conservation of momentum.

Data Tables

Mass of cart 1 _____ kg

Mass of cart 2 _____ kg

Elastic collisions

	Velocity before Collision		Velocity after Collision	
Trial Number	Cart 1 (m/s)	Cart 2 (m/s)	Cart 1 (m/s)	Cart 2 (m/s)
1				
2				
3				

	Momentum before Collision			Momentum after Collision			Ratio of total Momentum After/Before
Trial Number	Cart 1 (kg·m/s)	Cart 2 (kg·m/s)	Total (kg·m/s)	Cart 1 (kg·m/s)	Cart 2 (kg·m/s)	Total (kg·m/s)	
1							
2							
3							

Inelastic collisions

	Velocity before Collision		Velocity after Collision	
Trial Number	Cart 1 (m/s)	Cart 2 (m/s)	Cart 1 (m/s)	Cart 2 (m/s)
1				
2				
3				

	Momentum before Collision			Momentum after Collision			Ratio of total Momentum After/Before
Trial Number	Cart 1 (kg·m/s)	Cart 2 (kg·m/s)	Total (kg·m/s)	Cart 1 (kg·m/s)	Cart 2 (kg·m/s)	Total (kg·m/s)	
1							
2							
3							



Further Suggestions

Repeat the experiment with masses added to the carts.

Chapter 7

Energy Conservation in Collisions

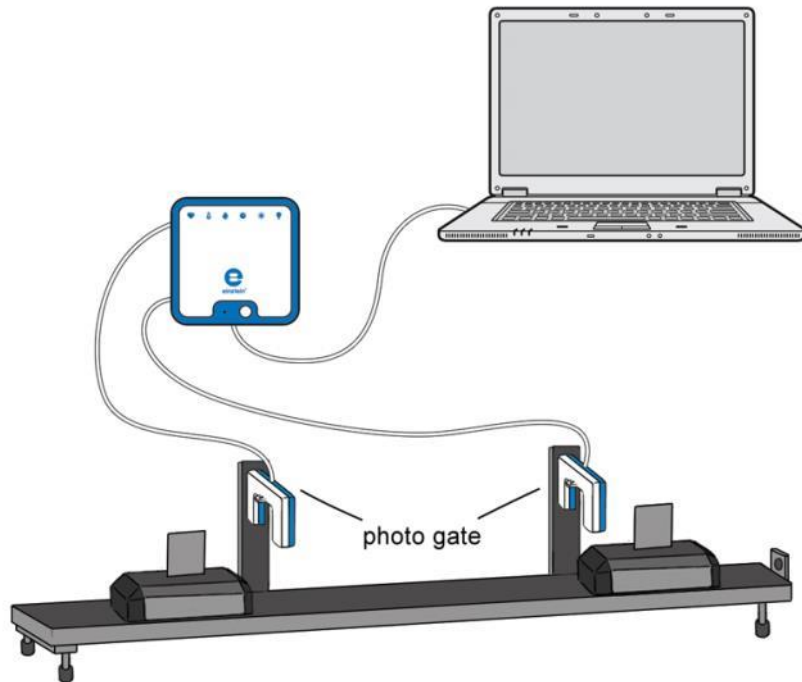


Figure 1



Introduction

Collisions between two carts can be classified as elastic – where the kinetic energy is conserved and inelastic – where the kinetic energy is not conserved.

In this experiment we will use two Photogate sensors to study the conservation of kinetic energy during collisions. Kinetic energy (KE) can be calculated from the mass (m) and the velocity (v) of an object in motion:


$$KE = \frac{1}{2}mv^2 \quad (1)$$



Equipment

- einstein™ LabMate and a computer with MiLAB Desktop
- Photogate sensor (2)
- Dynamic Track
- Dynamic cart (2)
- Flag (2)
- Two stands
- Bracket for Photogate sensor (2)
- Balance

123 Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect both Photogate sensors to ports on the einstein™LabMate.
3. Assemble the equipment as shown in Figure 1.
4. Attach a flag to each cart (see Figure 1).
5. Mount the Photogate sensors on the Dynamic Track using the brackets. Position the sensors about 20 – 25 cm apart along the track (see Figure 1) so that the flags block the Photogate sensors while passing through them.
6. Align the track so that it is horizontal. Test this by releasing a cart on the track from rest. The cart should not move.
7. In the **Current Setup Summary** window, choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Photogate sensors are selected under **Measurements**.

Current Setup Summary

Program the sensors to log data according to the following setup:




Sensor:	Photogate
Measurements:	Photogate
Rate:	100 samples per second
Samples:	10000
Duration:	1 minute 40 seconds

Note: Make sure that only the Photogate is selected and not the Smart Pulley. Make sure both Photogate sensors are selected.




Procedure

1. Measure the mass of your carts and record the measurements in your data table. Label the carts as cart 1 and cart 2.
2. Practice creating gentle collisions: place one cart at rest between the Photogate sensors. Release the other cart from outside the Photogate sensors' zone so that it rolls toward the first cart, magnetic bumper toward magnetic bumper. The carts should smoothly repel one another without physically touching.

Elastic collisions:


1. Set the magnetic plugs in the two carts to repel each other upon contact.
2. Position the carts so the magnetic bumpers are facing one another.
3. Select **Run** () to begin recording data.
4. Reproduce a collision like the one you practiced in step 2 in the Procedure.
5. After the second cart leaves the Photogate sensor's zone, select **Stop** ().
6. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.
7. Repeat steps 3 to 6 for two more collisions, each time with different initial velocities.

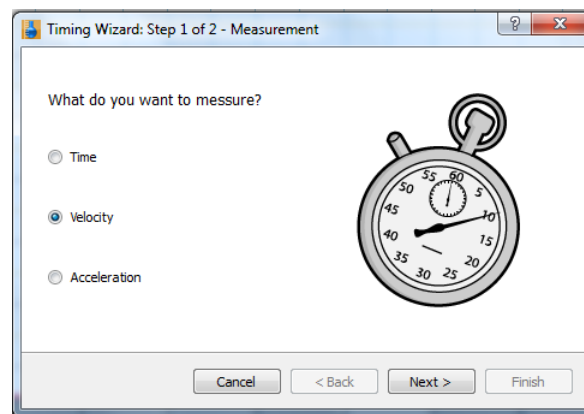
Inelastic collisions:

1. Set the magnetic plugs in the two carts to attract each other upon contact.
2. Select **Run** () to begin recording data.
3. Reproduce a collision like the one you practiced in step 2 in the Procedure. This time the carts should stick together.
4. After the second cart leaves the Photogate sensor's zone, select **Stop** ().
5. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.
6. Repeat steps 1 to 5 for two more collisions, each time with different initial velocities.

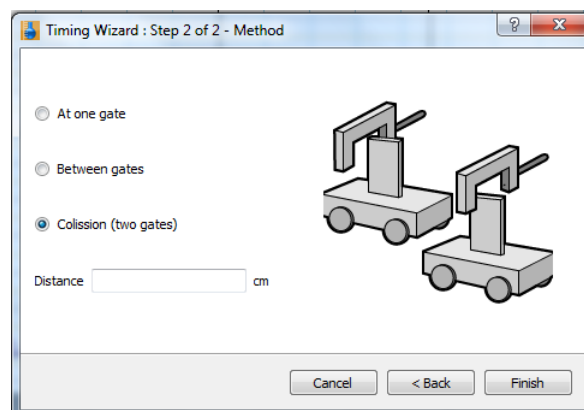
Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop.**

1. Select **Photogate** () from the **Analysis** menu on the upper toolbar to open the **Timing wizard** window:



2. Select **Velocity** and click **Next**.



3. Select **Collision** and enter the distance between the two Photogate sensors then select **Finish**.
4. Record the results in the data table.

Data Tables

Mass of cart 1 _____ kg

Mass of cart 2 _____ kg

Elastic collisions

	Velocity before Collision		Velocity after Collision	
Trial Number	Cart 1 (m/s)	Cart 2 (m/s)	Cart 1 (m/s)	Cart 2 (m/s)
1				
2				
3				

	Kinetic Energy before Collision			Kinetic Energy after Collision			Ratio of Total KE After/Before
Trial Number	Cart 1 (J)	Cart 2 (J)	Total (J)	Cart 1 (J)	Cart 2 (J)	Total (J)	
1							
2							
3							

Inelastic collisions

	Velocity before Collision		Velocity after Collision	
Trial Number	Cart 1 (m/s)	Cart 2 (m/s)	Cart 1 (m/s)	Cart 2 (m/s)
1				
2				
3				

	Kinetic Energy before Collision			Kinetic Energy after Collision			Ratio of Total KE After/Before
Trial Number	Cart 1 (J)	Cart 2 (J)	Total (J)	Cart 1 (J)	Cart 2 (J)	Total (J)	
1							
2							
3							

1. Use Equation (1) to determine the kinetic energy for each cart before and after the collision.
2. Calculate the ratio of the total kinetic energy after the collision to the total kinetic energy before the collision. Enter the values in your data table.
3. Discuss the six trials in terms of energy conservation.



Further Suggestions

Repeat the experiment with masses added to the carts.

Chapter 8

Friction Coefficient

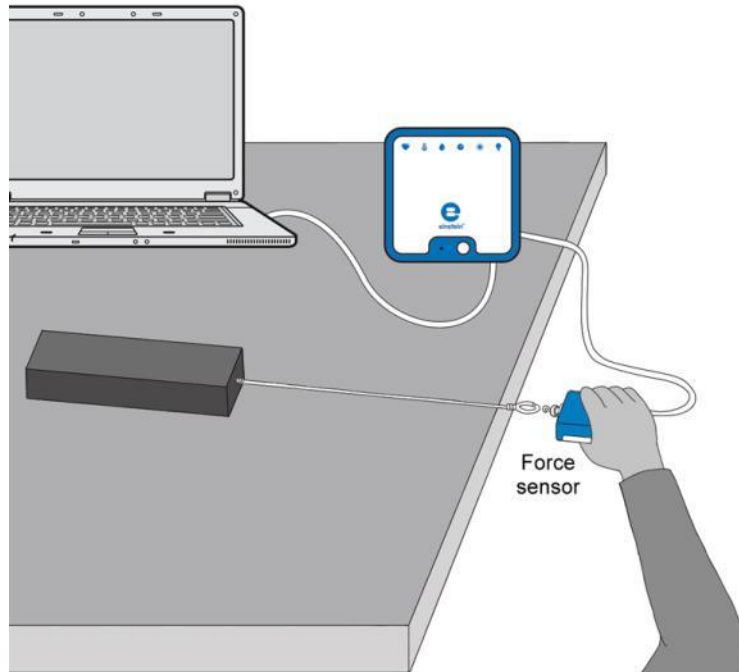


Figure 1



Introduction

Friction is the force that acts between two surfaces that slide or attempt to slide one over the other. For dry surfaces, the friction depends on the types of surfaces and on the normal force acting between them.

When the surfaces are at rest with respect to each other the friction is static friction and its magnitude can vary from zero to a maximum value:

$$f_s \leq \mu_s N \quad (1)$$

Where:

f_s = The static friction

μ_s = The static friction coefficient

N = The normal force

Static friction is what keeps an object on an inclined plane from sliding downwards.

When there is relative motion between the two surfaces, the static friction must be overcome by kinetic friction. The kinetic friction is given by:

$$f_k = \mu_k N \quad (2)$$

Where:

f_k = The kinetic friction

μ_k = The kinetic friction coefficient

In this experiment these relations are studied for a variety of surfaces.




Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Force sensor
- Blocks of several materials (e.g. wooden block and a brick)
- String
- Balance to measure the mass of the blocks

123

Equipment Setup Procedure

1. Launch MiLAB Desktop ().
4. Connect the Force sensor to one of the ports on the einstein™LabMate.
5. Assemble the equipment as shown in Figure 1.
6. Attach one end of the string to the block.
7. Attach the other end of the string to the Force sensor so that pulling the sensor will drag the block along the table or other surface. The Force sensor will measure the force acting on the block.
8. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Force sensor is selected under **Measurements**.






Current Setup Summary

Program the sensor to log data according to the following setup:

Sensor (Range):	Force (± 10 N or ± 50 N)
Measurements:	Force, Pull – positive (N)
Current Reading:	Set (sets as zero)
Rate:	10 samples per second
Samples:	1000
Duration:	1 minute 40 seconds



Procedure

1. Measure the mass of each block of material and record the measurements in your notebook.
2. Select **Run** () to begin recording data.
3. Place the block on a table or other surface.
4. Hold the Force sensor in your hand and pull it. Make sure that the string is horizontal to the surface on which the block is resting and gradually increase the applied force. When the block starts moving, maintain a constant velocity. Only when the block moves at constant velocity is the friction exactly balanced by the force acting on the block.
5. When you have pulled the block a short distance, select **Stop** ().
6. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.
7. Repeat the experiment with different materials. Remember to save the data from each experiment with a unique name.

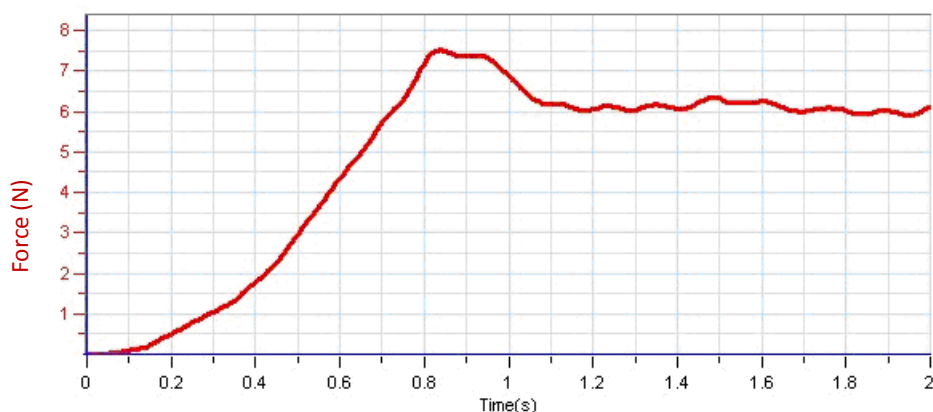





Figure 2



Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop.**

1. Use one cursor () to measure the maximum value of the force measured by the sensor before the block started moving. This is the maximum value of the static friction. Use this value to calculate μ_s , the static friction coefficient.
2. Find the average value of the force required to move the block:
 - a. Use two cursors () to select the portion of the graph which corresponds to the motion of the block.
 - b. From the **Analysis** window on the upper menu bar, select **Statistics** ().
 - c. Write down the **Average** value of the force for this portion of the graph.
3. Use the average value of the force and Equation (2) to calculate the kinetic friction coefficient.
4. Repeat these calculations using the data from blocks made from different materials and compare the coefficients.



Further Suggestions

1. A motor can be used to pull the string. This will ensure a more steady velocity.
2. To explore the effect of different velocities on the friction (theoretically there is none) you may use a motor to pull the string and change the velocity by changing the frequency of the motor's rotor.
3. You can perform a series of experiments to determine the effect of the normal force on the friction. Change the mass of the block (by putting extra weights on it) without changing the surface on which it rests. You can then use a spreadsheet to produce a graph of the friction vs. the normal force and derive the friction coefficient from the slope of this graph.

Chapter 9

Newton's Third Law

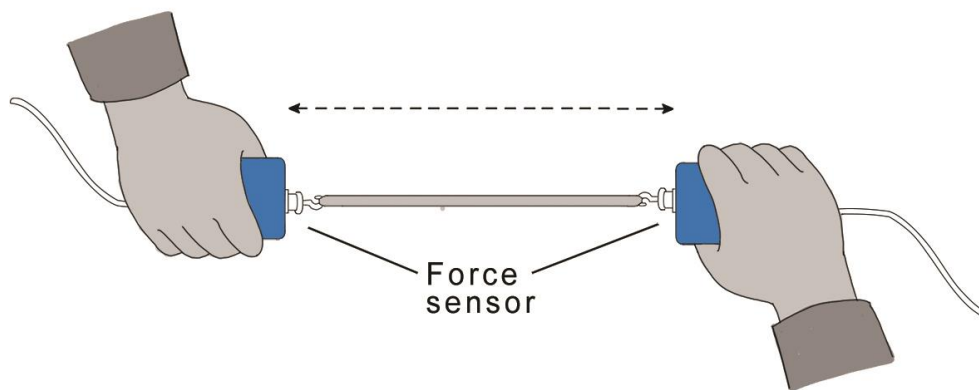


Figure 1



Introduction

Newton's Third Law is often stated as:

For every action, there is an equal and opposite reaction.

This statement means that when one body exerts a force on a second body, the second body also exerts a force on the first body. There is a pair of forces acting on the two interacting objects. The size of the force exerted by the first body is equal in size to the force exerted by the second body. The direction of the force exerted by the first body is opposite in direction to the force exerted by the second body. Forces always come in pairs – equal and opposite action-reaction force pairs.

In this experiment you will use two Force sensors to demonstrate Newton's Third Law.




Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Force sensors (2)
- String
- Rubber band

123

Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect the Force sensors to two ports on the einstein™LabMate.
3. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Force sensor is selected under **Measurements**.








Current Setup Summary

Program the sensor to log data according to the following setup:

Sensor (Range):	Force (± 50 N)
Measurements:	Force, Pull – positive (N)
Current Reading:	Set (sets as zero)
Rate:	10 samples per second
Samples:	500
Duration:	50 seconds



Procedure

1. Tie the two Force sensors together with a string about 20 cm long. Hold one Force sensor in your hand and have your partner hold the other Force sensor so that you can pull on each other (see Figure 1).
2. Select **Run** () to begin recording data.
3. Gently tug on your partner's Force sensor with your Force sensor, making sure the graph does not go off the scale. Also, have your partner tug on your sensor. You will have 50 seconds to try different pulls.
4. When you are done, select **Stop** ().
5. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.
6. Repeat the experiment with different materials. Remember to save the data from each experiment with a unique name.
7. What would happen if you used the rubber band instead of the string? Make a prediction using the **Predict** tool.
 - a. Open a new graph window by selecting **Graph** () from the **Workspace** window on the upper menu bar.
 - b. Select the **Predict** tool () from the graph tool bar. Click on the graph to sketch a prediction on the graph.
 - c. Repeat steps 2-5 using the rubber band instead of the string.



Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop**.

1. Examine the graphs.
 - a. What can you conclude about the two forces (your pull on your partner and your partner's pull on you)?
 - b. How are the magnitudes related?
 - c. How are the signs related?
2. How does the rubber band change the results - or does it change them at all?
3. While you and your partner are pulling on each other's Force sensors, do the forces upon the sensors have the same positive direction?
4. Is there any way to pull on your partner's Force sensor without your partner's Force sensor pulling back? Try it.



Further Suggestions

1. Fasten one Force sensor to your lab bench or table and repeat the experiment by pulling on the sensor which is not fastened to the bench. Does the bench pull back as you pull on it? Does it matter that the second force sensor is not held by a person?
2. Use a rigid rod to connect your Force sensors instead of a string and experiment with mutual pushes instead of pulls. Repeat the experiment. Does the rod change the way the force pairs are related

Chapter 10

The Impact of Constant Force on a Moving Body

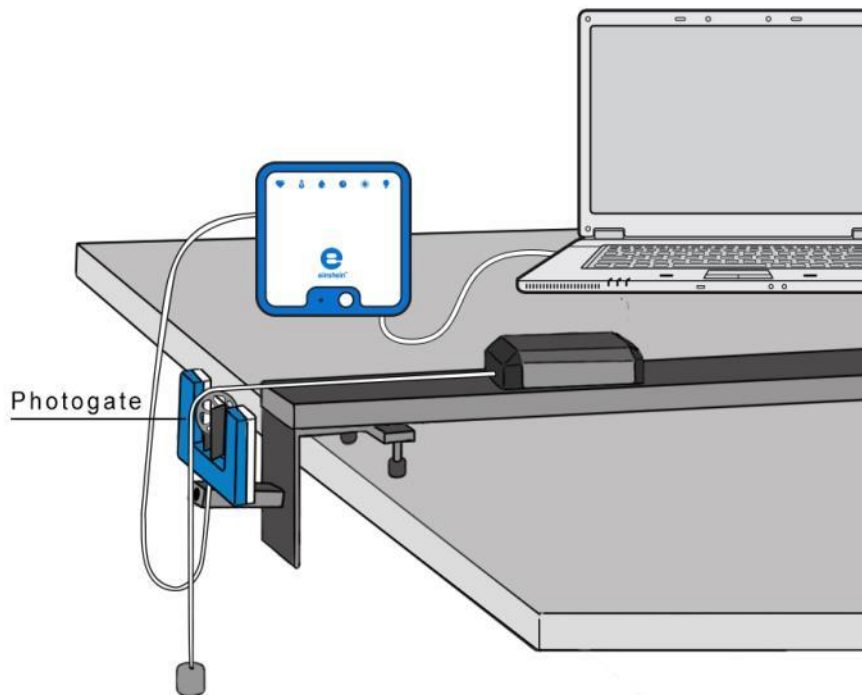


Figure 1



Introduction

In this experiment we explore the impact of applying a constant force to a cart. The force of gravity will be applied to the cart by means of a string suspended over a pulley and connected to a hanging weight (see Figure 1).

According to Newton's Second Law of Motion, applying a constant force to a body yields a motion with constant acceleration.


The cart's velocity as it is pulled by the weight will be monitored using the Smart Pulley sensor.



Equipment

- einstein™ LabMate and a computer with MiLAB Desktop
- Smart pulley sensor
- Dynamic Track
- Dynamic Cart
- Pulley bracket
- Weight (~100 g)
- String

123 Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Assemble the Smart Pulley sensor by mounting the pulley on the Photogate sensor with the rod provided.
3. Mount the Smart Pulley sensor on one end of the track using the pulley mounting bracket.
4. Connect the Smart Pulley sensor to one of the ports on the einstein™ LabMate.
5. Position the cart at the other end of the track.
6. Attach a string to the cart.
7. Attach a 100 g weight to the other end of the string.
8. Pass the string over the pulley.
9. Level the track and adjust the Smart Pulley height so that the string is parallel to the track.
10. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Smart Pulley sensor is selected under **Measurements**.




Current Setup Summary

Program the sensor to log data according to the following setup:

Sensor:	Smart Pulley
Measurements:	Velocity (m/s)
Rate:	25 samples per second
Samples:	100
Duration:	4 seconds

Note: Make sure that only the Smart Pulley is selected and not the Photogate.

Procedure

1. Hold the cart at the end of the track.
2. Select **Run** () to begin recording data.
3. Release the cart.
4. Select **Stop** () as the hanging mass reaches the floor.
5. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.

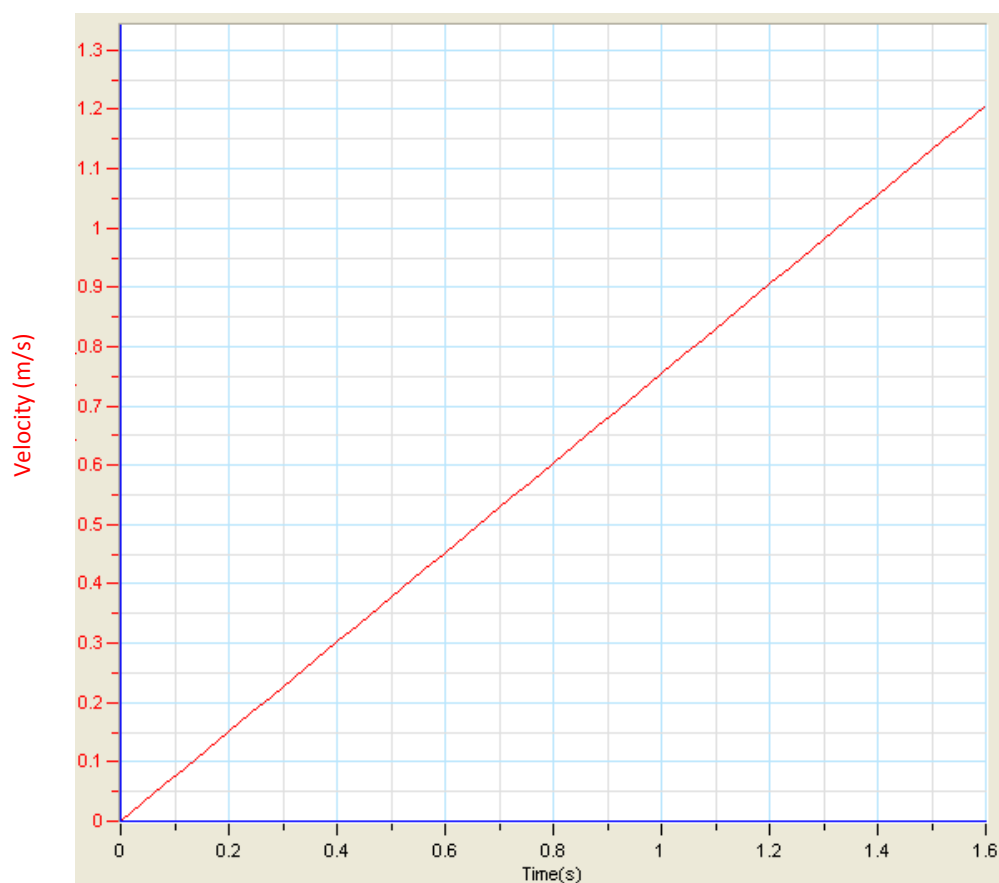



Figure 2



Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop.**

1. Discuss the resulting graph. Does it agree with Newton's Second Law of Motion?
2. What can be said about the velocity changes over equal time intervals?
3. Fit a straight line to your data that passes through your data points:
 - a. Select **Curve fit** () from the **Analysis** window on the upper menu bar.
 - b. In the **Curve fit** window which opens, choose **Linear** from the **Curve fit** drop down menu.
 - c. The linear fit will appear on the graph.
 - d. The linear fit equation will be displayed in the information on the graph when you drag the cursor to the linear fit line.
 - e. The slope of the linear fit line represents the acceleration of the cart.

Chapter 11

Newton's Second Law

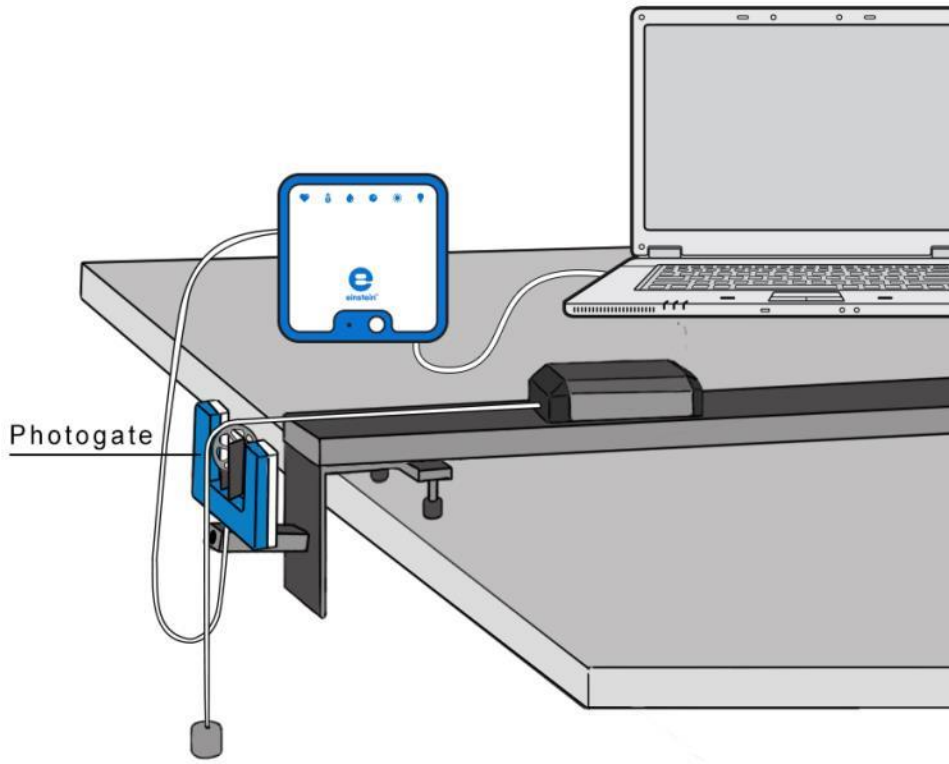


Figure 1



Introduction

Isaac Newton was the first to accurately define the relationship between the mass of a body m , the force applied to it F and the acceleration a (rate of change of the velocity) caused by this force. The acceleration is linearly proportional to the net force applied, that is, the sum of all forces on the object. The object accelerates in the same direction as the direction of the net force:

$$\vec{F} = m\vec{a} \quad (1)$$

In this experiment you will explore the relationship between force and the acceleration. You will use the force of gravity to accelerate a cart along a track. The acceleration will be measured with the aid of a Smart Pulley sensor.




Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Smart Pulley sensor
- Dynamic Track
- Dynamic Cart

- Pulley bracket
- Weights (one 10 g and two 20 g)
- String

123 Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Assemble the Smart Pulley sensor by mounting the pulley on the Photogate sensor with the rod provided.
3. Mount the Smart Pulley sensor on one end of the track using the pulley mounting bracket.
4. Connect the Smart Pulley to one of the ports on the einstein™Tablet+.
5. Position the cart at the other end of the track.
6. Attach a string to the cart. The string should be long enough so that when the cart is next to the Smart Pulley sensor, the string reaches the floor.
7. Attach a 10 g weight to the other end of the string.
8. Pass the string over the pulley.
9. Level the track and adjust the Smart Pulley height so that the string is parallel to the track.
10. Load the remaining weights on the cart.
11. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Smart Pulley sensor is selected under **Measurements**.




Current Setup Summary

Program the sensor to log data according to the following setup:

Sensor:	Smart Pulley
Measurements:	Velocity (m/s)
Rate:	25 samples per second
Samples:	500
Duration:	20 seconds

Note: Make sure that only the Smart Pulley is selected and not the Photogate.

Procedure

1. If the masses are not already known, measure the masses of the two objects attached at either end of the pulley's string before beginning the experiment:
 - a. Measure the mass of the cart including the weights on board. Record this as m_{cart} in your lab notebook.
 - b. Measure the mass of the weight at the other end of the pulley. Record this as m_{weight} in your lab notebook.
 - c. You may need to do this before setting up the track and pulley assembly.
2. Hold the cart at the end of the track.
3. Select **Run** () to begin recording data.
4. Release the cart.
5. Select **Stop** () as the hanging mass reaches the floor.
6. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.

7. Replace the hanging weight with a 20 g weight from the cart. Make sure that all the other weights are on the cart and repeat steps 1 to 6.
8. Repeat steps 11 to 6 with hanging weights of 30 g, 40 g and 50 g.

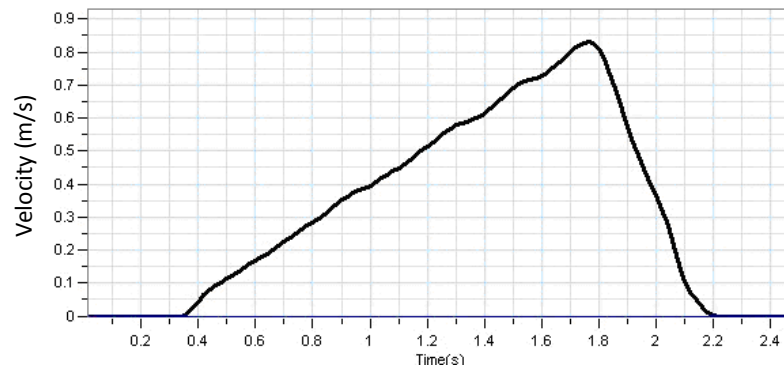


Figure 2



Data Analysis

To understand how Newton's second law of motion is applied to the system of the cart attached to a weight, consider each of the two objects at the two ends of the string separately. Using Newton's second law of motion (Equation (1)), you can write an equation for each object relating force to acceleration. Since the two objects are connected with a string, they move together and so have the same acceleration which you can label a .

$$F_{cart} = m_{cart}a \quad (2)$$

$$F_{weight} = m_{weight}a \quad (3)$$

Now you need to consider all the forces acting on each object in order to determine the net force on each object.

The cart

The cart is being pulled along the track by the tension on the cord, T . The cart may be slowed down by friction, f , as it is pulled along the track. We can sum up these forces using an equation:

$$F_{cart} = T - f \quad (4)$$

If we ignore the friction (some modern dynamic systems have a remarkably low friction coefficient), this equation can be simplified:

$$F_{cart} = T \quad (5)$$

The weight

The weight on the end of the string experiences the force of gravity pulling it towards the floor and the tension on the cord, T , attached to the cart. We can sum up these forces using an equation:

$$F_{weight} = m_{weight}g - T \quad (6)$$

Where:

g = The acceleration due to gravity

Substituting this equation into the relationship already found for the tension on the string (Equation (5)):

$$F_{\text{weight}} = m_{\text{weight}}g - F_{\text{cart}} \quad (7)$$

Now substituting in the original Newton's second law of motion equations (Equations (2) and (3)):

$$m_{\text{weight}}a = m_{\text{weight}}g - m_{\text{cart}}a \quad (8)$$


With some rearranging of this equation, you can find a relationship between the acceleration of the objects and their masses:

$$a = \frac{1}{m_{\text{cart}} + m_{\text{weight}}} \cdot m_{\text{weight}}g \quad (9)$$

Because the total mass, $m_{\text{cart}} + m_{\text{weight}}$, remains constant, the graph of acceleration vs the applied force, $m_{\text{weight}}g$ is a straight line with slope:

$$\text{slope} = \frac{1}{m_{\text{cart}} + m_{\text{weight}}} \quad (10)$$

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop.**

1. From the graph (Figure 2) you can see that the velocity increases linearly over time. That means that the acceleration is constant, as the acceleration is the rate of change of the velocity.
2. Use the cursors to select the linear range of the graph.
3. Select **Curve fit** () from the **Analysis** window on the upper menu bar.
4. In the **Curve fit** window which opens, choose **Linear** from the **Curve fit** drop down menu.
5. The linear fit will appear on the graph.
6. The linear fit equation will be displayed in the information on the graph when you drag the cursor to the linear fit line.
7. The slope of the linear fit line represents the acceleration of the cart.
8. Prepare a data table:

Data Table

m_{weight} (g)	a (m/s ²)	$F = m_{\text{weight}}g$ (N)

1. Repeat the calculations for each of your saved data files and fill in the data table.
2. Graph the acceleration vs. the applied force, $m_{\text{weight}}g$, and find the slope of the resulting line.
3. Compare the graph's slope to the theoretical one (see Equation (10)).
4. Calculate the relative error:

$$\text{Relative error (\%)} = \left| \frac{\text{Theoretical} - \text{Experimental}}{\text{Theoretical}} \right| \times 100\%$$



Further Suggestions

If there is a significant friction in your system, find the friction coefficient from the graph.

Chapter 12

Energy of a Tossed Ball

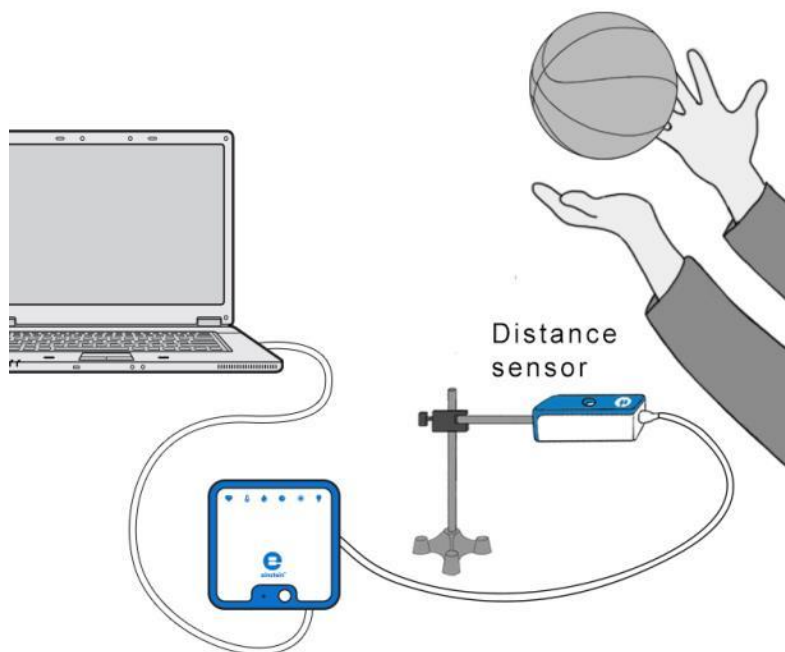


Figure 1



Introduction

When a body moves under the influence of gravity alone, its mechanical energy (the sum of its kinetic energy, KE , and potential energy, PE) is conserved.

$$KE + PE = \text{constant} \quad (1)$$


When a ball is tossed up in the air it begins with kinetic energy. As it rises it slows down, losing kinetic energy and gaining potential energy. On its way down, the ball loses potential energy but gains kinetic energy.



Equipment

- einstein™ LabMate and a computer with MiLAB Desktop
- Distance sensor
- Distance adaptor
- Small stand
- Clamp
- Basketball or similar sized ball

123 Equipment Setup Procedure




1. Measure and record the mass of the ball.
2. Launch MiLAB Desktop ().
3. Connect the Distance sensor with the Distance adaptor to one of the ports on the einstein™ LabMate.
4. Assemble the equipment as shown in Figure 1.
5. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Distance sensor is selected under **Measurements**.

Current Setup Summary

Program the sensor to log data according to the following setup:

Sensor:	Distance
Measurements:	Distance (m)
Rate:	25 samples per second
Samples:	500
Duration:	20 seconds



Procedure

1. Using two hands, practice tossing the ball straight up. The range should be from about 0.5 m above the Distance sensor to about 1.5 m above the Distance sensor.
2. Select **Run** () to begin recording data.
3. When you hear the clicking sound of the Distance sensor, toss the ball and move your hands out of the way.
4. Catch the ball when it comes back to about 0.5 m above the Distance sensor.
5. Select **Stop** ().
6. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.

Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop**.

Graph the Kinetic Energy

1. Display a graph of the **Velocity** by taking the derivative of the distance vs time graph:
 - a. Select **Math functions** () from the **Analysis** window on the upper menu bar.
 - b. In the **Math function** window which opens, choose **Derivative** from the **Function** drop down menu.
 - c. In the **G1** drop down menu select the Distance data.
 - d. The line which is drawn on the graph represents the velocity of the cart.
2. Use the velocity data to calculate the kinetic energy of the ball:
 - a. Select **Math functions** () from the **Analysis** window on the upper menu bar.
 - b. In the **Math function** window which opens, choose **Kinetic Energy** from the **Function**

drop down menu.

- c. In the **G1** drop down menu select the calculated derivative data.
- d. In the **A** edit box, enter the value of the mass of the ball.
- e. Type KE in the **Name** edit box; type J in the **Unit** edit box.

Graph the Potential Energy

1. Use the cursor to select the Distance data:
 - a. Select **Math functions** (f_{xy}) from the **Analysis** window on the upper menu bar.
 - b. In the **Math function** window which opens, choose **Linear** from the **Function** drop down menu.
 - c. In the **G1** drop down menu select the Distance data.
 - d. In the **A** edit box, enter the result of the mass of the ball multiplied by the free fall acceleration (9.8 m/s^2).
 - e. In the **B** edit box enter 0.
 - f. Type PE in the **Name** edit box; type J in the **Unit** edit box.

Graph the Kinetic Energy and the Potential Energy vs Position

1. Change the x-axis measure by selecting the down arrow (▼) from the **Graph** toolbar and choosing Distance as your x-axis measure.
2. Use the down arrows on the y-axes on either side of the graph to choose KE as the y-axis value along one side and PE along the other.
3. Discuss the graph in terms of the transitions between potential and kinetic energy and conservation of energy.

Chapter 13

Impulse and Momentum

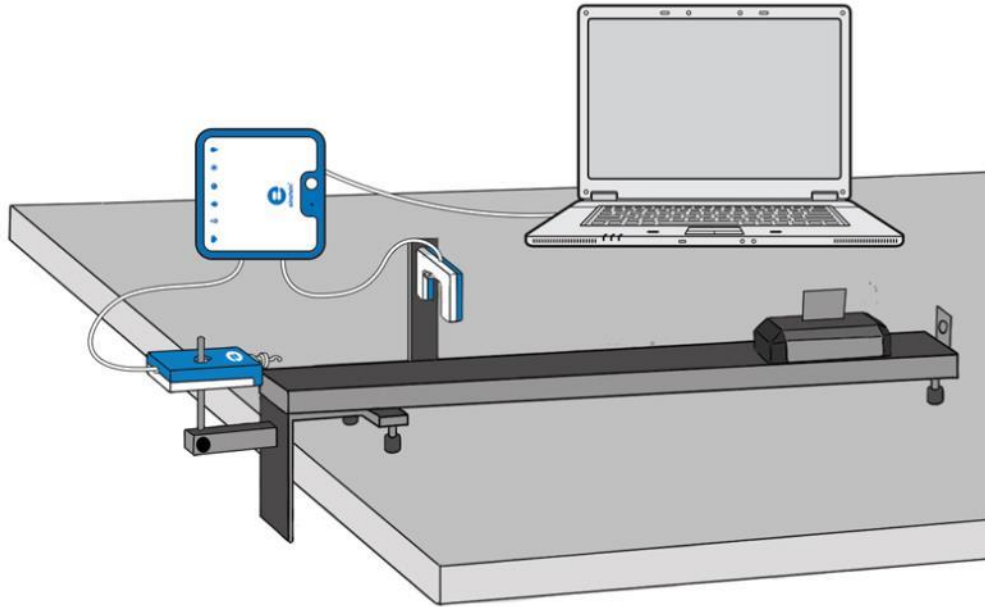


Figure 1



Introduction

Impulse is the product of a force F and the time for which it acts. Applying an impulse to a body changes its momentum. The change in momentum is equal to the magnitude of the impulse:

$$\Delta p = \int F \cdot dt \quad (1)$$

$$mv_2 - mv_1 = \int F \cdot dt \quad (2)$$

Where:

F = The force acting on the body

Δp = The change in momentum

m = The mass of the body

v_1, v_2 = The velocities of the body before and after the impulse

In this experiment a cart passes through a Photogate sensor, collides with a Force sensor and passes back through the Photogate sensor after the collision. A Photogate sensor is used to measure the velocities of the cart before and after the collision. The momentum of the cart is calculated using this measurement. The impulse is found by calculating the time integral of the force measured by the sensor. The calculated values of momentum and impulse will be compared and consistency with Equation (1) will be considered.




Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Force sensor
- Photogate sensor
- Dynamic Track
- Dynamic cart (standard, without plunger)
- Flag
- Bracket for Force sensor
- Bracket for Photogate sensor

123

Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect the Force sensor to one of the ports on the einstein™LabMate.
3. Connect the Photogate sensor to one of the ports on the einstein™LabMate.
4. Assemble the equipment as shown in Figure 1:
 - a. Mount the Force sensor at one end of the Dynamic Track using the bracket.
 - b. Mount the Photogate sensor on the Dynamic Track using the bracket. Mount the Photogate sensor near to the Force sensor but leave enough space for the flag on the cart to pass through the arms of the Photogate before colliding with the Force sensor.
 - c. Attach the flag to the top of the cart so that it is aligned with the length of the cart.
5. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Force and Photogate sensors are selected under **Measurements**.



Current Setup Summary


Program the sensor to log data according to the following setup:



Sensor (Range):	Force (± 50 N)
Measurements:	Force, Push – positive (N)
Current Reading:	Set (sets as zero)
Sensor:	Photogate
Measurements:	Photogate
Rate:	1000 samples per second
Samples:	10000
Duration:	20 seconds

Note: Make sure that only the Photogate is selected and not the Smart Pulley.



Procedure

1. Measure the mass of the cart. Record this value in your notebook.
2. Place the cart on the track on the end opposite to the Force sensor, beyond the Photogate sensor.
3. Select **Run** () to begin recording data.

4. Push the cart toward the Force sensor. Make sure that the initial push is strong. The cart must rebound with enough force to pass back through the arms of the Photogate sensor so that its velocity after the collision can be calculated.
5. After the cart has passed back through arms of the Photogate sensor, select **Stop** ().
6. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.

Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop**.

1. See Figure 2 for sample data from this experiment. The two rectangles represent the time when the flag on the cart passed through the Photogate sensor. The narrow peak at the center of the screen is the force measured by the Force sensor.

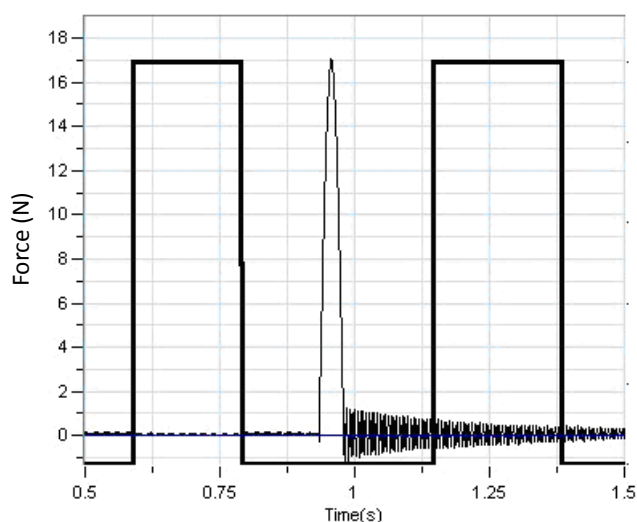

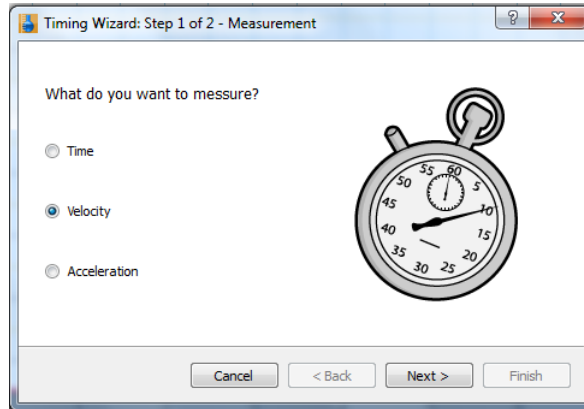
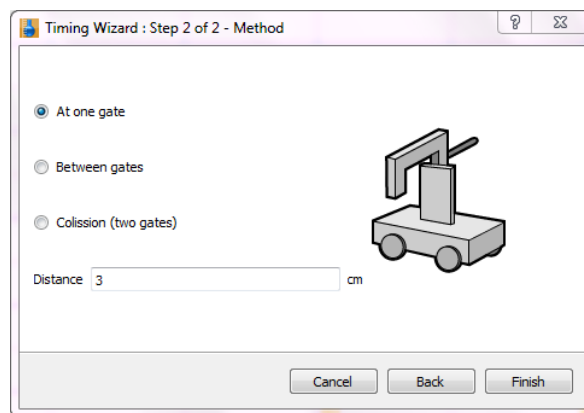


Figure 2

2. Calculate the change in momentum before and after the collision using data from the Photogate sensor:
 - a. You can use the **Timing Wizard** to calculate the velocity of the cart both before and after the collision.
 - i. Select **Photogate** () from the **Analysis** menu on the upper toolbar to open the **Timing wizard** window.



- ii. Select **Velocity** and click **Next**.



- iii. Select **At one gate**.
- iv. Enter the width of the flag (in cm) in the Distance text box.
- v. Select **Finish** and the **Timing Wizard** will return the values of the velocities of the cart, before and after the collision.
- b. Multiply the velocities by the mass m of the cart to calculate the momentum before and after the impulse:


$$p_1 = mv_1 ; p_2 = mv_2$$

- c. Calculate the difference in momentum:

$$\Delta p = p_2 - p_1$$

- d. Record this value in your notebook.

3. Calculate the impulse:

- a. Zoom in on the portion of the force vs time graph during which the impact occurred using the **Zoom** tool () on the **Graph** toolbar (see Figure 3).

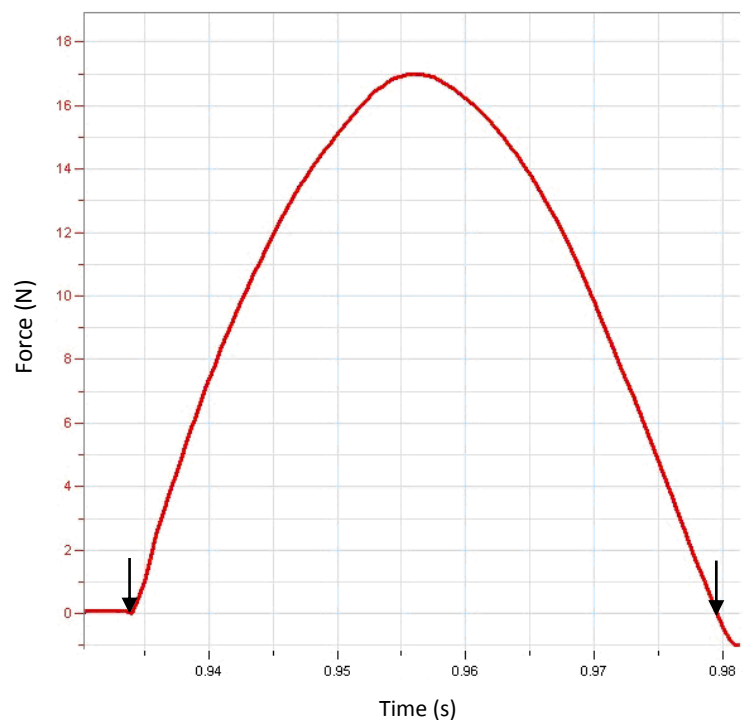




Figure 3

- b. Select **two cursors** () from the **Graph** toolbar; place the first cursor at the point when the force started acting and the second cursor at the point on the graph when the force stopped acting on the cart (see Figure 3).
 - c. Select **Area** () from the **Analysis** menu on the upper toolbar. MiLAB desktop will evaluate the area under the selected curve and display the area in the bottom left-hand corner of the graph.
 - d. Record the area in your notebook. This is the impulse. What are the impulse units?
4. Compare the amount of impulse to the change in momentum. What are your conclusions?



Further Suggestions

1. The surface of the cart that collides with the Force sensor may be covered with different materials (cardboard, rubber, different metals or plastics). This will cause changes in the shape of the graph describing the impulse: the duration and the maximum force may change. Does the change of momentum still equal the impulse?
2. Use the plunger cart which has a spring-loaded plunger on one end. Orient the cart so that the spring-loaded plunger collides with the Force sensor. This too will alter the shape of the graph. Does the change of momentum still equal the impulse?

Chapter 14

Hooke's Law: Finding the Spring Constant

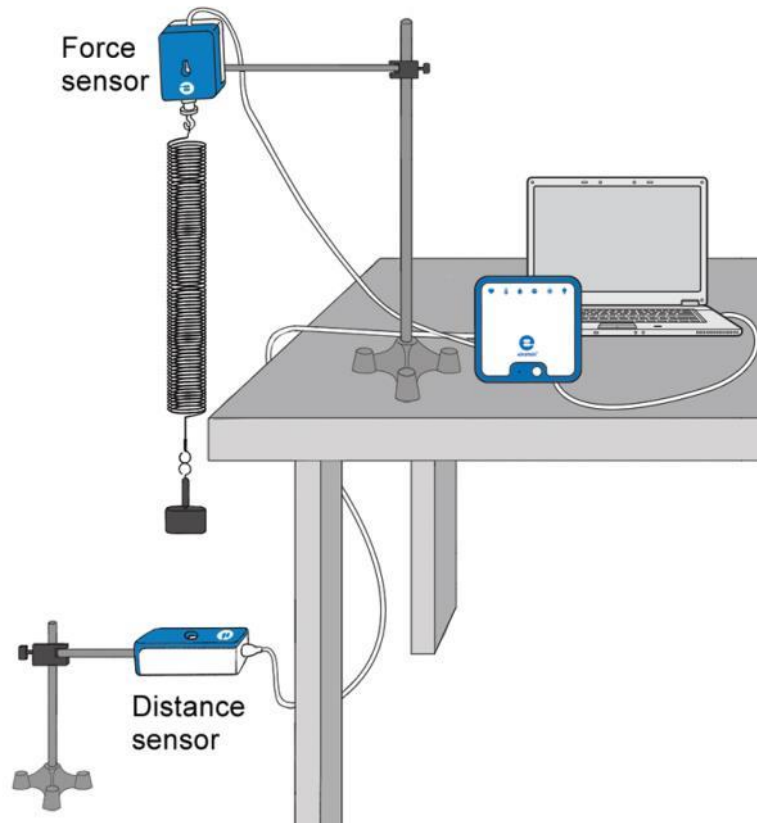


Figure 1

Introduction

When we apply a force to a spring, it stretches or compresses. The spring's extension or compression is proportional to the applied force:

$$F = kx \quad (1)$$

Where:

F = The applied force

K = The spring constant

X = The spring's displacement

This law is known as Hooke's Law. It enables us to use the extension or compression of the spring to measure force.

In this experiment we will use the Force sensor and the Distance sensor to calibrate a spring for use as a dynamometer (force meter).



Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Force sensor
- Distance sensor
- Distance adaptor
- Spring (~15 N/m)
- Slotted mass set
- Slotted mass hanger
- Stand and supporting rod (2)
- Clamp with hook to hang the spring



Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect the Distance sensor with the Distance adaptor to one of the ports on the einstein™LabMate.
3. Connect the Force sensor to one of the ports on the einstein™LabMate.
4. The distance between the two sensors should be about 70 cm.
1. Assemble the equipment as shown in Figure 1.
 - a. Make sure there are no physical obstacles between the hanging mass and the Distance sensor.
 - b. Use a mass of 100 g.
 - c. The distance between the mass and sensor should be about 70 cm.
5. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Distance and Force sensors are selected under **Measurements**.



Current Setup Summary



Program the sensor to log data according to the following setup:

Sensor:	Distance
Measurements:	Distance (m)
Sensor (Range):	Force (± 10 N)
Measurements:	Force, Pull – positive (N)
Current Reading:	Set (sets as zero)
Rate:	10 samples per second
Samples:	1000
Duration:	1 minute 40 seconds



Procedure

1. Make sure that the hanging mass is at rest.
2. Select **Run** () to begin recording data.
3. Wait 20 seconds and then add a weight of 50 g to the hanging mass so that the total mass is now 150 g. Bring the mass to rest.

4. Wait another 20 seconds then add another mass of 50 g and bring the mass to rest.
5. Repeat step 4 and increase the hanging mass by amounts of 50 g until you reach 500 g
6. When you have added 500 g to the spring, select **Stop** ().
7. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.
8. Use two cursors to determine the spring's extension for each hanging mass. Record these values in the data table.

Data Table

Hanging Mass (g)	Applied Force (N)	Extension (m)



Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop**.

1. What was the force applied to the spring when the hanging mass was 100 g?
2. Use data from the Force sensor to fill in the Applied Force column in the data table, recording force in units of Newtons.
3. Use data from the Distance sensor to fill in the Extension column in the data table, recording extension in units of meters.
4. Plot a graph of the applied force versus the spring's extension.
5. Fit a straight line to your data points that passes through the origin.
6. What are the units of the slope?
7. Use the graph to calculate the spring constant, k .

Chapter 15

Simple Harmonic Motion

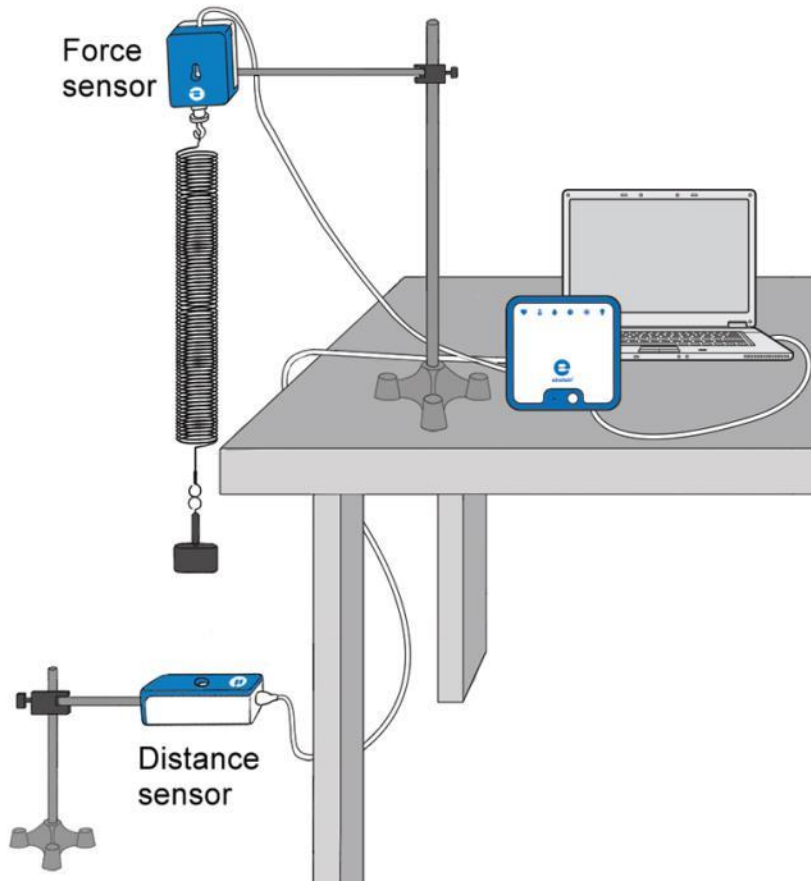


Figure 1

Introduction

When a force acting on a body is directly proportional to the displacement of that body from its resting (equilibrium) position and when this force is in the opposite direction of the displacement from the resting position, then the body will move with what it called simple harmonic motion. Simple harmonic motion is a type of periodic motion.

A spring with a mass attached can be used to observe simple harmonic motion. When the spring and the mass are held vertically so that gravity pulls the mass toward the ground, the end of the spring is displaced toward the ground. A restoring force will act to pull the spring and the mass attached back toward the resting position according to Hooke's Law.

The relation of the force F to the displacement x from the equilibrium position is:

$$F = -kx \quad (1)$$

Where:

k = The spring constant

The spring with the mass will move up and down periodically. The motion is described by the following equation:

$$x = A \cos 2\pi f t \quad (2)$$

Where:

A = The amplitude of the motion

f = The frequency of the motion

The period of the motion is the amount of time it takes to repeat the period of motion once. It is related to the spring constant and the size of the mass (m , measured in kg):

$$T = 2\pi \sqrt{\frac{m}{k}} \quad (3)$$

and can also be expressed as the inverse of the frequency of the motion:

$$T = \frac{1}{f} \quad (4)$$

In this experiment we examine the motion of a mass attached to a spring and oscillating vertically. The force acting on the spring and the position of the mass are measured simultaneously.




Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Force sensor
- Distance sensor
- A mass attached to a spring (the frequency of the oscillation should be 0.5-2 Hz and the amplitude should be 5-20 cm)
- 1 kg mass (2)
- Stand with a clamp to hold the force sensor and the spring
- Stand with a clamp to hold the distance sensor
- C-clamp to clamp the stand to the counter
- Meter stick
- 1 large 5cm x 8cm index card
- Balance to measure the mass



Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect the Force sensor to one of the ports on the einstein™LabMate.
3. Connect the Distance sensor to one of the ports on the einstein™LabMate.
4. Assemble the equipment as shown in Figure 1:
 - a. Hang the spring from the Force sensor.
 - b. Carefully attach the 1 kg mass to the spring.
 - c. Place the Distance sensor directly beneath the mass. When the spring is fully extended, the mass and the Distance sensor must be at least 40 cm apart.
5. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the

experiment. Make sure that only the Force and Distance sensors are selected under **Measurements**.



Current Setup Summary

Program the sensor to log data according to the following setup:




Sensor (Range):	Force (± 50 N)
Measurements:	Force, Pull – positive (N)
Current Reading:	Set (sets as zero)
Sensor:	Distance
Measurements:	Distance (m)
Rate:	25 samples per second
Samples:	1000
Duration:	40 seconds



Procedure

- Using a meter stick and two known masses, measure the spring constant k :
 - Place a 1 kg mass of the end of the spring. Gently let it come to rest. (Do not allow the spring to oscillate).
 - When the spring comes to its resting (equilibrium) position, use the meter stick to measure the distance between the floor and the bottom of the 1 kg mass. Record this distance.
 - Put an additional 1 kg mass on the spring and let it come gently to rest. (Do this carefully!) When the spring comes to its equilibrium position, use the meter stick to measure the distance between the floor and the bottom of the first 1 kg mass used. Find the difference in the spring extensions measured.


Note: It is necessary to measure to the bottom of the first 1 kg mass in order to determine the distance the spring stretched. Measurements should always be taken relative to the same point on the first mass.

- Calculate and record the change in Force, ΔF , using Newton's second law of motion $F = ma$. In the case of using two 1 kg masses, this is given by $1 \text{ kg} \times 9.8 \text{ m.s}^{-2}$.
 - Calculate the spring constant k using Hooke's Law $F = kx$. Divide the change in force ΔF by the change in displacement, Δx , of the first 1 kg mass after the second 1 kg mass was added.
- Using a 1 kg mass, measure the period of oscillation (T) of the mass on the end of the spring:
 - Place the 1 kg mass on the end of the spring, suspended above the Distance sensor.
 - Attach the 5 cm x 8 cm index card to the bottom of the mass so that the broad side of the card is facing the Distance sensor. Gently pull the 1 kg mass down and let go. It will oscillate up and down.
 - Select **Run** () to begin recording data.
 - After about 15 oscillations, select **Stop** ().
 - Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.





Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop**.

- Working with either the Force curve or the Distance curve, measure the period of oscillation by using **two cursors** () from the **Graph** toolbar. Put the first cursor on the first peak and the second cursor on the 11th peak. Record the value of Δt , which will appear in the text box on the graph as Δx . The period, T , will be $\Delta t/10$. Record this value of T .
- Calculate the spring constant k using the period of oscillation and the following rearrangement of Equation (3):

$$k = \frac{4\pi^2 m}{T^2}$$

- Compare the values of k which you measured using two different methods.
- Create a graph of force vs distance by selecting the down arrow () from the **Graph** toolbar and choosing distance as your x -axis measure.
- Fit a straight line to the resulting graph:
 - Select **Curve fit** () from the **Analysis** window on the upper menu bar.
 - In the **Curve fit** window which opens, choose **Linear** from the **Curve fit** drop down menu.
 - The linear fit will appear on the graph and the fit equation will be displayed below the x -axis. From Equation (1), the slope of this graph is the spring constant k .
 - Compare this value of k with those calculated previously.

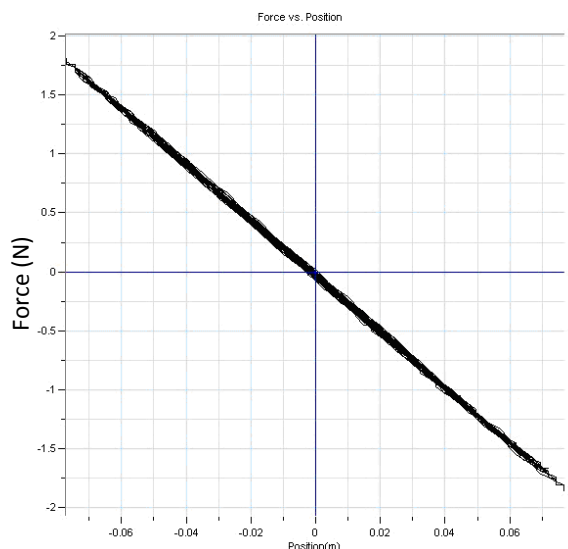


Figure 2



Further Suggestions

- Measure the period of oscillation with a 2 kg mass and calculate the spring constant k .
- Explore the relationship of the velocity to the distance:
 - Use the distance sensor to measure the velocity of the oscillating spring.
 - Calculate the amplitude, A for the maximum velocity:

$$V_{max} = \frac{2\pi}{T} A$$

Chapter 16

Energy in Simple Harmonic Motion

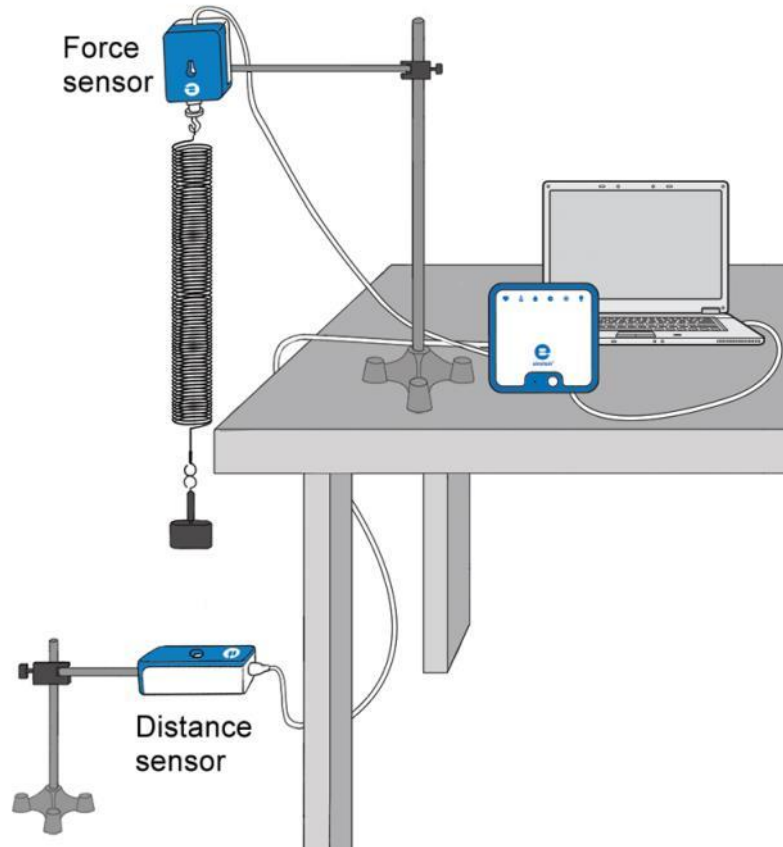


Figure 1

Introduction

The motion of a mass suspended from a spring is a motion under conservative forces: gravitational and elastic.

The kinetic energy is given by:

$$KE = \frac{1}{2}mv^2 \quad (1)$$

Where:

m = The mass of the suspended body

v = The velocity of the suspended body

The potential energy is given by:

$$PE = \frac{1}{2}kx^2 \quad (2)$$

Where:

k = The spring constant

x = The position of the suspended body as measured from the equilibrium point

The principle of conservation of the mechanical energy implies that:

$$E = KE + PE \quad (3)$$

Where:

E = A constant that represents the total mechanical energy of the system




Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Distance sensor
- Spring (~15 N/m)
- Slotted mass set
- Slotted mass hanger
- Stand and supporting rod
- Clamp with hook to hang the spring
- C-clamp to clamp the stand to the counter



Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect the Distance sensor to one of the ports on the einstein™LabMate.
3. Assemble the equipment as shown in Figure 1:
 - a. Make sure that there are no physical obstacles between the hanging mass and the Distance sensor.
 - b. Use a mass of 200 g.
 - c. The distance between the hanging mass and the Distance sensor should be about 60 cm.
4. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Distance sensor is selected under **Measurements**.



Current Setup Summary

Program the sensor to log data according to the following setup:





Sensor:	Distance
Measurements:	Distance (m)
Rate:	10 samples per second
Samples:	2000
Duration:	3 minutes 20 seconds



Procedure

The Spring Constant

1. Make sure that the hanging mass is at rest.

2. Select **Run** () to begin recording data.
3. Add a 400 g mass to the hanging mass so that the total mass is now 600 g.
4. Bring the hanging mass to rest, wait until the reading stabilizes, and then select **Stop** ().
5. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.
6. Use **two cursors** () from the **Graph** toolbar to determine how much the spring was stretched after adding the 400 g mass.
7. Calculate k , the spring constant, using Hooke's Law ($F = kx$) and the gravitational force on the hanging mass, m ($F = mg$):



$$k = \frac{\Delta mg}{\Delta l} \quad (4)$$

Where:

Δl = The displacement of the spring

8. Record this value in your notebook.

Energy in Simple Harmonic Motion



1. Make sure that the hanging mass is at rest.
2. Select **Run** () to begin recording data.
3. Lift the mass about 5 cm above the equilibrium position and release.
4. After 20 seconds select **Stop** ().



Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop.**

Plot a Graph of Potential Energy - $PE = \frac{1}{2}k(x-x_0)^2$

1. Use the cursor to find the equilibrium position of the spring x_0 . This is the position of the spring before the oscillations. Record the value of x_0 in your notebook.
2. Create a graph of the displacement of the spring ($x-x_0$) as it changes over time with the oscillations:
 - a. Select **Math functions** () from the **Analysis** window on the upper menu bar.
 - b. In the **Math function** window which opens, choose **Linear** from the **Function** drop down menu.
 - c. In the **G1** drop down menu select the Distance data.
 - d. In the **A** edit box, enter the negative of the equilibrium position, $-x_0$.
 - e. Enter *Displacement* in the **Name** edit box and *m* in the **Unit** edit box.
3. Create a graph of the potential energy as it changes over time with the oscillations:
 - a. Select **Math functions** () from the **Analysis** window on the upper menu bar.
 - b. In the **Math function** window which opens, choose **Quadratic** from the **Function** drop down menu.
 - c. In the **G1** drop down menu select the displacement data which you calculated in the previous step.
 - d. In the **A** edit box, enter $\frac{1}{2}k$, that is, half the value of the spring constant.
 - e. In the **B** and **C** edit boxes, enter 0.
 - f. Enter *PE* in the **Name** edit box and J in the **Unit** edit box.
 - g. Hide the Linear function and the Distance graph. The PE graph should be displayed.

Plot a Graph of Kinetic Energy - $KE = \frac{1}{2}mv^2$

1. Open a new graph window and display the original distance graph.

2. Create a graph of the velocity of the spring, v , as it changes over time with the oscillations:
 - a. Select **Math functions** (f_{xy}) from the **Analysis** window on the upper menu bar.
 - b. In the **Math function** window which opens, choose **Derivative** from the **Function** drop down menu.
 - c. In the **G1** drop down menu select the Distance data.
 - d. Enter *Velocity* in the **Name** edit box and m/s in the **Unit** edit box.
3. Create a graph of the kinetic energy as it changes over time with the oscillations:
 - a. Select **Math functions** (f_{xy}) from the **Analysis** window on the upper menu bar.
 - b. In the **Math function** window which opens, choose **Kinetic Energy** from the **Function** drop down menu.
 - c. In the **G1** drop down menu select the velocity data which you calculated in the previous step.
 - d. In the **A** edit box, enter the mass of the weight, m .
 - e. Enter *KE* in the **Name** edit box and J in the **Unit** edit box.

Display the Graphs of Kinetic Energy and Potential Energy as a Function of Position

1. Change the x -axis measure by selecting the down arrow (▼) from the **Graph** toolbar and choosing Distance as your x -axis measure.
2. Display the calculated graphs of *PE* and *KE* as a function of position. Use the down arrows (▼) on the upper right and upper left to choose the y -axis scale which corresponds to *PE* and *KE*.
3. Calculate the total energy of the system and display this value on the graph:
 - a. Select **Math functions** (f_{xy}) from the **Analysis** window on the upper menu bar.
 - b. In the **Math function** window which opens, choose **Add** from the **Function** drop down menu.
 - c. In the **G1** drop down menu select *PE*.
 - d. In the **G2** drop down menu select *KE*.
 - e. Enter *Total Energy* in the **Name** edit box and J in the **Unit** edit box.
4. Discuss the graph in terms of the transitions between potential and kinetic energy and conservation of energy.

Chapter 17

Simple Pendulum

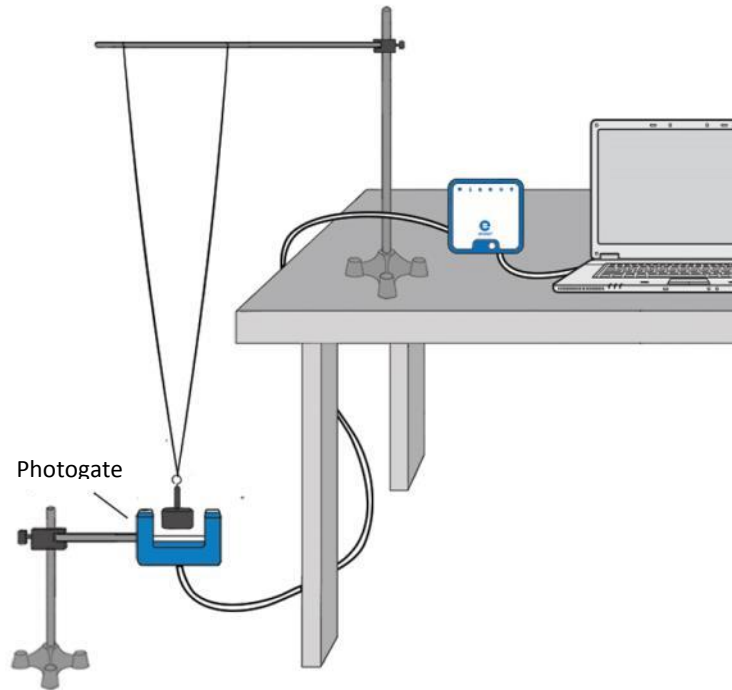


Figure 1



Introduction

The period of a pendulum is given by:

$$T = 2\pi \sqrt{\frac{\ell}{g}} \quad (1)$$

Where:

ℓ = The length of the pendulum

g = The acceleration due to gravity


In this experiment we will use a Photogate to explore Equation (1).



Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Photogate sensor
- Weight (~200 g)
- String
- Stand (2)
- Pendulum clamp
- Meter stick

123 Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect the Photogate sensor to one of the ports on the einstein™LabMate.
3. Connect the Distance sensor to one of the ports on the einstein™LabMate.
4. Assemble the equipment as shown in Figure 1:
 - a. Use one stand to hang the mass from two strings. Attach the strings to a horizontal rod and space them about 10 cm apart, as shown in Figure 1. This arrangement will let the mass swing only along a line, and will prevent the mass from striking the Photogate sensor. The length of the pendulum is the distance from the point on the rod halfway between the strings to the center of the mass. The pendulum length should be at least 1 m long.
 - b. Attach the Photogate sensor to the second stand. Position it so that the mass blocks the Photogate's light beam while hanging straight down.
5. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Photogate sensor is selected under **Measurements**.





Current Setup Summary

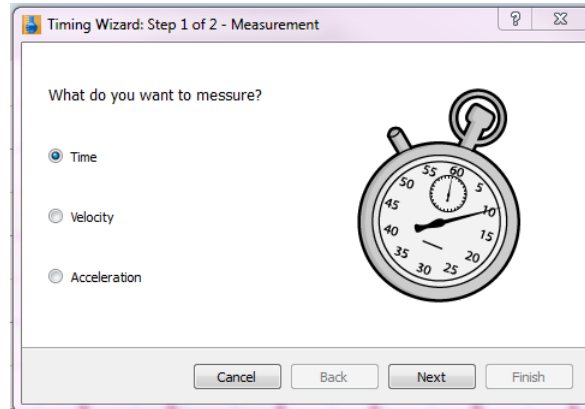
Program the sensor to log data according to the following setup:

Sensor:	Photogate
Measurements:	Photogate
Rate:	100 samples per second
Samples:	1000
Duration:	10 seconds

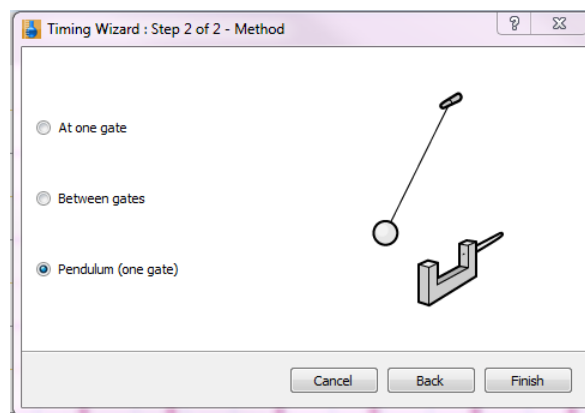
Note: Make sure that only the Photogate is selected and not the Smart Pulley.

Procedure

1. Measure the length of the pendulum. Record the length in the data table.
2. Pull the mass to the side about 10° from vertical and release.
3. Select **Run** () to begin recording data.
4. After 10 seconds select **Stop** ().
5. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.
6. You can use the **Timing Wizard** to calculate the period of the pendulum.
 - a. Select **Photogate** () from the **Analysis** menu on the upper toolbar to open the **Timing wizard** window.



- b. Select **Pendulum (one gate)**.



- c. Select **Finish** and the **Timing Wizard** will return the values of the period of motion.
- d. Record this value in your data table.
7. Repeat your measurement as above and record the results in your data table.
8. Repeat steps 1 to 6 for various pendulum lengths. Change the length of the pendulum in steps of 10 cm, from 1.0 m to 0.50 m.

Data Table

Length (m)	Period (s) -Trial 1	Period (s) – Trial 2	Average Period (s)



Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop**.

1. Plot a graph of the square of the period (T^2) vs. the pendulum's length (ℓ).
2. Does the graph agree with the relation in Equation (1)?
3. Fit a straight line to your data points that passes through the origin.
4. Determine the slope of the linear fit and use it to calculate the value of the acceleration due to gravity, g .



Further Suggestions

1. Explore the pendulum's period versus the pendulum's amplitude.
2. Explore the pendulum's period versus the pendulum's mass.

Chapter 18

Physical Pendulum

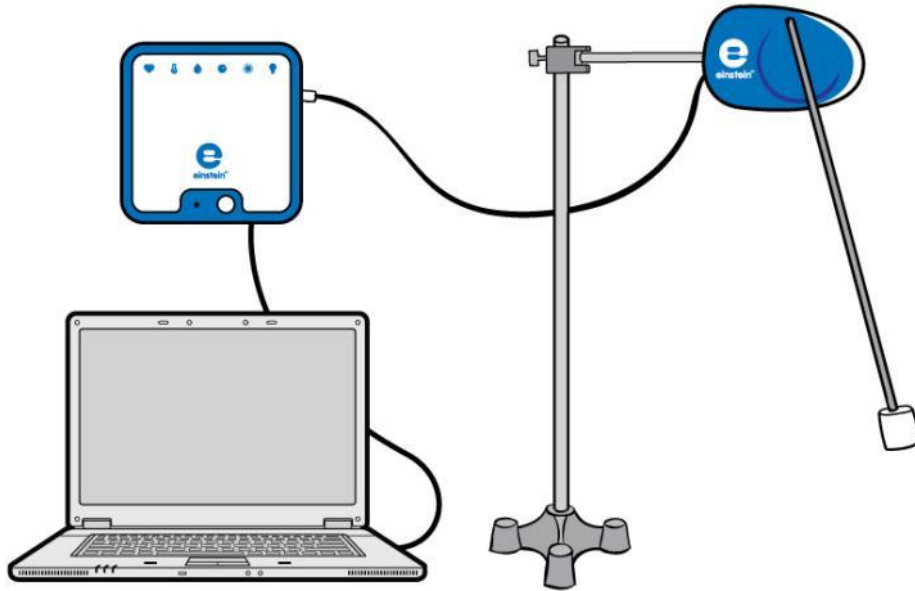


Figure 1



Introduction

In this experiment we explore the oscillations of a pendulum. We use the Rotary Motion sensor to measure the angular position of the pendulum.

The period of a point pendulum is given by:

$$T = 2\pi \sqrt{\frac{\ell}{g}} \quad (1)$$

Where:

ℓ = The length of the pendulum

g = The acceleration due to gravity

We will use a pendulum that is made of a rigid metal rod with a cylindrical weight attached to the rod's end (see Figure 1). If the weight is much heavier than the rod, the point pendulum approximation is good. If not, we must consider the physical pendulum where the period is given by:

$$T = 2\pi \sqrt{\frac{I}{mg\ell}} \quad (2)$$

Where:

m = The mass of the pendulum

I = The moment of inertia of the pendulum

The moment of inertia of the pendulum is the sum of the moment of inertia of the rod (which is pivoting about an axle which is at the end of the rod) and the moment of inertia of a point mass (the weight):

$$I = \frac{m_1 \ell^2}{3} + m_2 \ell^2 \quad (3)$$

Where:

m_1 = The mass of the rod

m_2 = The mass of the weight



Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Rotary motion sensor
- Weight (~200 g)
- Steel rod
- Stand
- Pendulum clamp



Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect the Rotary Motion sensor to one of the ports on the einstein™LabMate.
3. Assemble the equipment as shown in Figure 1.
4. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Photogate sensor is selected under **Measurements**.



Current Setup Summary

Program the sensor to log data according to the following setup:

Sensor:	Rotary Motion
Measurements:	Rotary Motion
Rate:	25 samples per second
Samples:	1000
Duration:	40 seconds




Procedure

1. Measure the mass of the rod. Record this value in your notebook.
2. Measure the mass of the weight. Record this value in your notebook.
3. Measure the length of the pendulum. Record this value in your notebook.
4. Select **Run** () to begin recording data.
5. Raise the pendulum and allow it to swing downwards and continue with this motion back and forth.
6. After 40 seconds select **Stop** ().
7. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.

Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop.**

1. Zoom in on the graph using the **Zoom** tool () on the **Graph** toolbar to display four or five periods of the oscillation (see Figure 2 below).

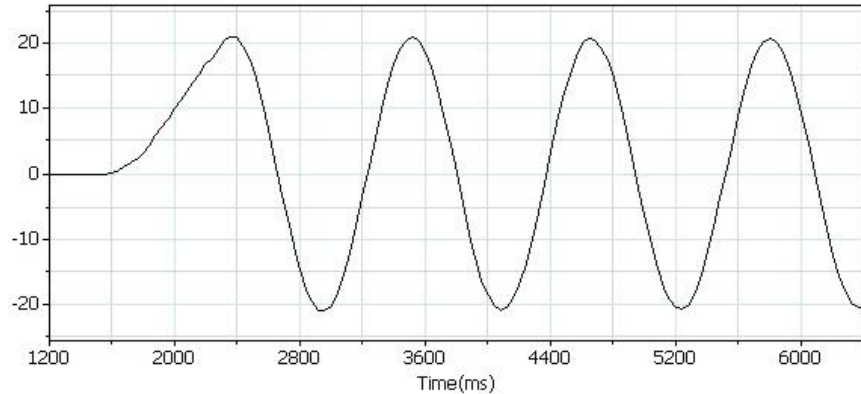



Figure 2

2. Use the cursors to measure the period T and the frequency f of the oscillations. Record these values in your notebook.
3. Use Equation (3) in the introduction to calculate the moment of inertia of the pendulum.
4. Use Equations (1) and (2) in the introduction to calculate the pendulum's period. Compare the results with the measured period. Is the point pendulum approximation appropriate in this case?
5. Apply a **Fourier Transform** to the data:
 - a. Select **Math functions** () from the **Analysis** window on the upper menu bar.
 - b. In the **Math function** window which opens, choose **Fourier Transform** from the **Function** drop down menu.
 - c. In the **G1** drop down menu select the angle data.
6. The peak on the Fourier Transform graph appears at the frequency of the pendulum.

Fourier Transform :

Every periodic phenomenon that we sample can be transformed from the time domain (time along the x-axis) to the frequency domain (frequency along the x-axis). The Fourier transform presents the data as one or more peaks appearing at the frequency of the periodic phenomenon.

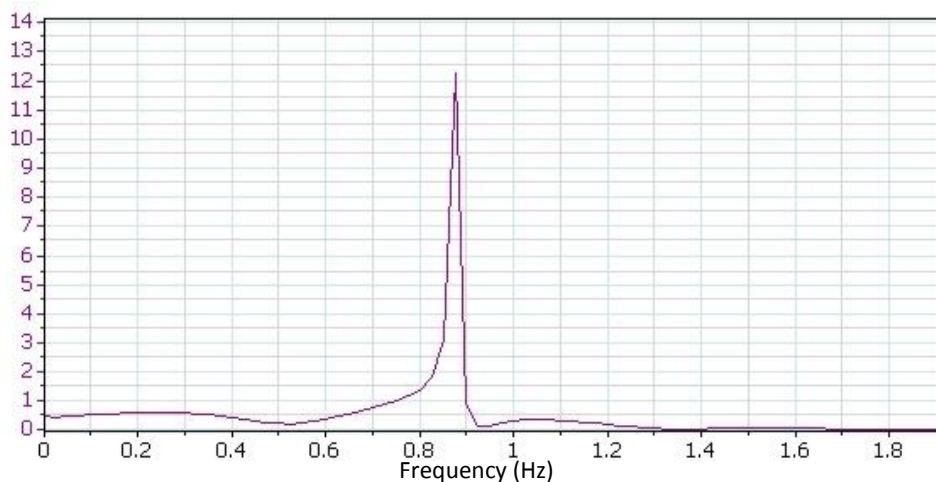


Figure 3

7. Use the cursor to read the frequency value of the main peak from the Fourier transform and see if it matches the frequency you measured in step 2.
8. Create a graph of the angular velocity:
 - a. Display the original graph.
 - b. Select **Math functions** (f_{∞} +) from the **Analysis** window on the upper menu bar.
 - c. In the **Math function** window which opens, choose **Derivative** from the **Function** drop down menu.
9. Explore the relationship of the velocity to the position: Display a graph of the angular velocity vs. angle.
 - a. Change the x-axis measure by selecting the down arrow (▼) from the **Graph** toolbar and choosing Angle as your x-axis measure.
 - b. Display angular velocity along the y-axis by using the down arrow (▼) on the top right or top left of the graph to make the selection.

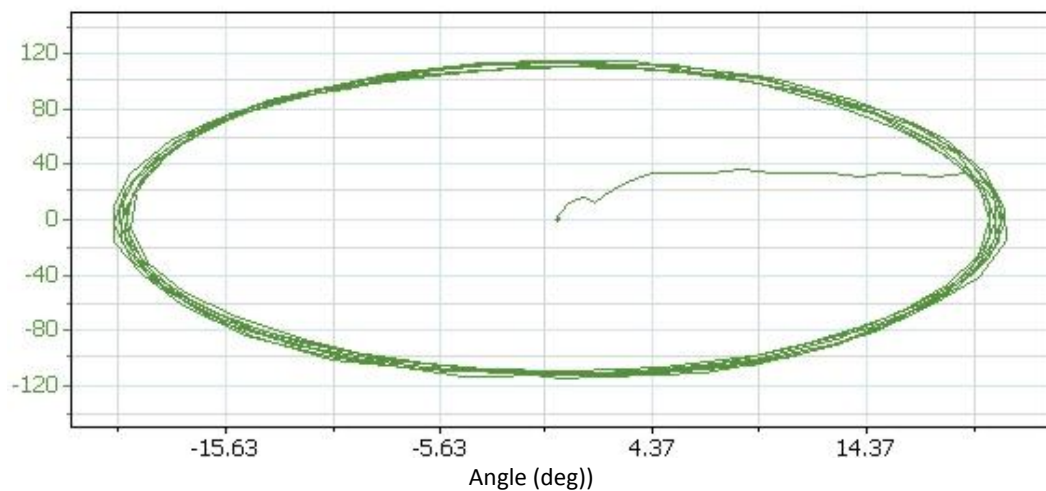


Figure 5



Further Suggestions

Investigate the motion of a pendulum moving through wide angles (more than 90°). Is it now harmonic motion?

Chapter 19

Specific Heat

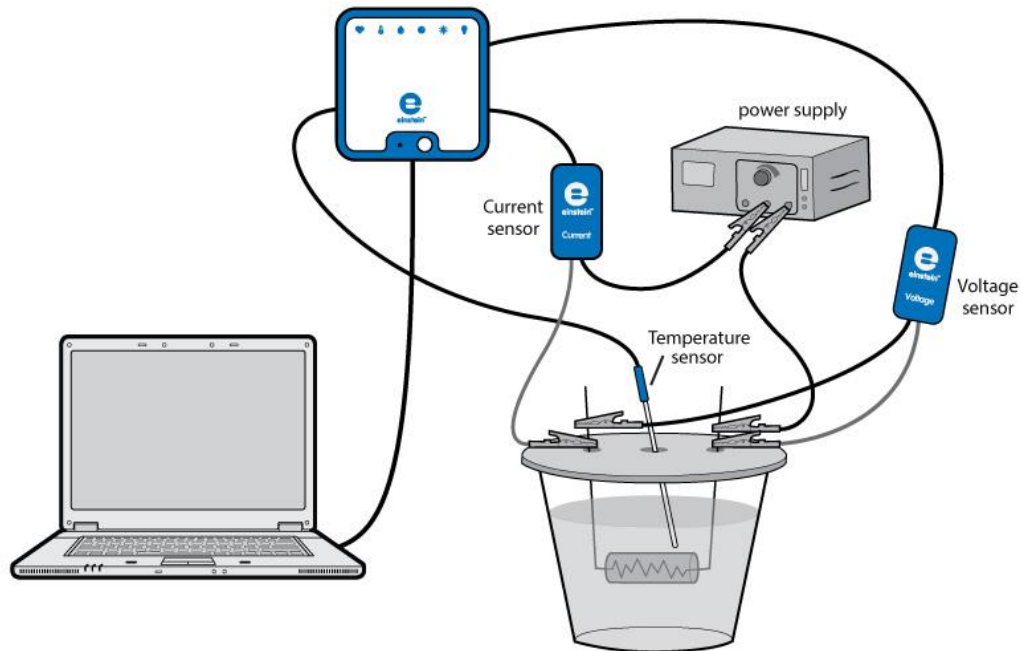


Figure 1



Introduction

The specific heat is the amount of heat per unit mass required to raise the temperature of a substance by one degree Celsius. The relationship between heat and temperature change is expressed as:

$$Q = mc\Delta T \quad (1)$$

Where:

Q = The amount of heat added or removed

m = The mass of the heated substance

c = The specific heat

ΔT = The temperature change

This relationship does not apply if a phase change is encountered, because the heat added or removed during a phase change does not change the temperature.

In this experiment we will determine the specific heat of water. We will heat the water by passing current through an electric resistor immersed in the water. The energy dissipated by the resistor as heat is given by:

$$Q = VI\Delta t \quad (2)$$

Where:

V = The voltage drop across the resistor

I = The current through the resistor

Δt = The heating time

The known value of the specific heat of water is 1 calorie/gram °C = 4.186 joule/gram °C




Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Temperature sensor (-40 °C to 140 °C)
- Current sensor (± 2.5 A)
- Voltage sensor (± 25 V)
- Polystyrene cup
- Plexiglas plate to use as a cover to the polystyrene cup, with two small holes for the resistor's legs and another hole for the temperature sensor.
- Power supply (6 V, 2 A)
- Resistor ($5\ \Omega$, 10 W)
- Two alligator clips
- Wires



Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect the Temperature sensor to one of the ports on the einstein™LabMate.
3. Connect the Current sensor to one of the ports on the einstein™LabMate.
4. Connect the Voltage sensor to one of the ports on the einstein™LabMate.
5. Fill the polystyrene cup with 40 mL of water. Measure the volume of water you are using or measure its mass.
6. Assemble the setup as shown in Figure 1 and Figure 2:
 - a. Bend the two legs of the resistor and pass them through the two small holes in the cup's cover.
 - b. Hold the legs in place with the two alligator clips as shown in Figure 1. Place the cover on the cup. The resistor must be immersed in the water.
 - c. Insert the Temperature sensor through the third hole on the cover. The probe's tip should be immersed in the water as shown in Figure 1.
7. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Temperature, Current and Voltage sensors are selected under **Measurements**.

Assemble the setup as shown in Figure 1:

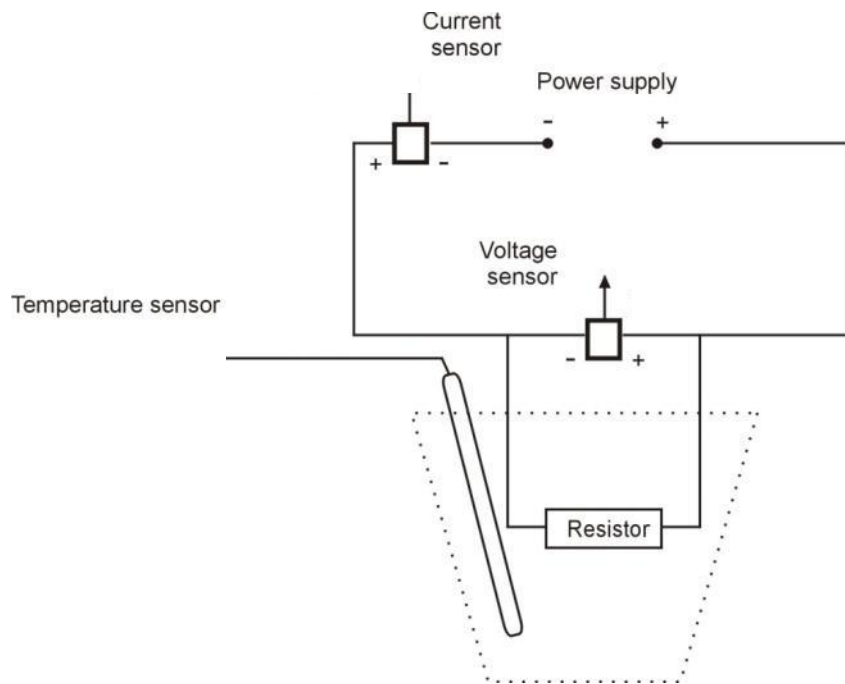


Figure 2



Current Setup Summary




Program the sensors to log data according to the following setup:

Sensor:	Temperature (-40 °C – 140 °C)
Measurements:	Temperature (°C)
Sensor:	Current (± 2.5 A)
Measurements:	Current (A)
Current Reading:	Set (sets as zero)
Sensor:	Voltage (± 25 V)
Measurements:	Voltage (V)
Current Reading:	Set (sets as zero)
Rate:	Every second
Samples:	500
Duration:	8 minutes 20 seconds

Note: Make sure that only the external Temperature sensor (-40 °C – 140 °C) is selected and not the internal Temperature sensor (-30 °C – 50 °C).






Procedure

1. Select **Run** () to begin recording data.
2. Switch the power supply to 6V DC and turn it on.
3. Observe the graph.
4. After 6 minutes select **Stop** ().
5. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.



Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop**.

1. What is the mass of the water that you have poured into the cup? Record the mass in your notebook and explain how you determined this number (by measurement or by calculation?).
2. Use the cursor () to read the value of the voltage. Record this value in your notebook.
3. Use the cursor () to read the value of the current. Record this value in your notebook.
4. Looking at the temperature graph, what can you say about the relationship between the amount of heat transferred to the water and the temperature change which occurred?
5. Use both cursors () to mark two points on the temperature graph. Make sure to select two points where the temperature is increasing. Record the time difference and the temperature difference between the two points in your notebook.
6. Use Equation (2) to calculate the amount of heat dissipated by the resistor. Record this value in your notebook.
7. Use Equation (1) to calculate the specific heat of water. Record this value in your notebook.
8. Compare the value that you have just calculated with the known value (see Introduction).



Further Suggestions

Repeat the experiment with 80 mL of water and compare the slopes of the two graphs.

Chapter 20

Boyle's Law

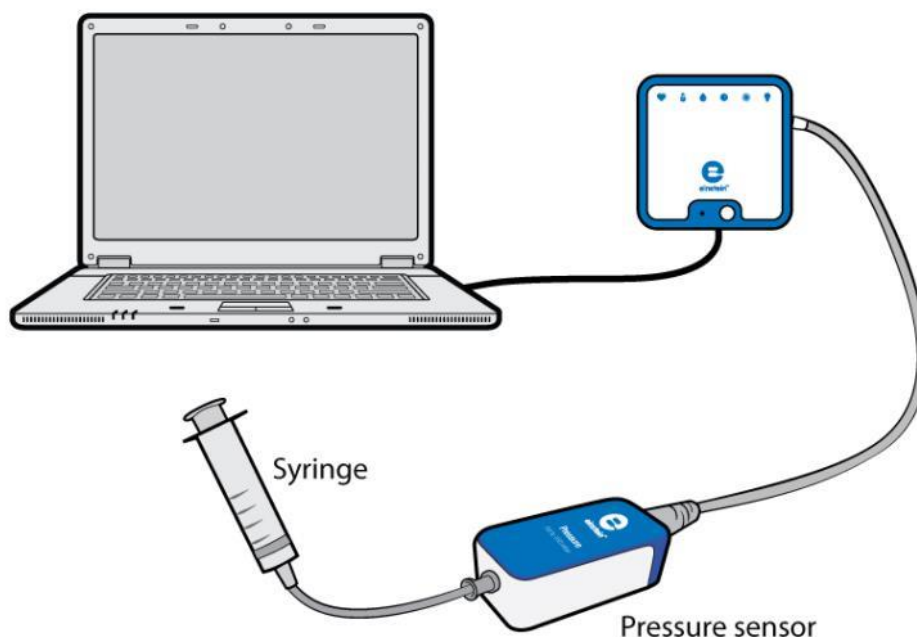


Figure 1



Introduction

Boyle's law states that at constant temperature, the pressure of a given mass of a dry gas is inversely proportional to its volume:

$$P \propto \frac{1}{V} \quad (1)$$

Where:

P = The pressure

V = The volume of the gas


In this experiment we will vary the volume of air in a syringe and measure the pressure in the syringe, with the Pressure sensor connected directly to the syringe.



Equipment

- einstein™ LabMate and a computer with MiLAB Desktop
- Pressure sensor (150 to 1150 mbar)
- Syringe (50 mL)

123 Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect the Pressure sensor to one of the ports on the einstein™LabMate.
3. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Pressure sensor is selected under **Measurements**.







Current Setup Summary

Program the sensor to log data according to the following setup:

Sensor:	Pressure (150 to 1150 mbar)
Measurements:	Pressure (kPa)
Sampling:	Manual
Samples:	50

Note: Ensure that only the external Pressure sensor (150 – 1150 mbar) is selected and not the internal Pressure sensor (0 – 400 kPa).

Procedure

1. Pull out the syringe's plunger to the 50 mL mark in order to fill the syringe with air.
2. Connect the Pressure sensor directly to the syringe's nozzle (see Figure 1).
3. Measure the length of the pendulum. Record this value in your notebook.
4. Select **Run** () to begin recording data.
5. Collect the data manually: Select **Manual Sampling** () each time you wish to record a data sample.
6. Select **Manual Sampling** () to measure the initial pressure.
7. Set the syringe to a volume of 45 mL, then Select **Manual Sampling** ().
8. Repeat step 7 for syringe volumes of 40 mL, 35 mL, 30 mL, 25 mL and 20 mL.
9. Select **Stop** () to stop collecting data.
10. Select **Export** () from the **Graph** toolbar to save the data as a csv file.

Data Analysis

1. Open the exported data in a suitable spreadsheet or graphing program).
2. Add a column to the data and enter the volume corresponding to each measurement of pressure (see Figure 2).

	Samples	Exp. 12-Pressure I/O-1	Edited data-Volume(mL)
1	0	99.29	50
2	1	112.14	45
3	2	123.57	40
4	3	142.14	35
5	4	165	30
6	5	199.29	25
7	6	241.43	20

Figure 2

3. Create a new column in which you will calculate the reciprocal of the volume.
4. Calculate the reciprocal of the volume for each measurement.
5. Create a plot of P vs $1/V$.

Questions

1. What variables are held constant while the pressure is changing?
2. Is the relationship between Pressure and Volume direct or inverse? Explain.
3. Can you infer what the gas pressure will be if the volume is reduced to 10 mL?

Chapter 21

Charge Produced by Friction

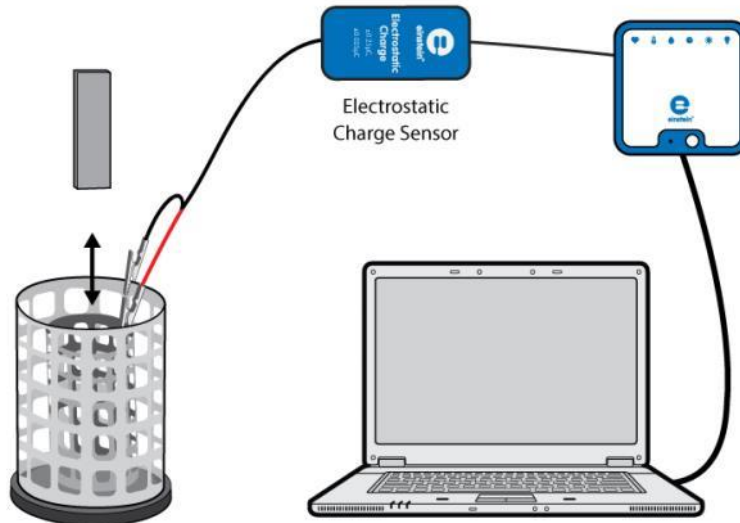


Figure 1



Introduction

In this experiment you will charge pairs of objects by rubbing them together. Some materials release electrons more easily than others. When you rub the two objects together, some electrons from one object are transferred to the second object. For example, when rubbing a piece of polyvinyl chloride (PVC) plastic with wool, you will find that the PVC gains electrons and so becomes negatively charged, while the wool becomes positively charged. This tells you that wool gives up electrons more readily than PVC. In this experiment, you will measure the charges on these object pairs using the Electrostatic Charge sensor.




Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Electrostatic Charge sensor
- Test leads with BNC connector
- Faraday ice pail
- Materials: Glass rod (Pyrex is best), ebonite rod, PVC plastic strip (or pipe), silk cloth, neoprene rubber glove, wool cloth
- Silk thread

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Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect the Electrostatic Charge sensor to one of the ports on the einstein™LabMate.
3. Connect the test leads to the Electrostatic Charge sensor.
4. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the

experiment. Make sure that only the Electrostatic Charge sensor is selected under **Measurements**.



Current Setup Summary

Program the sensor to log data according to the following setup:

Sensor:	Electrostatic Charge
Range:	$\pm 0.025 \text{ } (\mu\text{C})$
Measurements:	Charge $\pm 0.025 \text{ } (\mu\text{C})$
Current Reading:	Set (sets as zero)
Rate:	10 samples per second
Samples:	1000
Duration:	1 minute 40 seconds



Procedure

1. Wrap the small woolen cloth around the end of the PVC plastic strip or the glass rod. Secure it tightly with the silk thread (see Figure 2).

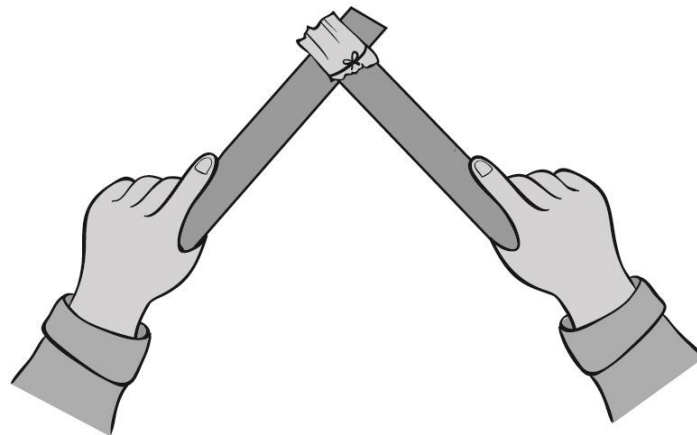


Figure 2

2. Short circuit the two leads of the Electrostatic charge sensor. To short circuit the sensor, connect the positive (red) and negative (black) leads.
3. Select **Run** () to begin recording data.
4. Rub the woolen cloth along the length of a strip of PVC plastic (see Figure 2).
5. Lower the PVC plastic strip into the lower half of the inner cylinder of the Faraday pail and hold it suspended there, without allowing it to touch the pail (see Figure 1).
6. Select **Stop** () to stop collecting data.
7. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.
8. Remove the strip from the Faraday pail.
9. Short circuit the two leads of the Electrostatic charge sensor.
10. Next, insert the woolen cloth into the pail and record the readings.
11. Repeat steps 1 to 9 with other pairs of materials, rubbing cloth against a strip or rod.



Questions

1. What happens when you rub a woolen cloth against PVC plastic?
2. Are the objects that have been rubbed together always equal and opposite in charge when you measure them? Explain.
3. Which of the pairs of materials that you have rubbed together give off electrons most easily?

Chapter 22

Electrification by Contact

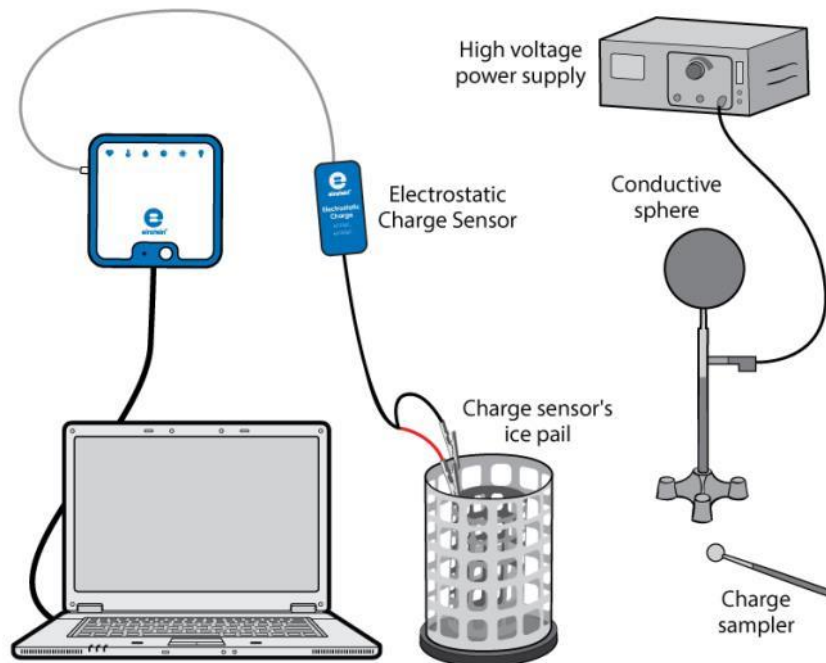


Figure 1


Introduction

When a neutral conductive object is brought into contact with a negatively charged object, the two together function as a single large object. The excess electrons on the negatively charged object, which repel each other, now have more space to spread out to distribute the negative charge. Electrons from the charged object flow to the uncharged object thus charging it. If the two negatively charged objects are then separated, they each maintain their negative charge.

Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Electrostatic Charge sensor
- Test leads with BNC connector
- Faraday ice pail
- Conductive sphere
- Insulating rod
- Stand
- High voltage power supply
- Charge sampler

123 Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect the Electrostatic Charge sensor to one of the ports on the einstein™LabMate.
3. Connect the test leads to the Electrostatic Charge sensor.
4. Assemble the equipment as shown in Figure 1.
 - a. Connect the red lead of the Electrostatic Charge sensor to the inner cylinder of the Faraday ice pail.
 - b. Connect the black lead to the outer cylinder of the Faraday ice pail.
 - c. Connect the conductive sphere to the high voltage output of the high voltage power supply.
5. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Electrostatic Charge sensor is selected under **Measurements**.

Note: You may need to ground the outer cylinder of the Faraday ice pail









Current Setup Summary




Program the sensor to log data according to the following setup:

Sensor:	Electrostatic Charge
Range:	± 0.025 (μC)
Measurements:	Charge ± 0.025 (μC)
Current Reading:	Set (sets as zero)
Rate:	10 samples per second
Samples:	1000
Duration:	1 minute 40 seconds



Procedure

1. Turn on the power supply.
2. Short circuit the two leads of the Electrostatic charge sensor. To short circuit the sensor, connect the positive (red) and negative (black) leads.
3. Select **Run** () to begin recording data.
4. Ground the charge sampler to remove any residual charge from it.
5. Lower the charge sampler into the inner basket of the Faraday ice pail. Observe the resulting graph.
6. Select **Stop** () to stop collecting data.
7. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.
8. Short circuit the two leads of the Electrostatic charge sensor.
9. Select **Run** () to begin recording data.
10. Touch the conductive sphere with the charge sampler, and then lower the charge sampler into the inner basket of the Faraday ice pail. Observe the resulting graph.
11. Select **Stop** () to stop collecting data.
12. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.
13. Short circuit the two leads of the Electrostatic charge sensor.

14. Select **Run** () to begin recording data.
15. Touch the conductive sphere with the charge sampler a second time, then lower the charge sampler into the inner basket of the Faraday ice pail. Does the graph change? Explain your observations.
16. Select **Stop** () to stop collecting data.
17. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.
18. Short circuit the two leads of the Electrostatic charge sensor.
19. Now ground the charge sampler to remove any residual charge from it, then repeat the charge measurement. Explain the changes in the graph.

Questions

1. Is the conductive sphere charged positively or negatively?
2. Explain how the spheres were charged.
3. Explain the process by which you charged the charge sampler.

Chapter 23

Charge Produced by Induction

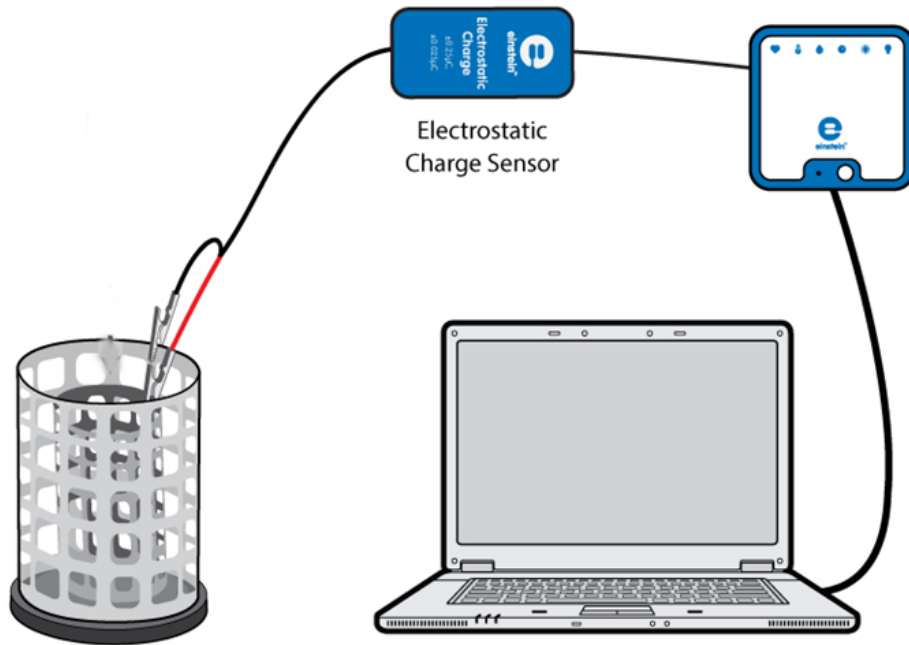


Figure 1



Introduction

In this experiment we will charge a pair of conductive spheres by induction and then measure the charge on each sphere.

In the induction process, a charged object is brought near to a neutral conducting object without touching the two objects together. In this case, we will use two connected conductive cylinders as our neutral object. The presence of a charged object near a neutral conductor will force (or induce) electrons within the conductor to move. The movement of electrons leaves an imbalance of charge on opposite sides of the neutral conductor. While overall the object is neutral (i.e. has the same number of electrons as protons), there is an excess of positive charge on one cylinder and an excess of negative charge on the other cylinder. Once the cylinders have been separated, each one is left with a net charge.




Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Electrostatic Charge sensor
- Test leads with BNC connector
- Faraday ice pail
- Two conductive spheres on an insulated stand (each sphere's diameter must be smaller than the diameter of the Faraday ice pail inner cylinder)
- PVC plastic strip or pipe
- A piece of woolen cloth



Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect the Electrostatic Charge sensor to one of the ports on the einstein™LabMate.
3. Connect the test leads to the Electrostatic Charge sensor.
4. Assemble the equipment as shown in Figure 1.
 - a. Connect the red lead to the inner cylinder of the Faraday ice pail.
 - b. Connect the black lead to the outer cylinder of the Faraday ice pail.
5. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Charge sensor is selected under **Measurements**.

Note: You may need to ground the outer cylinder of the Faraday ice pail



Current Setup Summary

Program the sensor to log data according to the following setup:

Sensor:	Electrostatic Charge
Range:	± 0.025 (μC)
Measurements:	Charge ± 0.025 (μC)
Current Reading:	Set (sets as zero)
Rate:	10 samples per second
Samples:	1000
Duration:	1 minute 40 seconds



Procedure

1. Bring the two conductive spheres into contact (see Figure 2).

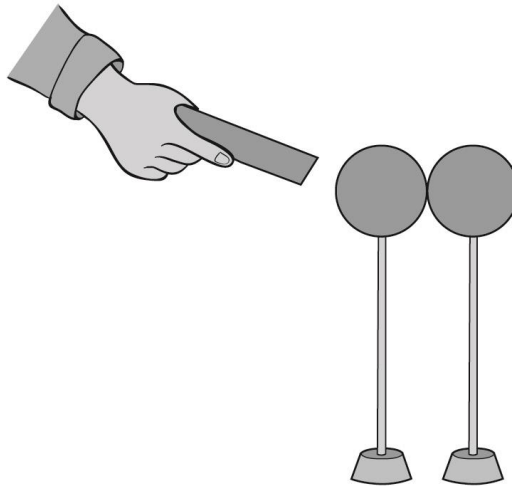





Figure 2

2. Rub the PVC strip with the woolen cloth to charge it.
3. Bring the PVC strip near one sphere but don't touch it.
4. With the PVC strip still near one sphere hold the insulating rod of the other sphere and move it away to separate the spheres.
5. Short circuit the two leads of the Electrostatic charge sensor. To short circuit the sensor, connect the positive (red) and negative (black) leads.
6. Select **Run** () to begin recording data.
7. Hold the sphere that was nearest to the PVC rod by its insulating rod and insert it into the lower half of the inner cylinder of the Faraday ice pail, while not letting it touch the Faraday ice pail.
8. Select **Stop** () to stop collecting data.
9. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.
10. Remove the sphere.
11. Short circuit the two leads of the Electrostatic charge sensor.
12. Now repeat steps 5 to **Error! Reference source not found.**, inserting the other sphere into the pail and recording the readings.



Questions

1. What happens when you rub a piece of PVC plastic with a woolen cloth?
2. Explain how the spheres were charged.
3. Were the two spheres charged equally and opposite, when you measured them? Explain.
4. Use your measurements to determine the sign of the charge on the PVC strip. Explain.

Chapter 24

Conductive and Insulating Materials

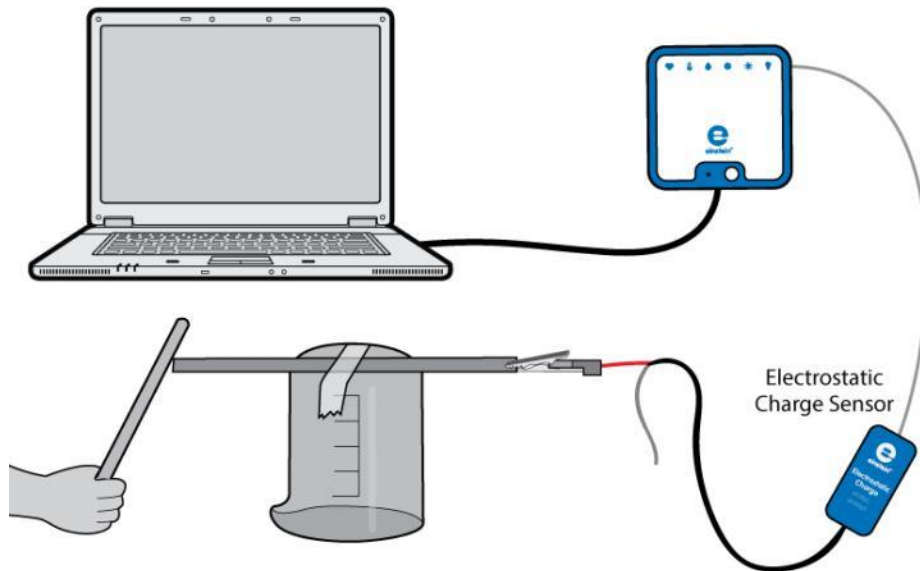


Figure 1



Introduction

Different types of atoms hold onto their electrons more or less tightly. With some types of materials, such as metals, the outermost electrons in the atoms are so loosely bound that they chaotically move in the space between the atoms of that material influenced by nothing more than room-temperature heat energy. Because these virtually unbound electrons are free to leave their respective atoms and float around in the space between adjacent atoms, they are often called free electrons.

In other types of materials such as glass, the atoms' electrons have very little freedom to move around. While external forces such as physical rubbing can force some of these electrons to leave their respective atoms and transfer to the atoms of another material, they do not move between atoms within that material very easily.

This relative mobility of electrons within a material is known as electric *conductivity*. Conductivity is determined by the types of atoms in a material (the number of protons in each atom's nucleus, determining its chemical identity) and how the atoms are linked together with one another. Materials with high electron mobility (many free electrons) are called *conductors*, while materials with low electron mobility (few or no free electrons) are called *insulators*.

Here are a few common examples of conductors and insulators:

Conductors:

Silver, Copper, Gold, Aluminum, Iron, Steel, Brass, Bronze, Mercury, Graphite, Dirty water, Concrete

Insulators:

Glass, Rubber, Oil, Asphalt, Fiberglass, Porcelain, Ceramic, Quartz, (Dry) cotton, (Dry) paper, (Dry) wood, Plastic, Air, Diamond, Pure water

It must be understood that not all conductive materials have the same level of conductivity, and not all insulators are equally resistant to electron motion.

For instance, silver is the best conductor in the *conductors* list, offering easier passage for electrons than any other material cited. Dirty water and concrete are also listed as conductors, but these materials are substantially less conductive than any metal.

In this activity we will classify several materials as conductors or insulators by studying the mobility of free charges in the materials.




Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Electrostatic Charge sensor
- Test leads with BNC connector
- PVC strip or pipe
- A piece of woolen cloth
- Beaker
- Tape
- Variety of rods and strips of different materials like metals, graphite, plastic materials, wood, paper and others

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Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect the Electrostatic Charge sensor to one of the ports on the einstein™LabMate.
3. Connect the test leads to the Electrostatic Charge sensor.
4. Assemble the equipment as shown in Figure 1.
5. Tape one of your materials on an inverted beaker (see Figure 1).
6. Connect the red lead of the Electrostatic Charge sensor to one end of the material to be tested.
7. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Electrostatic Charge sensor is selected under **Measurements**.




Current Setup Summary

Program the sensor to log data according to the following setup:

Sensor:	Electrostatic Charge
Range:	± 0.025 (μC)
Measurements:	Charge ± 0.025 (μC)
Current Reading:	Set (sets as zero)
Rate:	10 samples per second
Samples:	1000
Duration:	1 minute 40 seconds



Procedure

1. Short circuit the two leads of the Electrostatic charge sensor. To short circuit the sensor, connect the positive (red) and negative (black) leads.
2. Select **Run** () to begin recording data.
3. Rub the PVC strip with the woolen cloth to charge it.
4. Touch the free end of the test material with the PVC strip.
5. Observe the resulting graph. Will you classify the material as a conductor or as an insulator?
6. Repeat steps 1 to 5 for each material.

Based on your findings, prepare a list of conductive materials and a list of insulating materials.

Chapter 25

Voltage Measurements

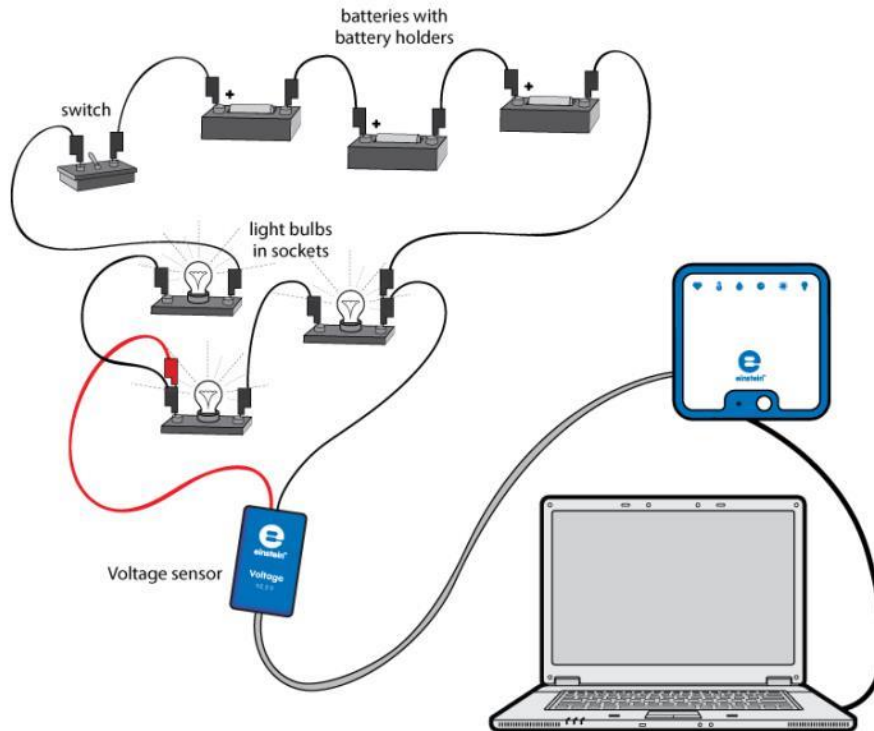


Figure 1



Introduction

A voltmeter is an instrument used to measure the voltage drop between two points. A digital voltmeter presents this voltage as a number on a screen. The measuring technique is to digitally compare the measured voltage drop with an internal reference voltage. The data logger does not just measure the voltage drop – it also stores the data for future analysis.


In this experiment we will use the Voltage sensor to measure voltage drops across several points in a basic electrical circuit. We will also learn the various display options.



Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Voltage sensor (± 25 V)
- 1.5 V battery with battery holder (3)
- Small light bulbs, 1.5 V (3)
- Light bulb sockets (3)
- Connecting wires
- Switch (On/Off)

123 Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect the Voltage sensor to one of the ports on the einstein™LabMate.
3. Assemble the equipment as shown in Figures 1 and 2. Notice that the negative lead of the voltage sensor is fixed to point A, but the positive lead will be connected to the various points in the circuit.

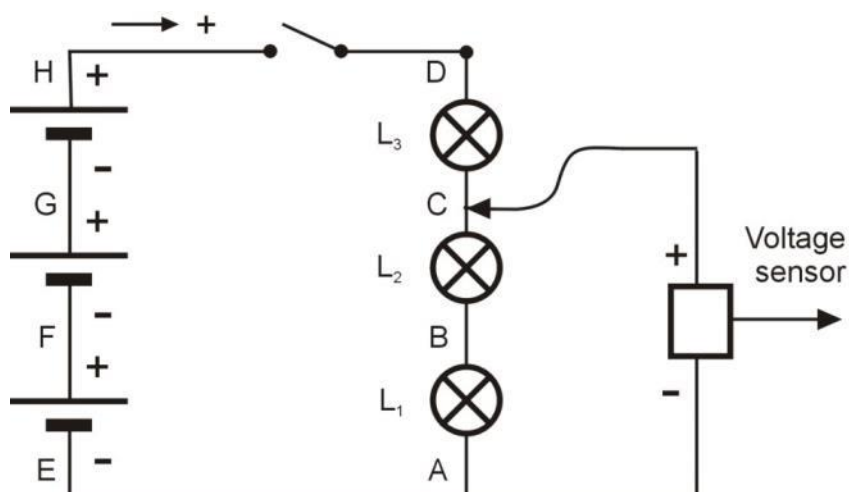


Figure 2


4. Short circuit the two leads of the Voltage sensor. To short circuit the sensors, connect the positive (red) and negative (black) leads.
5. Connect the Voltage sensor to one of the ports on the einstein™LabMate.
6. Disconnect the two leads of the Voltage sensor.
7. In the window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Voltage sensor is selected under **Measurements**.







Current Setup Summary

Program the sensor to log data according to the following setup:

Sensor:	Voltage (± 25 V)
Measurements:	Voltage (V)
Current Reading:	Set (sets as zero)
Rate:	10 samples per second
Samples:	1000
Duration:	1 minute 40 seconds

Procedure

1. Make sure the switch is in the Off position.
2. Select **Meter Window** () from the **Work Space** menu bar. Move the **Meters** window which opens to a location which does not cover the **Graph** window.

3. Select **Run** () to begin recording data.
4. Bring the positive lead of the Voltage sensor into contact with point H on the circuit (see Figure 2).
5. Observe the readings in the meter window and on the graph and in the table.
6. Record the voltage value in your data table.
7. Turn the switch to the on position. Record the voltage value in your data table.
8. Bring the positive lead of the Voltage sensor into contact with point D on the circuit. Record the voltage value in your data table.
9. Repeat step 8 with points C, B, A, E, F and G.
10. The **Meters** window has four different display options. Repeat the measurements while exploring the **Analog** (), **Bar** (), **Color** () and **Digital** () display options.
11. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.

Data Table

Positive lead of the Voltage sensor connected to point:	Voltage Drop (V)
H (switch off)	
H (switch on)	
D	
C	
B	
A	
E	
F	
G	



Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop**.

1. Explain the change in the voltage drop between point A and point H after turning the switch from off to on.
2. Discuss the different measurements that you made.
3. Discuss the advantages of the three different display windows: **Meters**, **Graph** and **Table** and the different display options within the **Meters** window.

Chapter 26

EMF, Voltage and Internal Resistance

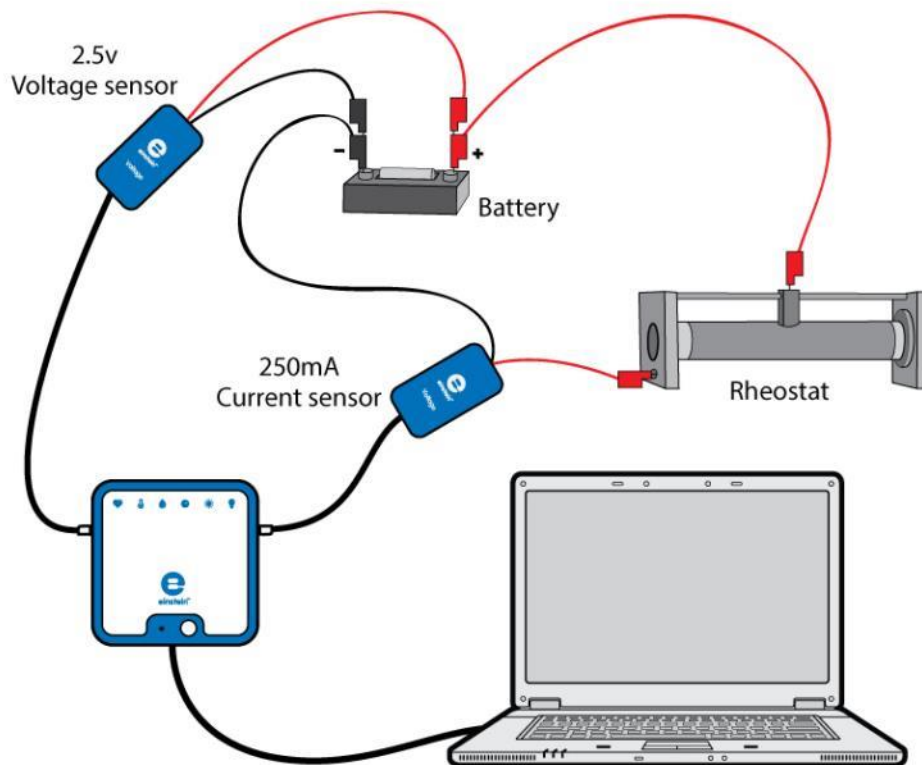


Figure 1

Introduction

The potential difference between the terminals of a voltage source when it is not connected to an external circuit is the electromotive force (EMF) of that source. The symbol ε is used to represent the electromotive force. When an external circuit is connected to the voltage source, the potential difference V between the terminals will drop below its open circuit value. The difference between ε and V is caused by the internal resistance r of the voltage source. The value of V will be:

$$V = \varepsilon - Ir \quad (1)$$

Where:

I = The current through the external circuit

In this experiment the relationship between the voltage V and the current flow I will be explored.




Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Voltage sensor ± 2.5 V
- Current sensor ± 2.5 A
- 1.5 V battery with battery holder
- Rheostat ($\sim 15 \Omega$)



Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect the Current sensor to one of the ports on the einstein™LabMate.
3. Connect the Voltage sensor to one of the ports on the einstein™LabMate.
4. Assemble the electric circuit as shown in Figures 1 and 2.

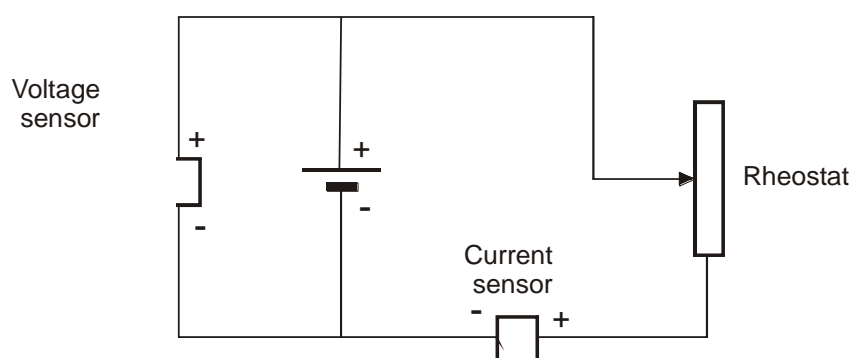


Figure 2

5. Connect the Current sensor and the rheostat in series with the battery, and then connect the Voltage sensor in parallel with the battery.
6. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Current and Voltage sensors are selected under **Measurements**.
7. Make sure to choose the Current sensor as the x-axis.





Current Setup Summary

Program the sensors to log data according to the following setup:

Sensor:	Voltage (± 2.5 V)
Measurements:	Voltage (V)
Current Reading:	Set (sets as zero)
Sensor:	Current (± 2.5 A)
Measurements:	Current (A)
Current Reading:	Set (sets as zero)
Sampling:	Manual
Samples:	10



Procedure

1. Select **Run** () to enable data recording.
2. Set up the **Graph** window to display the data as a graph of voltage as a function of current:
3. From the **Graph** window, select the down arrow (▼) and choose Current as the x-axis measure if you did not set this previously in the Equipment Setup Procedure.
4. Make sure that both the right and left y-axes of the graph display voltage. Use the down arrow (▼) on the left and right sides to choose Voltage as your y-axis measure if necessary.
5. Collect the data manually: Select **Manual Sampling** () on the main toolbar each time you wish to record a data sample.
6. Disconnect the sliding terminal of the rheostat. Record the first data sample. Reconnect the terminal to the rheostat.
7. Change the resistance of the rheostat, begin with higher values and gradually reduce the resistance. After each change record the data. Do not measure currents higher than 2.5 A.

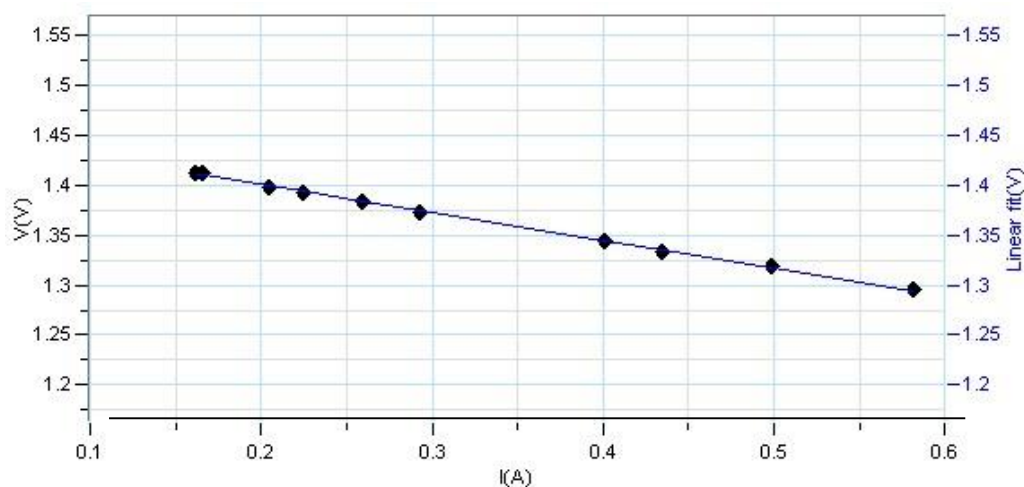





Figure 3




Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop**.

1. Apply a linear fit to the graph (see Figure 3):
 - a. Use either a **single cursor** () to fit the entire graph or **two cursors** () to specify a region of the graph.
 - b. Select **Curve fit** () from the **Analysis** window on the upper menu bar.
 - c. In the **Curve fit** window which opens, choose **Linear** from the **Curve fit** drop down menu.
 - d. The fit equation will be displayed next to the second cursor.
2. Record in your notebook the equation of the linear fit to the graph Voltage vs. Current.
3. Answer the following questions:
 - a. What is the value of the internal resistance of the battery?
 - b. What is the EMF of the battery?
 - c. What is the meaning of the points where the graph intersects the axes?



Further Suggestions

1. You may repeat the experiment with two batteries connected in parallel or in series. You may need to change the sensors to measure greater voltages and currents.
2. You may perform a continuous sweep of the changing resistance: Set the data logger up to measure 100 points at a rate of 10 samples per second and then select **Run** (). Move the movable terminal of the rheostat slowly.

Chapter 27

I-V Characteristics of a Wire, a Light Bulb and a Diode

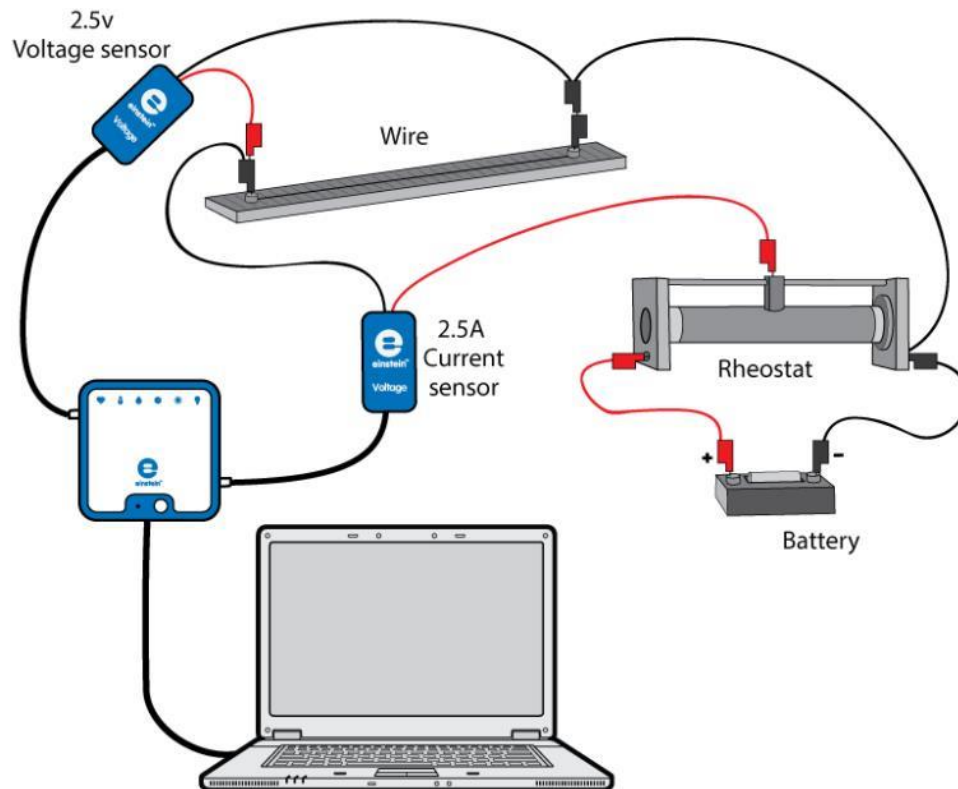


Figure 1



Introduction


In this experiment we explore the current-voltage (I - V) characteristics of various electronic components.



Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Voltage sensor ± 2.5 V (or ± 25 V)
- Current sensor ± 2.5 A
- Metal wire stretched on a ruler
- Light bulb (3.5 V)
- Diode
- 1.5 V battery with battery holder
- Rheostat ($\sim 15 \Omega$)

123 Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect the Current sensor to one of the ports on the einstein™ Tablet or einstein™LabMate.
3. Connect the Voltage sensor to one of the ports on the einstein™ Tablet or einstein™LabMate.
4. Assemble the electric circuit as shown in Figure 1:
 - a. Connect the rheostat as a voltage divider.
 - b. Connect the Current sensor and the metallic wire in series with the rheostat.
 - c. Connect the Voltage sensor in parallel with the wire.
5. You can choose to work with one 1.5 V battery or with three 1.5 V batteries, depending on the Voltage sensor available to you (see Figures 1 and 2).
6. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Current and Voltage sensors are selected under **Measurements**.
7. Make sure to choose the Voltage along the x-axis.

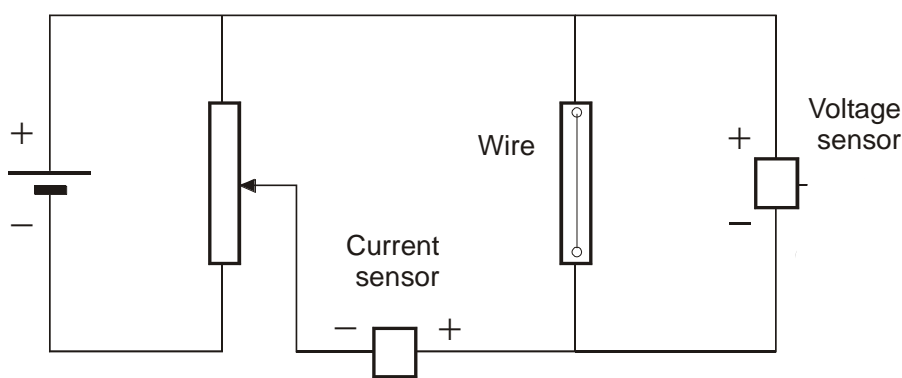


Figure 2



Current Setup Summary

Program the sensors to log data according to the following setup:

Sensor:	Voltage (± 2.5 V) or (± 25 V)
Measurements:	Voltage (V)
Current Reading:	Set (sets as zero)
Sensor:	Current (± 2.5 A)
Measurements:	Current (A)
Current Reading:	Set (sets as zero)
Sampling:	Manual
Samples:	20



Procedure

1. Select **Run** () to enable data recording.
2. Collect the data manually: Select **Manual Sampling** () on the main toolbar each time you wish to record a data sample.
3. Place the sliding terminal of the rheostat in a low voltage position and record the first data sample.
4. Change the potential difference between the terminals of the wire. Begin with lower values and gradually increase the voltage. After each change record the data. Do not measure currents higher than 2.5 A.

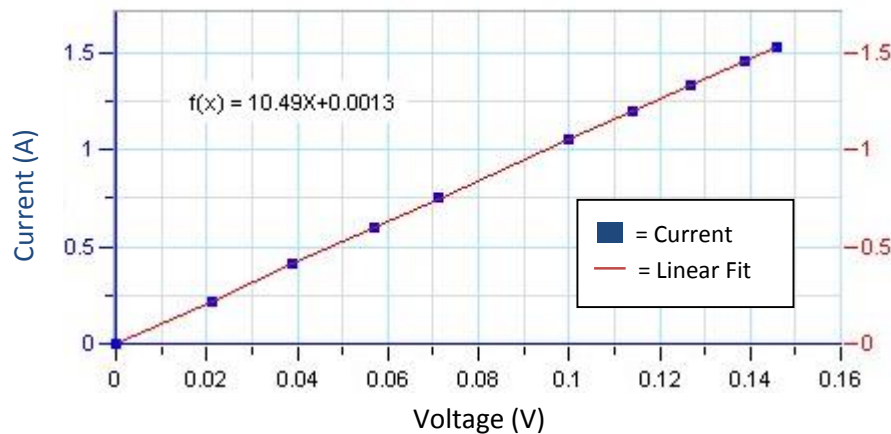







Figure 3

5. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.
6. Replace the wire with the diode and repeat the experiment.
7. Replace the diode with the light bulb and repeat the experiment. Each time you change the voltage wait a few seconds for the bulb to reach full brightness and then select **Manual Sampling** ().




Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop**

1. Analyze the results for the metallic wire:
 - a. Use either a **single cursor** () to fit the entire graph or **two cursors** () to specify a region of the graph.
 - b. Select **Curve fit** () from the **Analysis** window on the upper menu bar.
 - c. In the **Curve fit** window which opens, choose **Linear** from the **Curve fit** drop down menu.
 - d. The fit equation will be displayed next to the second cursor.
2. The value of the slope is the resistance of the wire. Record this value in your notebook.
3. Repeat this procedure for the other electronic components (the diode and the light bulb) to create I-V graphs for all of the components examined.



Further Suggestions

1. Repeat this procedure with different lengths of the wire and create a graph of Resistance vs. Wire length.
8. By measuring the diameter of the wire you may calculate the resistivity ρ of the metal. You may want to compare different metals.
2. During the experiment with the light bulb you may use a Light sensor simultaneously with the Voltage and Current sensors. You can then compare the power output with the light intensity (see Figure 4). To display a graph of the power:
 - a. Select **Math functions** () from the **Analysis** window on the upper menu bar.
 - b. In the **Math function** window which opens, choose **Multiply** from the **Function** drop down menu.
 - c. In the **G1** drop down menu select the current and in the **G2** drop down menu select the voltage.

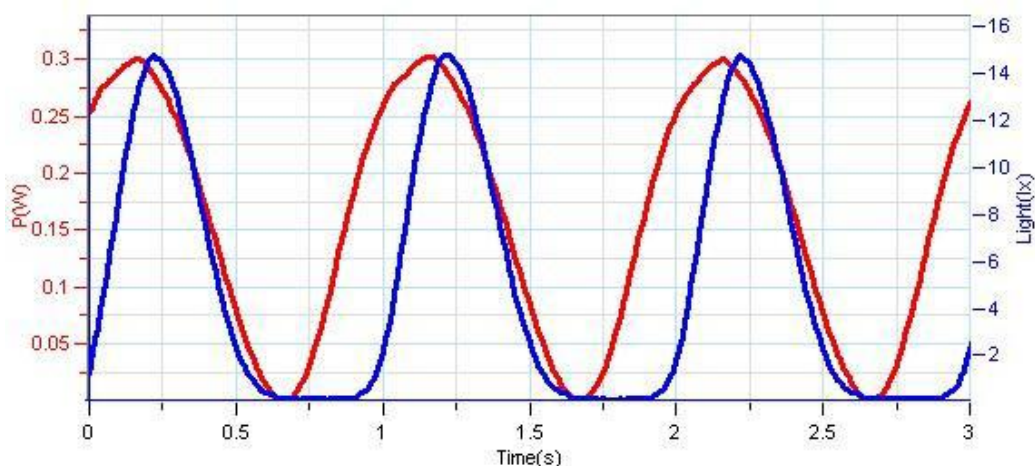


Figure 4

Chapter 28

Resistance of a Wire

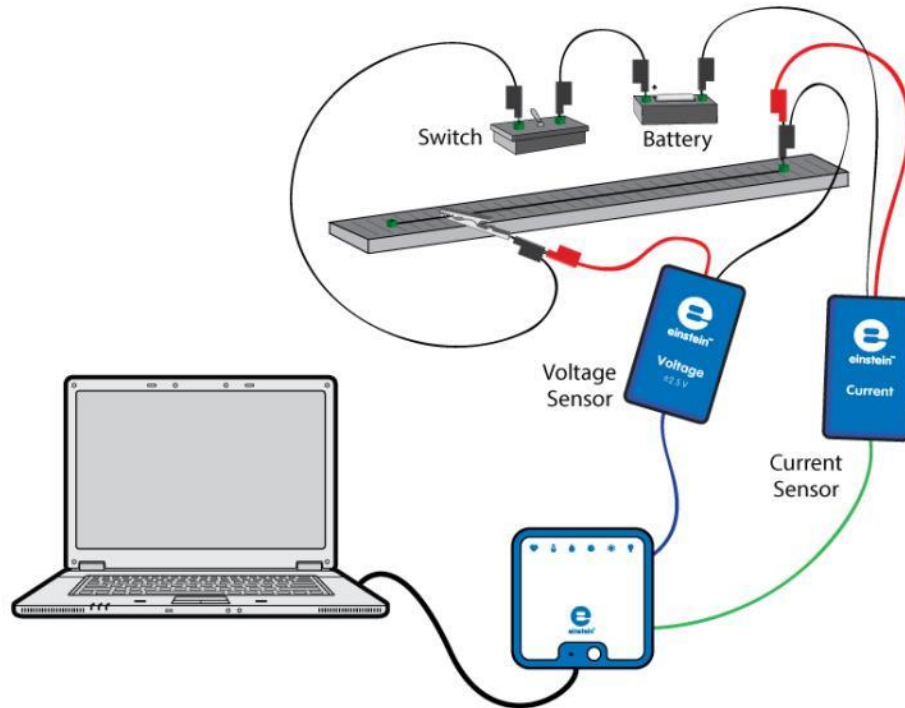


Figure 1

Introduction

The resistance of a wire depends on its length, its cross sectional area and on the material it is made from. The resistance R of a wire is given by:

$$R = \rho \frac{\ell}{A} \quad (1)$$

Where:

ρ = The specific electrical resistance of the material, resistivity

ℓ = The length of the wire

A = The cross sectional area of the wire

In this experiment we will explore this relationship.




Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Voltage sensor (± 2.5 V)
- Current sensor (± 2.5 A)
- Resistance wire stretched on a 50 cm ruler (Nichrome, diameter: 0.25 mm)
- Optional: Resistance wire stretched on a 50 cm ruler (Nichrome, diameter: 0.5 mm)
- 1.5 V battery with battery holder
- Connecting wires
- Alligator clip
- Switch (On/Off)
- Caliper

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Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect the Current sensor to one of the ports on the einstein™LabMate.
3. Connect the Voltage sensor to one of the ports on the einstein™LabMate.
4. Short circuit the two leads of the Voltage sensor and short circuit the two leads of the Current sensor.
To short circuit a sensor, connect the positive (red) and negative (black) leads.
5. Disconnect the two leads of the Voltage sensor and the two leads of the Current sensor.
6. Assemble the circuit as shown in Figure 1 and Figure 2.

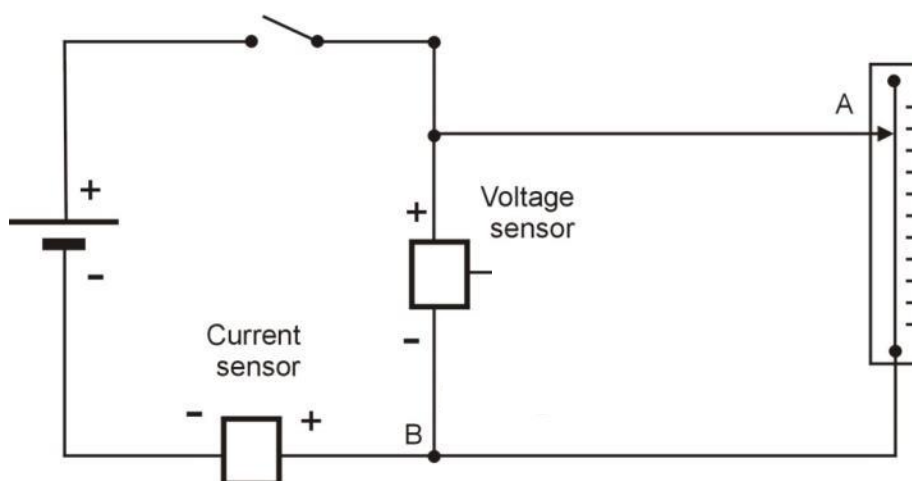


Figure 2

Note: Make sure to connect the sensors with the correct polarity. The red lead of the sensor is the positive input and the black is negative.

7. Use the alligator clip to connect to any point on the resistance wire (Point A in Figure 2).
8. Make sure that the switch is in the Off position.
9. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Current and Voltage sensors are selected under **Measurements**.








Current Setup Summary

Program the sensors to log data according to the following setup:

Sensor:	Voltage (± 2.5 V)
Measurements:	Voltage (V)
Current Reading:	Set (sets as zero)
Sensor:	Current (± 2.5 A)
Measurements:	Current (A)
Current Reading:	Set (sets as zero)
Sampling:	Manual
Samples:	10



Procedure

1. Use the Caliper to measure the diameter of the resistance wire.
2. Clip the alligator clip to the resistance wire at the 10 cm mark.
3. Select **Run** () to enable data recording.
4. Open the **Meter Window** () from the **Work Space** menu bar. Use the **Digital** () display option.
Repeat to open one window for each sensor. Use the dropdown menu to select the Current sensor in one Meter Window and the Voltage sensor in the other.
5. Collect the data manually: Select **Manual Sampling** () on the main toolbar each time you wish to record a measurement.
6. Turn the switch to the On position.
7. Record the voltage and current values in your data table.
8. Turn the switch to the Off position.
9. Clip the alligator clip to the resistance wire next to the 15 cm mark and repeat steps 6 to 8.
10. Increase the resistance wire length by measures of 5 cm until reaching 50 cm and repeat steps 6 to 8 for each length.
11. Select **Stop** () to stop collecting data.

Data Table

Diameter of the wire: _____ mm

Cross sectional area of the wire: _____ cm²

Length of Wire (cm)	Voltage (V)	Current (A)	Resistance (R)
10			
15			
20			
25			
30			
35			
40			
45			
50			



Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop.**

1. Use Ohm's law ($V=IR$) and the data from your table to calculate the resistance for every length of wire in the data table. Record those values in the Resistance column of the table.
2. Plot a graph of the resistance (y -axis) vs. the wire's length (x -axis).
3. Fit a straight line to your data points that passes through the origin.
4. Does your graph agree with Equation (1)?
5. What are the units of the slope?
6. What is the resistance of the wire per unit length?
7. Use Equation (1) to calculate the specific electrical resistance of the material.



Further Suggestions

1. Repeat the experiment with a wire of the same material but of a different cross section area.
2. Discuss the dependence of the resistance on the wire's cross section area.

Chapter 29

Resistors in Series

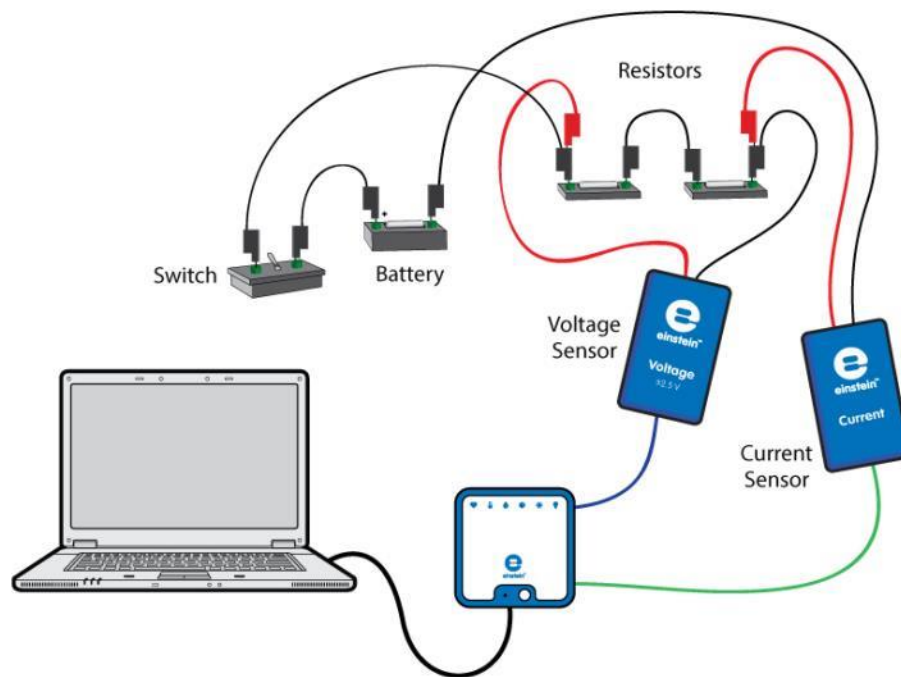


Figure 1



Introduction

Resistors can be connected in series; that is, the current flows through them one after another. The circuits in Figure 1 and Figure 2 show two resistors connected in series. The arrow indicates the positive direction of the current.

Since there is only one path for the current to travel, the current passing through each of the resistors is equivalent.

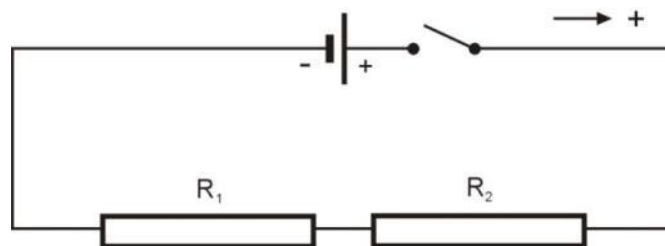


Figure 2

The voltage drops across the resistors must add up to the total voltage supplied by the battery. Resistors connected in series can be replaced with a single resistor, called an equivalent resistor, whose resistance equals the sum of the individual resistances of the resistors:

$$R_{EQUIVALENT} = R_1 + R_2 \quad (1)$$

The equivalent resistor will draw the same amount of current from the battery as the original circuit with two resistors.




Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Voltage sensor (± 2.5 V)
- Current sensor (± 250 mA)
- Resistor ($10\ \Omega$)
- Resistor ($20\ \Omega$)
- 1.5 V battery with battery holder
- Connecting wires
- Switch (On/Off)

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Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect the Voltage sensor to a port on the einstein™LabMate.
3. Connect the Current sensor to a port on the einstein™LabMate.
4. Short circuit the two leads of the Voltage sensor and short circuit the two leads of the Current sensor.
To short circuit a sensor, connect the positive (red) and negative (black) leads.
5. Disconnect the two leads of the Voltage sensor and the two leads of the Current sensor.
6. Assemble the circuit as shown in Figure 1 and Figure 3.

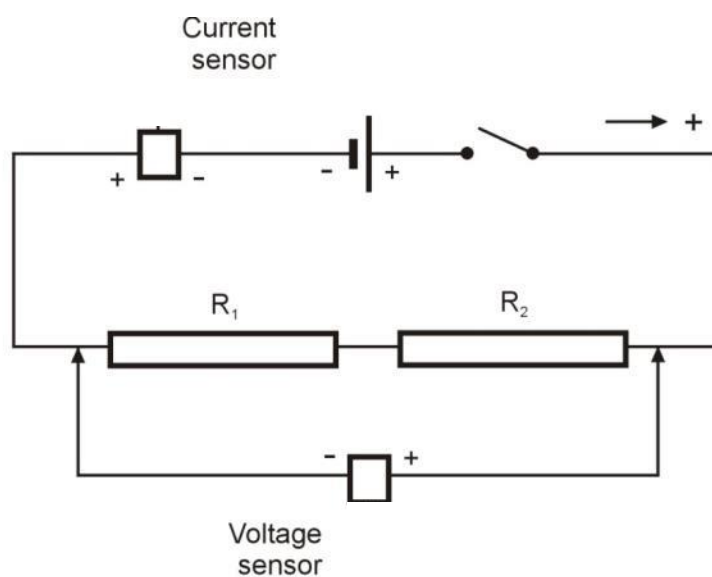


Figure 3

Note: Make sure to connect the sensors with the correct polarity. The red lead of the sensor is the positive input and the black is negative.

7. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Current and Voltage sensors are selected under **Measurements**.



Current Setup Summary

Program the sensors to log data according to the following setup:

Sensor:	Voltage (± 2.5 V)
Measurements:	Voltage (V)
Current Reading:	Set (sets as zero)
Sensor:	Current (± 250 mA)
Measurements:	Current (mA)
Current Reading:	Set (sets as zero)
Sampling:	Manual
Samples:	10



Procedure

1. Turn the switch to the On position.
2. Open the **Meter Window** () from the **Work Space** menu bar. Use the **Digital** () display option. Repeat to open one window for each sensor. Use the dropdown menu to select the Current sensor in one Meter Window and the Voltage sensor in the other.
3. Select **Run** () to enable data recording.
4. Collect the data manually: Select **Manual Sampling** () on the main toolbar each time you wish to record a data sample.
5. Select **Manual Sampling** () and record the voltage and current values in your data table.
6. Connect the leads of the Voltage sensor across resistor R_1 . Select **Manual Sampling** () and record the voltage value in your data table.
7. Connect the leads of the Voltage sensor across resistor R_2 . Select **Manual Sampling** () and record the voltage value in your data table.
8. Select **Stop** () to stop collecting data.

Note: If the current value is displayed in mA you have to divide it by 1000 to convert the value to A.

Data Table

Description	Symbol and Unit	Procedure Step	Value
Voltage applied to both resistors	V (V)	5	
Current	I (A)	5	
Voltage across R_1	V_1 (V)	6	
Voltage across R_2	V_2 (V)	V_2 (V)	



Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop.**

1. What is the relationship between the voltage applied to both resistors (V), the voltage across R_1 (V_1) and the voltage across R_2 (V_2)?
2. Use Ohm's Law ($V=IR$) and data from your measurements to calculate R_1 .
3. Use Ohm's Law and data from your measurements to calculate R_2 .
4. Apply Ohm's Law to the complete circuit to calculate the equivalent resistance of the circuit, $R_{\text{EQUIVALENT}}$.
5. What is the relationship between R_1 , R_2 and $R_{\text{EQUIVALENT}}$? Does it agree with Equation (1) in the Introduction above?



Further Suggestions

Plan and perform an experiment to demonstrate that the current is the same at all points along the circuit.

Chapter 30

Resistors in Parallel

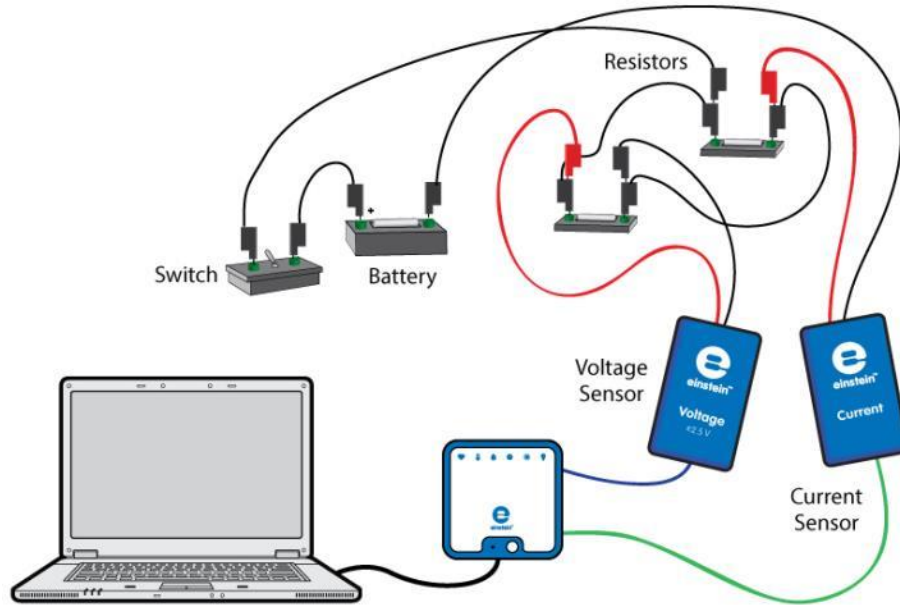


Figure 1



Introduction

Resistors can be connected in such a way that they branch out from a single point (known as a node), and join up again somewhere else along the circuit. This is known as a parallel connection. Each of the two resistors in Figure 2 provides a separate path for current to travel between points A and B. The arrow indicates the positive direction of the current.

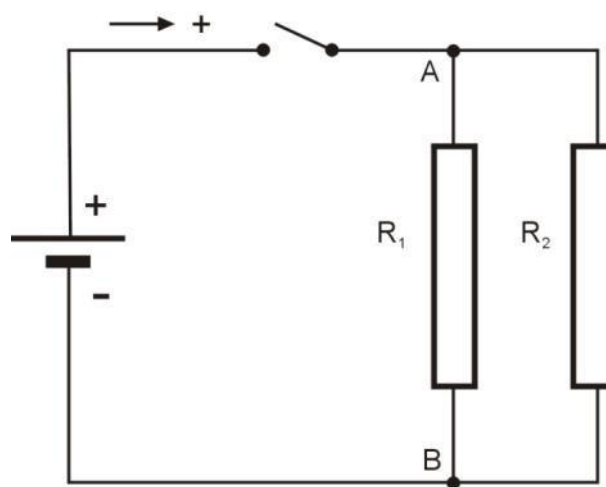


Figure 2

At point A along the circuit, the potential must be the same for each resistor. Similarly, at point B along the circuit, the potential must also be the same for each resistor. So, between points A and B, the potential difference is the same. That is, each of the two resistors in the parallel circuit must have the same voltage drop. Also, the current splits as it travels from point A to point B. Therefore, the sum of the currents through the two branches is the same as the current at A and at B (where the currents from the branch reunite). Resistors connected in parallel can be replaced with a single resistor, called an equivalent resistor. The reciprocal of the resistance of the equivalent resistor equals the sum of the reciprocals of the resistances of the individual resistors:

$$\frac{1}{R_{EQUIVALENT}} = \frac{1}{R_1} + \frac{1}{R_2} \quad (1)$$

The equivalent resistor will draw from the battery the same current as the original circuit.




Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Voltage sensor (± 2.5 V)
- Current sensor (± 250 mA)
- Resistor (10Ω), Resistor (20Ω)
- 1.5 V battery with battery holder
- Connecting wires
- Switch (On/Off)

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Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect the Voltage sensor to a port on the einstein™LabMate.
3. Connect the Current sensor to a port on the einstein™LabMate.
4. Short circuit the two leads of the Voltage sensor and short circuit the two leads of the Current sensor.
To short circuit a sensor, connect the positive (red) and negative (black) leads.
5. Disconnect the two leads of the Voltage sensor and the two leads of the Current sensor.

6. Assemble the circuit as shown in Figure 1 and Figure 3:

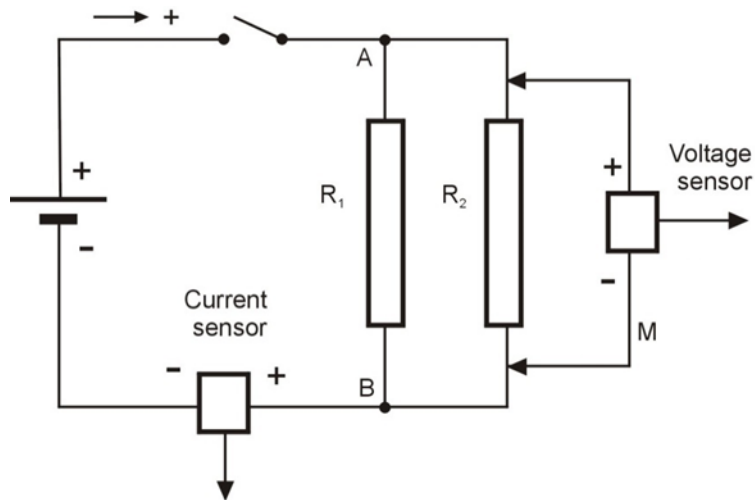


Figure 3

Note: Make sure to connect the sensors with the correct polarity. The red lead of the sensor is the positive input and the black is negative.





7. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Voltage and Current sensors are selected under **Measurements**.

Current Setup Summary


Program the sensors to log data according to the following setup:

Sensor:	Voltage (± 2.5 V)
Measurements:	Voltage (V)
Current Reading:	Set (sets as zero)
Sensor:	Current (± 250 mA)
Measurements:	Current (mA)
Current Reading:	Set (sets as zero)
Sampling:	Manual
Samples:	10

Procedure

- Turn the switch to the On position.
- Open the **Meter Window** () from the **Work Space** menu bar. Use the **Digital** () display option. Repeat to open one window for each sensor. Use the dropdown menu to select the Current sensor in one Meter Window and the Voltage sensor in the other.
- Select **Run** () to enable data recording.
- Collect the data manually: Select **Manual Sampling** () on the main toolbar each time you wish to

record a data sample.

5. Select **Manual Sampling** () and record the voltage and current values in your data table.
6. Rearrange the circuit to measure the current that flows through resistor R_1 : Remove the Current sensor, connect the negative terminal of the battery directly to point B and connect the Current sensor between resistor R_1 and point B (see Figure 4).

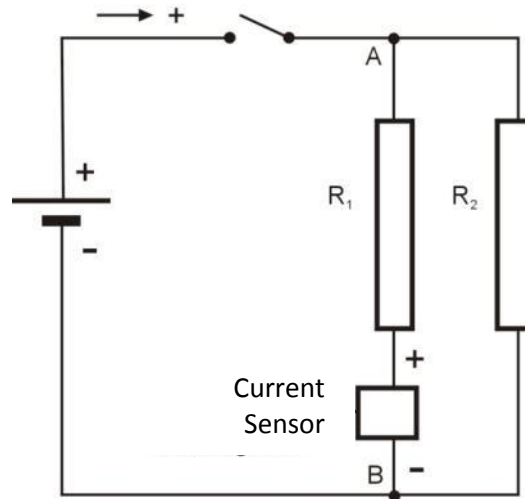




Figure 4

7. Select **Manual Sampling** () and record the current value in your data table.
8. Rearrange the circuit to measure the current that flows through resistor R_2 .
9. When you have collected all the data you need, select **Stop** () to stop collecting data.

Note: If the current value is displayed in mA you have to divide it by 1000 to convert the value to A.

Data Table

Description	Symbol and Unit	Procedure Step	Value
Voltage applied to both resistors	V (V)	5	
Current through battery	I (A)	5	
Current through R_1	I_1 (A)	7	
Current through R_2	I_2 (A)	8	



Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop.**

1. What is the relationship between the current that flows through the battery (I), the current through R_1 (I_1) and the current through R_2 (I_2)?
2. Use Ohm's Law ($V=IR$) and data from your measurements to calculate R_1 .
3. Use Ohm's Law and data from your measurements to calculate R_2 .
4. Apply Ohm's Law to the complete circuit to calculate the equivalent resistance of the circuit, $R_{\text{EQUIVALENT}}$.
5. What is the relationship between R_1 , R_2 and $R_{\text{EQUIVALENT}}$? Does it agree with Equation (1) in the Introduction above?

Chapter 31

Resistors in Mixed Connection

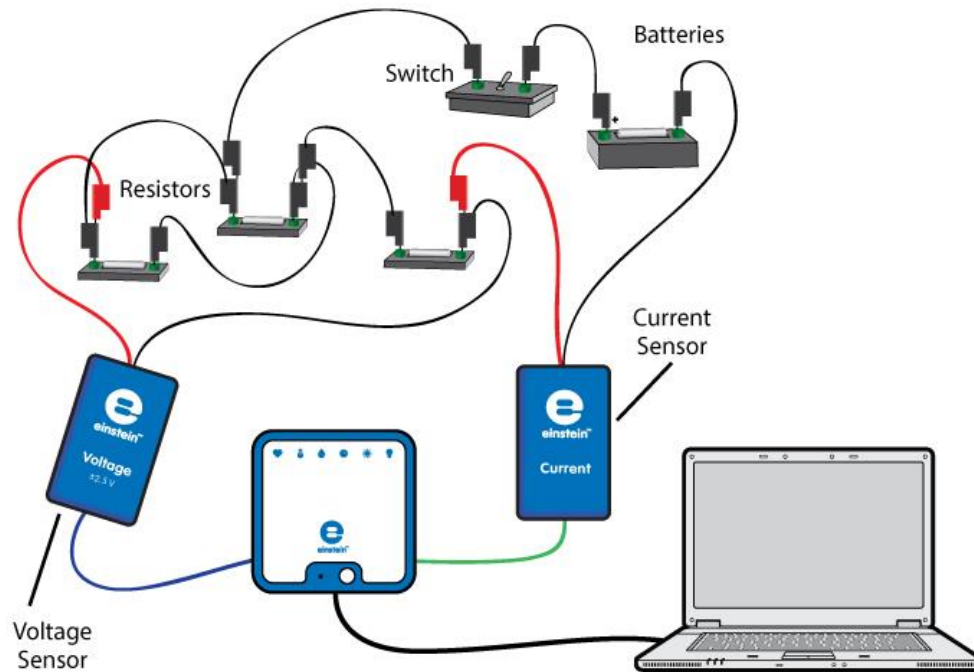


Figure 1

Introduction

If there are more than two resistors in a network they may be connected in a combination of series and parallel connections. Figure 2 shows two resistors R_1 and R_2 connected in parallel. They in turn are connected in series with R_3 . The arrow indicates the positive direction of the current.

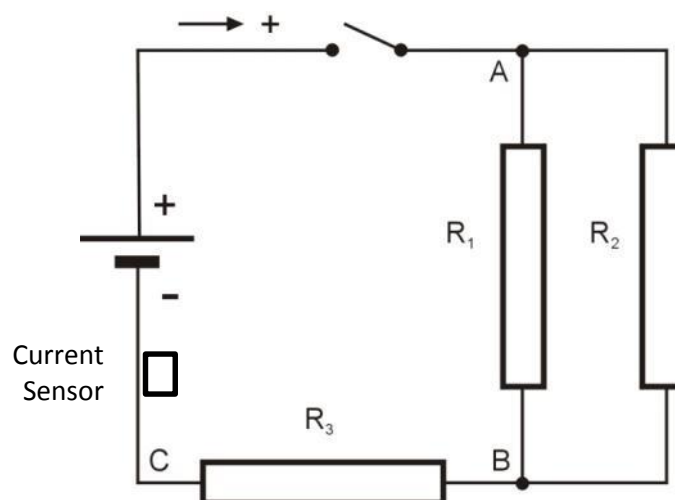


Figure 2

To calculate the equivalent resistance we must first calculate the equivalent resistance of the two resistors in parallel, R_1 and R_2 :

$$\frac{1}{R_{1,2}} = \frac{1}{R_1} + \frac{1}{R_2} \quad (1)$$

Then add this to R_3 to get the total equivalent resistance of the circuit:

$$R_{EQUIVALENT} = R_{1,2} + R_3 \quad (2)$$




Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Voltage sensor (± 2.5 V)
- Current sensor (± 250 mA)
- Resistor (20Ω)
- Resistor (30Ω)
- Resistor (8Ω)
- 1.5 V battery with battery holder
- Connecting wires
- Switch (On/Off)

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Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect the Voltage sensor to a port on the einstein™LabMate.
3. Connect the Current sensor to a port on the einstein™LabMate.
4. Short circuit the two leads of the Voltage sensor and short circuit the two leads of the Current sensor.
To short circuit a sensor, connect the positive (red) and negative (black) leads.
5. Disconnect the two leads of the Voltage sensor and the two leads of the Current sensor.
6. Connect the Current sensor in series with R_3 so that it measures the current through R_3 .
7. Connect the Voltage sensor between points A and C (see Figure 2).
8. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Voltage and Current sensors are selected under **Measurements**.



Current Setup Summary

Program the sensors to log data according to the following setup:

Sensor:	Voltage (± 2.5 V)
Measurements:	Voltage (V)
Current Reading:	Set (sets as zero)
Sensor:	Current (± 250 mA)
Measurements:	Current (mA)
Current Reading:	Set (sets as zero)
Sampling:	Manual
Samples:	10



Procedure

1. Turn the switch to the On position.
2. Open the **Meter Window** () from the **Work Space** menu bar. Use the **Digital** () display option.
Repeat to open one window for each sensor. Use the dropdown menu to select the Current sensor in one Meter Window and the Voltage sensor in the other.
3. Select **Run** () to enable data recording.
4. Collect the data manually: Select **Manual Sampling** () on the main toolbar each time you wish to record a data sample.
5. Select **Manual Sampling** () and record the voltage drop across all the resistors in your data table.
6. Connect the Voltage sensor between points A and B (see Figure 2).
7. Select **Manual Sampling** () and record the voltage drop across R_1 and R_2 in your data table.
8. Connect the Voltage sensor between points B and C (see Figure 2).
9. Select **Manual Sampling** () and record both the voltage drop across R_3 and the current that flows through it in your data table.
10. Rearrange the circuit to measure the current that flows through resistor R_1 (see Figure 1).
11. Select **Manual Sampling** () and record the current value in your data table.
12. Rearrange the circuit to measure the current that flows through resistor R_2 .
13. Select **Manual Sampling** () and record the current value in your data table.
14. When you have collected all the data you need select **Stop** ().

Note: If the current value is displayed in mA you have to divide it by 1000 to convert the value to A.

Data Table

Description	Symbol and Unit	Experimental Procedure Step	Value
Voltage applied to all three resistors	$V_{AC}(V)$	5	
Voltage drop across R_1 and R_2	$V_{AB}(V)$	7	
Voltage drop across R_3	$V_{BC}(V)$	9	
Current through R_2	$I_2(A)$	8	
Current through R_3	$I_3(A)$	9	
Current through R_1	$I_1(A)$	10	
Current through R_2	$I_2(A)$	12	



Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop.**

- What is the relationship between the current that flows through R_3 (I_3), through R_1 (I_1) and through R_2 (I_2)?
- What is the relationship between:
 - The voltage applied to the resistor network - V_{AC} ?
 - The voltage drop across R_1 and R_2 - V_{AB} ?
 - The voltage drop across R_3 - V_{BC} ?
- Use Ohm's Law ($V=IR$) and data from your measurements to calculate R_1 .
- Use Ohm's Law and data from your measurements to calculate R_2 .
- Use Ohm's Law and data from your measurements to calculate R_3 .
- Apply Ohm's Law to the complete circuit to calculate the equivalent resistance of the circuit, $R_{EQUIVALENT}$.
- What is the relationship between R_1 , R_2 , R_3 and $R_{EQUIVALENT}$? Does this match Equation (2) in the Introduction above?

Chapter 32

Connections of Batteries

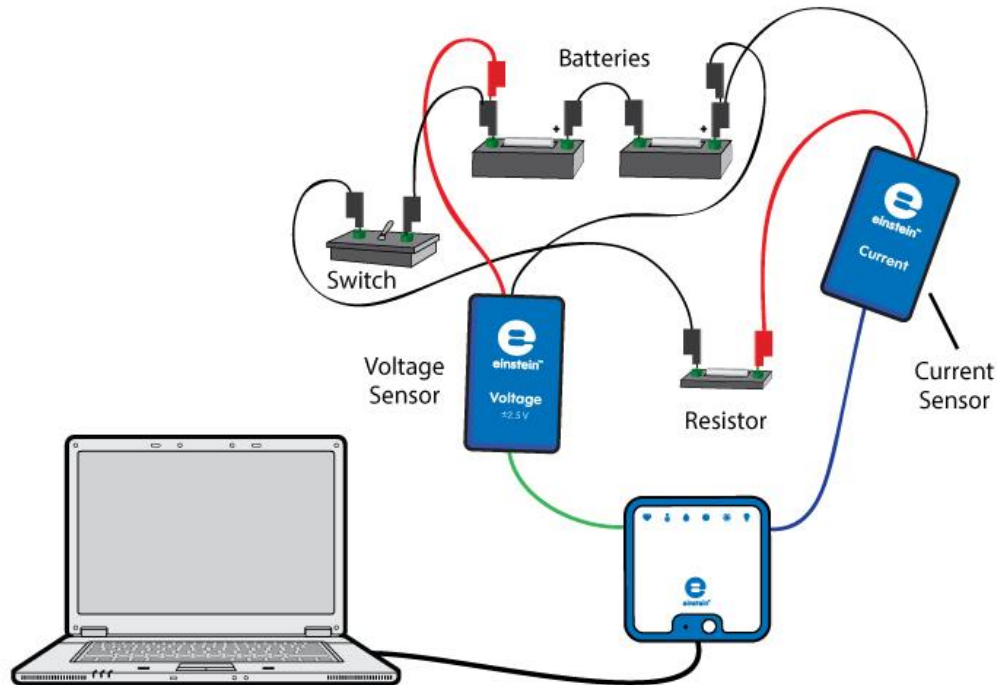


Figure 1

Introduction

A battery is characterized by its electromotive force, \mathcal{E} , and internal resistance, r . The voltage drop across the battery (V) is given by:

$$V = \mathcal{E} - Ir \quad (1)$$

Where:

I = The current drawn from the battery

If two identical batteries are connected in series the effective electromotive force and internal resistance are:

$$\mathcal{E}' = 2\mathcal{E} \quad (2)$$

$$r' = 2r \quad (3)$$

If two identical batteries are connected in parallel the effective electromotive force and internal resistance are:

$$\mathcal{E}' = \mathcal{E} \quad (4)$$

$$r' = \frac{r}{2} \quad (5)$$

In this experiment we will examine these relationships.




Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Voltage sensor (± 2.5 V)
- Current sensor 2.5 A
- 1.5 V battery with battery holder (2)
- Resistor ($2\ \Omega$, 5 W)
- Connecting wires
- Switch (On/Off)



Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect the Voltage sensor to a port on the einstein™LabMate.
3. Connect the Current sensor to a port on the einstein™LabMate.
4. Short circuit the two leads of the Voltage sensor and short circuit the two leads of the Current sensor.
To short circuit the sensors, connect the positive (red) and negative (black) leads.
5. Disconnect the two leads of the Voltage sensor and the two leads of the Current sensor.
6. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Voltage and Current sensors are selected under **Measurements**.



Current Setup Summary

Program the sensors to log data according to the following setup:

Sensor:	Voltage (± 2.5 V)
Measurements:	Voltage (V)
Current Reading:	Set (sets as zero)
Sensor:	Current (± 2.5 A)
Measurements:	Current (A)
Current Reading:	Set (sets as zero)
Sampling:	Manual
Samples:	10



Procedure

Batteries in series:

1. Assemble the equipment as shown in Figure 1 and Figure 2.

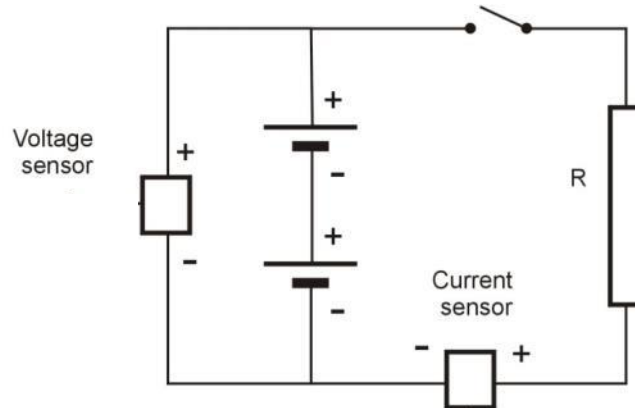


Figure 2

Note: Make sure to connect the sensors with the correct polarity. The red lead of the sensor is the positive input and the black is negative.

2. Make sure the switch is in the Off position.
3. Open the **Meter Window** () from the **Work Space** menu bar. Use the **Digital** () display option. Repeat to open one window for each sensor. Use the dropdown menu to select the Current sensor in one Meter Window and the Voltage sensor in the other.
4. Select **Run** () to enable data recording.
5. Collect the data manually: Select **Manual Sampling** () on the main toolbar each time you wish to record a data sample.
6. Select **Manual Sampling** () to make the first reading. Record the values in your data table.
7. Turn the switch to the On position.
8. Select **Manual Sampling** () to make the second reading. Record the values in your data table.
9. Return the switch to the Off position.

Batteries in parallel

1. Rearrange the circuit as shown in Figure 3.

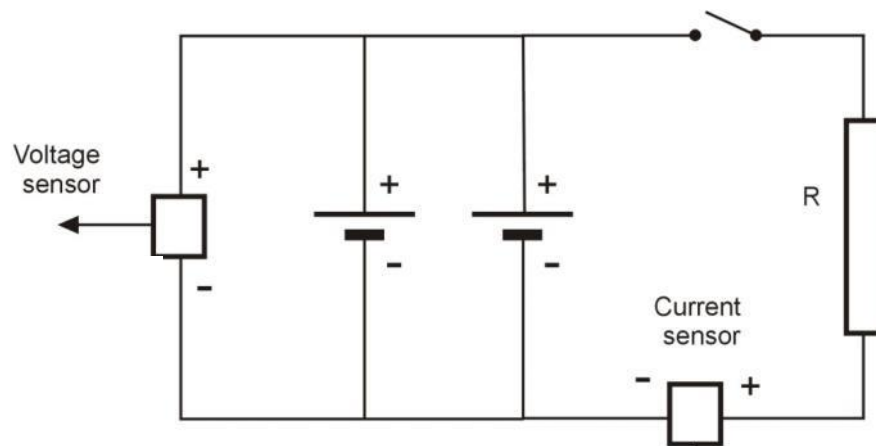





Figure 3

2. Make sure the switch is in the Off position.
3. Select **Manual Sampling** () to make the third reading. Record the values in your data table
4. Turn the switch to the On position.
5. Select **Manual Sampling** () to make the fourth reading. Record the values in your data table.
6. Return the switch to the Off position.
7. Select **Stop** () to stop collecting data.

Data Table

Batteries in series

	Voltage (V)	Current (A)
Switch is off		
Switch is on		

Batteries in parallel

	Voltage (V)	Current (A)
Switch is off		
Switch is on		



Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop.**

1. Explain why, when the switch is in the Off position, the voltage reading represents the electromotive force of the batteries.
2. Use Equation (1) to calculate the effective internal resistance in each of the different connections.
3. Do your calculations agree with expressions (2) and (3)?

Chapter 33

Charge Measurements in a Parallel Plate Capacitor

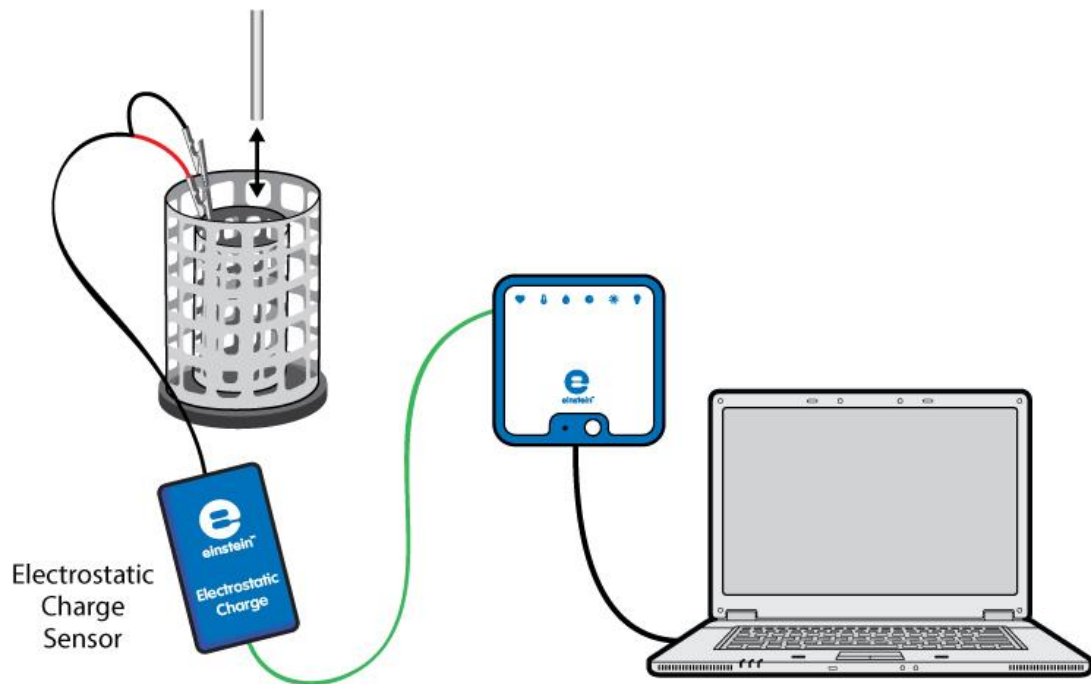


Figure 1

Introduction

A capacitor is an electronic component that is able to store electric charge. A parallel plate capacitor is composed of two parallel conductive plates that are placed close to each other. When connected to a power supply the inside surfaces of the plates are charged with equal and opposite charges. The charge on each plate is proportional to the applied voltage:

$$Q = CV \quad (1)$$

Where:

Q = The magnitude of the charge on each plate

C = A constant called capacitance that depends on the geometrical and physical properties of the capacitor

V = The applied voltage

In this activity we will explore the charge on a parallel plate capacitor.




Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Electrostatic Charge sensor
- Test leads with BNC connector
- Faraday ice pail
- Metal plate with handle (2)
- Right angle clamp (2)
- Stand (2)
- Black banana lead
- Red banana lead
- High voltage power supply
- Charge sampler

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Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect the Electrostatic Charge sensor to one of the ports on the einstein™LabMate.
3. Connect the test leads to the Electrostatic Charge sensor.
4. Assemble the equipment as shown in Figure 1.
5. Connect the red lead of the Electrostatic Charge sensor to the inner cylinder of the Faraday ice pail.
6. Connect the black lead to the outer cylinder of the Faraday ice pail.
7. Use the red banana lead to connect one plate to the +3 kV socket of the high voltage power supply (see Figure 2).
8. Use the black banana lead to connect the second plate to the -3 kV socket of the high voltage power supply (see Figure 2).
9. Position the two plates parallel to each other so that the distance between them is 3 cm (see Figure 2).
10. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Electrostatic Charge sensor is selected under **Measurements**.

Note: You may need to ground the outer cylinder of the Faraday ice pail.




Current Setup Summary

Program the sensor to log data according to the following setup:

Sensor:	Electrostatic Charge
Range:	$\pm 0.025 \mu\text{C}$
Measurements:	Charge $\pm 0.025 (\mu\text{C})$
Current Reading:	Set (sets as zero)
Rate:	10 samples per second
Samples:	1000
Duration:	1 minute 40 seconds



Procedure

1. Turn on the power supply.
2. Adjust the power supply's output voltage to 5 kV.
3. Short circuit the two leads of the Electrostatic charge sensor. To short circuit the sensor, connect the positive (red) and negative (black) leads.
4. Select **Run** () to begin recording data.
5. Touch the inside of the plate that is connected to the positive terminal of the power supply with the charge sampler (see Figure 2).

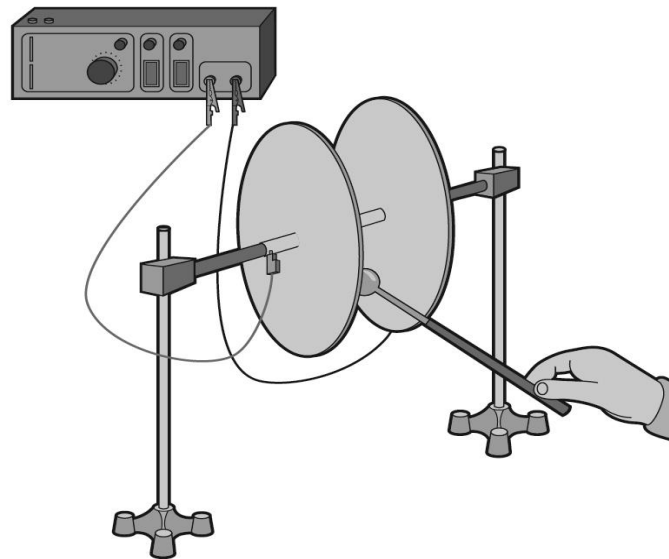


Figure 2

6. Lower the charge sampler into the inner basket of the Faraday ice pail. Record the data logger's readings in your data table.
7. Short circuit the two leads of the Electrostatic charge sensor.
8. Ground the charge sampler to remove its charge.
9. Touch the inside of the plate that is connected to the negative terminal of the power supply with the charge sampler, and then repeat steps 6 to 7.
10. Adjust the output voltage of the power supply to 4 kV and repeat steps 4 to 9.
11. Repeat this procedure for all output voltages listed in the data table.

Data Table

Output Voltage (kV)	Charge on Positive Plate (nC)	Charge on Negative Plate (nC)
5		
4		
3		
2		
1		



Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop.**

1. Compare the charge on the positive plate to the charge on the negative plate.
2. Plot a graph of the charge on one plate vs. the applied voltage.
3. Discuss the graph in regard to Equation (1).
4. Apply a linear fit to the plot.
5. Use the linear fit equation to calculate the capacitance of the parallel plate.



Questions

1. How are the plates charged?



Further Suggestions

1. Explore the dependence of the capacitance on the distance between the plates. How will your measurements change if the plates are closer to each other?

Chapter 34

Charging and Discharging a Capacitor

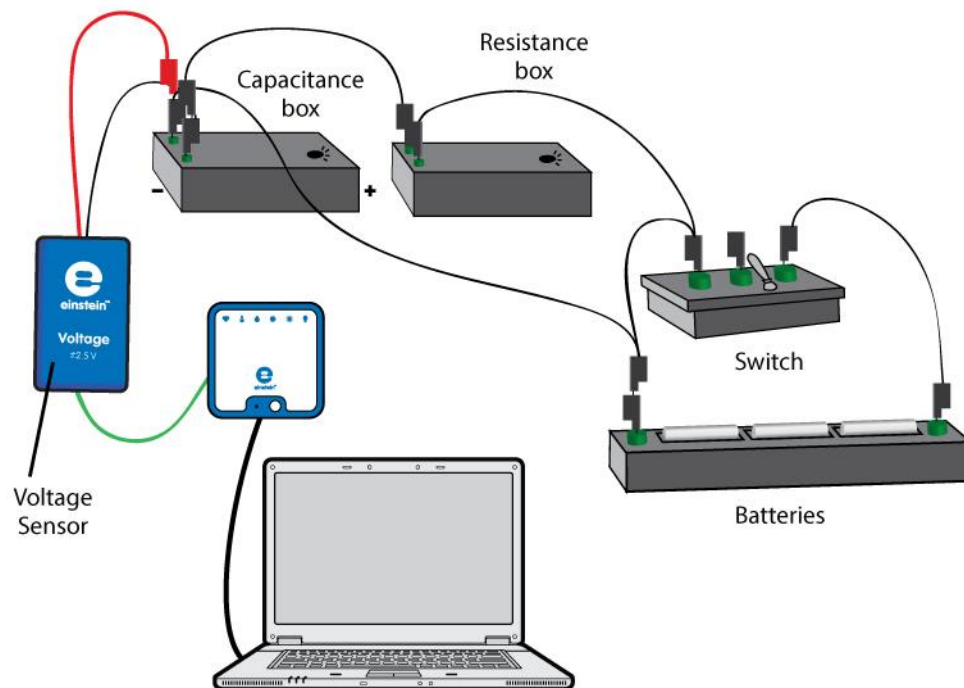


Figure 1

Introduction

When a capacitor and a resistor are connected in series to a DC voltage source the charging rate decreases as time passes. The charging current I is given by:

$$I = I_0 e^{-\frac{t}{RC}} \quad (1)$$

Where:

I_0 = The current at time $t=0$

R = The resistance

C = The capacitance

The voltage V across the capacitor gradually increases according to the following formula:

$$V = \varepsilon(1 - e^{-\frac{t}{RC}}) \quad (2)$$

Where:

ε = The electromotive force (EMF) of the source

When the charged capacitor is connected to a resistor, it will discharge and the potential difference across its terminals will exponentially decrease:

$$V = V_0 e^{-\frac{t}{RC}} \quad (3)$$

Where:

V_0 = The initial voltage of the capacitor

The natural logarithm of Equation (3) is:

$$\ln V = \ln V_0 - \frac{t}{RC} \quad (4)$$

And $\ln V$ as a function of time is a straight line with slope $-\frac{1}{RC}$.



Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Voltage sensor
- Box of capacitors
- Box of resistors
- 1.5 V battery with battery holder (3)
- Switch with one pole and two positions (1P2T)



Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect the Voltage sensor to one of the ports on the einstein™LabMate.
3. Assemble the electric circuit as shown by Figures 1 and 2:

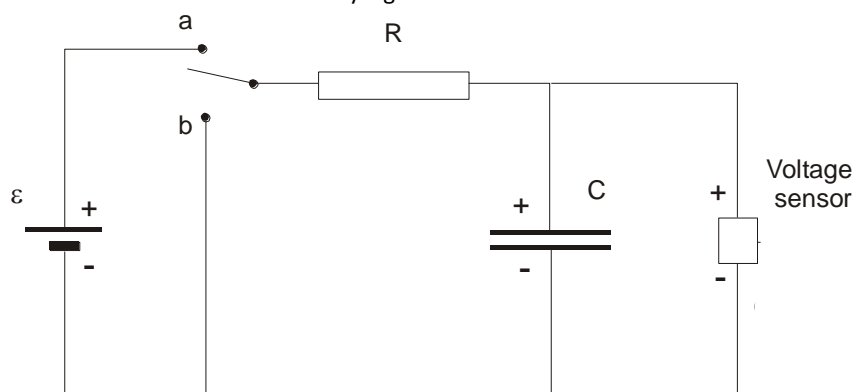


Figure 2

4. Select a capacitor of 1000μF and resistors of 500, 1000 or 2000 Ω.
5. Attach the red plug of the Voltage sensor to the higher potential terminal of the capacitor, as the Voltage sensor only measures in this polarity.
6. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Voltage sensor is selected under **Measurements**.




Current Setup Summary

Program the sensor to log data according to the following setup:

Sensor:	Voltage (± 2.5 V) or (± 25 V)
Measurements:	Voltage (V)
Current Reading:	Set (sets as zero)
Rate:	10 samples per second
Samples:	1000
Duration:	1 minute 40 seconds



Procedure

1. Move the switch to the “b” position (see Figure 2) and wait a few seconds for the capacitor to be completely discharged.
2. Select **Run** () to begin recording data.
3. Switch to the “a” position to start charging the capacitor.
4. When the capacitor is fully charged move the switch to the “b” position to record the discharging process.

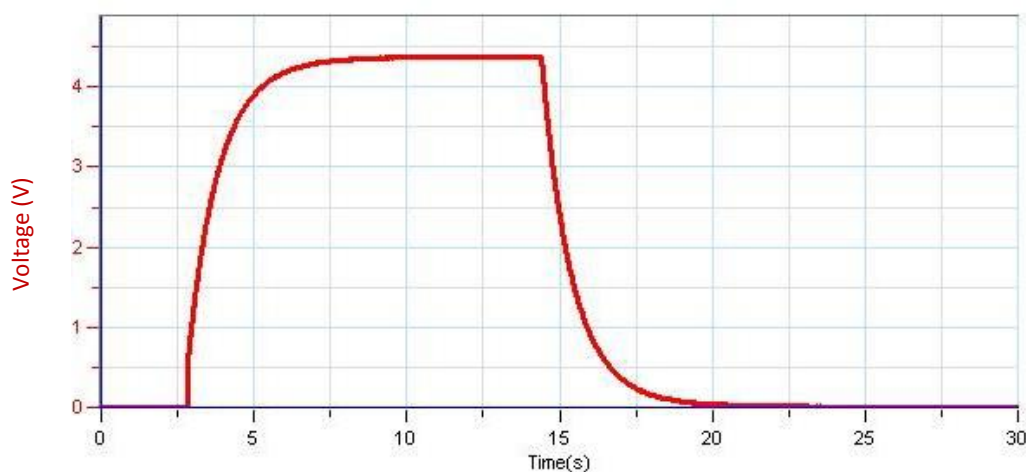





Figure 3

5. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.



Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop**.

1. Zoom in on the discharge part of the graph using the **Zoom** tool () on the **Graph** toolbar (see Figure 4).
2. Use **two cursors** () from the **Graph** toolbar to select the part of the graph that doesn't contain zero or near zero voltage values (see Figure 4).

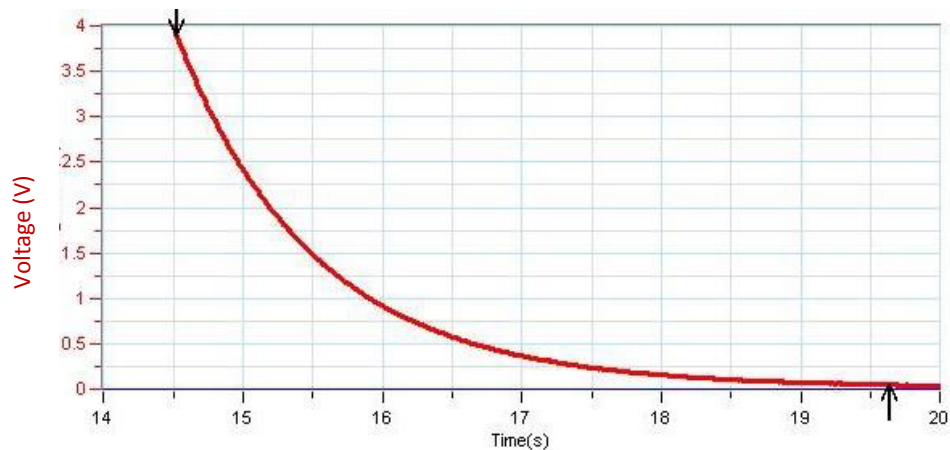


Figure 4

3. Select **Math functions** (f_{∞}) from the **Analysis** window on the upper menu bar.
 - a. In the **Math function** window which opens, choose **Ln** from the **Function** drop down menu.
 - b. In the **G1** drop down menu, select the voltage. This will give a graph of $\ln V$ vs. time (Figure 5).
4. Next, fit a line to your processed data:
 - a. Select **Curve fit** (fit) from the **Analysis** window on the upper menu bar.
 - b. In the **Curve fit** window which opens, choose **Linear** from the **Curve fit** drop down menu.
 - c. The fit equation will be displayed next to the second cursor

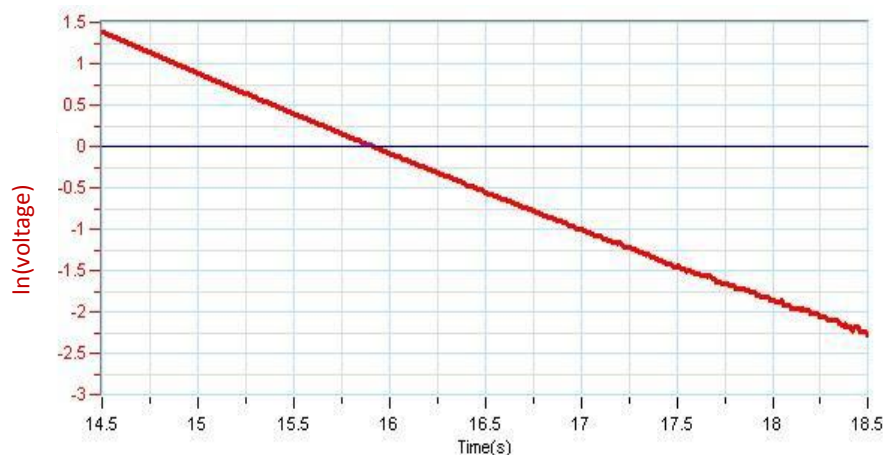


Figure 5


5. Verify that your results fit the theory (Equation (4)) by comparing the slope to its predicted value:

$$|slope| = \frac{1}{RC}$$



Further Suggestions

1. You can repeat the experiment with different resistors and capacitors.
2. You may use a Current sensor simultaneously with a Voltage sensor. You then have many options:
 - a. Plot the derivative of the voltage vs the current:
 - (i) (Select **Math functions** (f_{∞}) from the **Analysis** window on the upper menu bar.
 - (ii) In the **Math function** window which opens, choose **Derivative** from the **Function** drop down menu.

- (iii) In the G1 drop down menu select the voltage.
- (iv) The potential difference between the terminals of the capacitor is proportional to the charge on them, and since the current is the derivative of the charge it is expected that the voltage derivative will be proportional to the current.
- b. Plot the integral of the current vs the voltage.
 - i. Select **Math functions** () from the Analysis window on the upper menu bar.
 - ii. In the Math function window which opens, choose Integral from the Function drop down menu.
 - iii. In the **G1** drop down menu select the current.

Chapter 35

Magnetic Field of a Bar Magnet

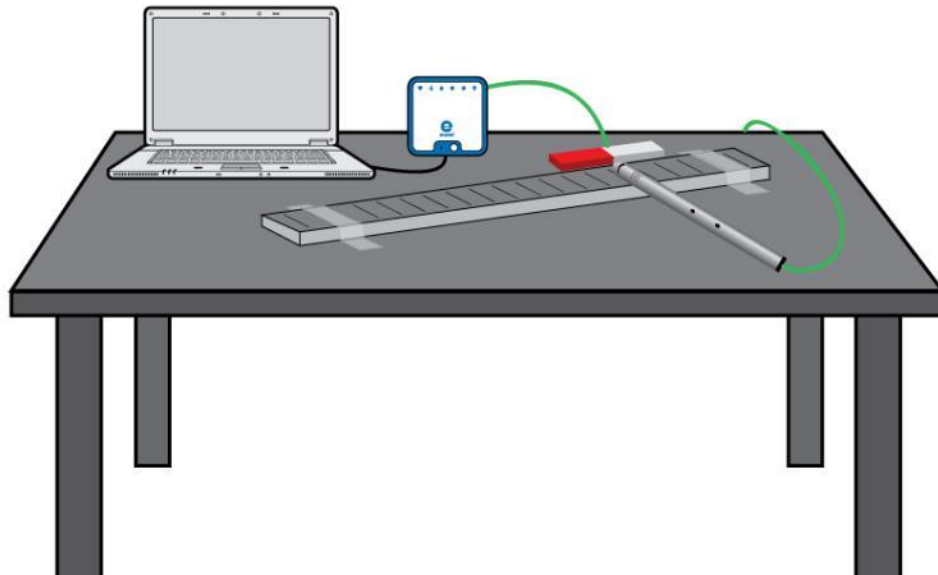


Figure 1



Introduction


A bar magnet is a seemingly ordinary piece of metal that induces a magnetic field in its vicinity. This magnetic field affects any magnetic material that lies within it. In this experiment you will explore the nature of the magnetic field that surrounds a bar magnet.



Equipment

- einstein™ LabMate and a computer with MiLAB Desktop
- Magnetic Field sensor
- Bar magnet
- Ruler (nonmetallic)
- Clear tape

123 Equipment Setup Procedure








1. Launch MiLAB Desktop ().
2. Connect the Magnetic Field sensor to one of the ports on the einstein™ LabMate.
3. Tape the ruler to the tabletop using clear tape.
4. Place the bar magnet next to the ruler so that the 4 cm mark on the ruler sits near one edge of the bar magnet (see Figure 1).
5. Use the pull down menu in the **Current Setup Summary** window to select the Magnetic Field sensor.
6. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Magnetic Field sensor is selected under **Measurements**.

Current Setup Summary

Program the sensor to log data according to the following setup:

Sensor:	Magnetic field ± 10 mT
Measurements:	Magnetic (mT)
Sampling:	Manual
Samples:	50

Procedure

1. Position the edge of the magnetic probe on the zero mark of the ruler. Make sure that the probe is perpendicular to the ruler.
2. Select **Run** () to enable data recording.
3. Collect the data manually: Select **Manual Sampling** () on the main toolbar each time you wish to record a data sample.
4. Select **Manual Sampling** () to record the magnetic field's strength at the 0 cm mark.
5. Now position the edge of the magnetic probe at the 1 cm mark of the ruler, keeping the probe perpendicular to the ruler, then select **Manual Sampling** () to record the magnetic field's strength at the 1 cm mark.
6. Move the sensor along the ruler at 1 cm intervals. Each time take a reading manually by selecting **Manual Sampling** () until you have reached a point 4 cm beyond the other end of the bar magnet.
7. Select **Stop** () to stop collecting data.
8. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.



Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop.**

Observe the graph on the MiLAB Desktop screen and answer the following questions.

Use the cursors to read values on the graph. The point values will be displayed in the information bar on the graph.

1. What was the strongest positive magnetic field in the vicinity of the bar magnet?
2. Where on the bar magnet did you measure the strongest positive magnetic field?
3. What was the most negative magnetic field in the vicinity of the bar magnet?
4. Where on the bar magnet did you measure the most negative magnetic field?
5. Where on the bar magnet did you measure zero magnetic field?
6. What can you infer from the fact that the magnetic field around a bar magnet has both positive and negative values? Will two bar magnets attract or repel each other?



Further Suggestions

1. Explore the magnetic field of a pair of bar magnets.
2. Explore the magnetic field of a horseshoe (U-shaped) magnet.

Chapter 36

The Magnetic Field Near a Current-Carrying Wire

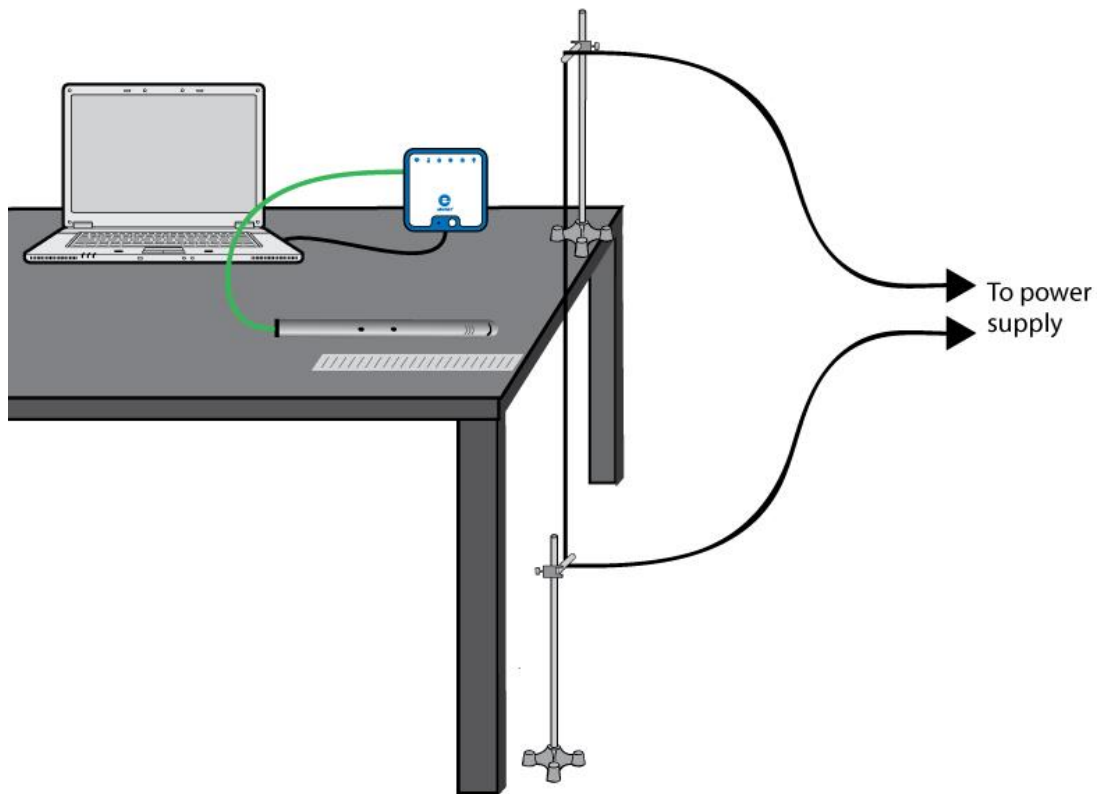


Figure 1

Introduction

An electric current produces a magnetic field. When an electric current is running through a long wire, the magnetic field (B) near the wire is given by:

$$B = \frac{\mu_o}{2\pi} \cdot \frac{I}{r} \quad (1)$$

Where:

μ_o = The permeability of free space (the magnetic constant)

I = The current through the wire

r = The distance from the wire

In this experiment we will use the Magnetic Field sensor to explore the strength of the magnetic field near a long conductive wire while it is carrying a current.



Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Magnetic Field sensor
- Long conductive wire (about 2 m long)
- 10 A DC power supply
- Stand (2)
- Right angle clamp (2)
- Short plastic rod (2)
- Ruler (nonmetallic)
- Clear tape



Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect the Magnetic Field sensor to one of the ports on the einstein™LabMate.
3. Assemble the equipment as shown in Figure 1.
 - a. Use the right angle clamps to attach the plastic rods to the stands.
 - b. Place one stand on the table and the other stand on the floor below it.
 - c. Tape the wire to both the plastic rods. Make sure that the wire is tight and touches the table's edge.
 - d. Tape the ruler to the tabletop with clear tape. Make sure that the zero mark is up against the wire.
 - e. Connect the two ends of the wire to the power supply.
 - f. Set the sensor switch to the high sensitivity range.
4. Use the pull down menu in the **Current Setup Summary** window to select the Magnetic Field sensor.
5. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Magnetic Field sensor is selected under **Measurements**.



Current Setup Summary






Program the sensor to log data according to the following setup:

Sensor:	Magnetic Field ± 0.2 mT
Measurements:	Magnetic (mT)
Sampling:	Manual
Samples:	50



Procedure

1. Position the edge of the magnetic probe on the 1 cm mark of the ruler. Make sure that the probe is perpendicular to the table edge (see Figure 1).
2. Open the **Meter Window** () from the **Work Space** menu bar. Use the **Digital** () display option.
3. Select **Run** () to enable data recording. Collect the data manually: Select **Manual Sampling** () on the main toolbar each time you wish to record a data sample.

- Record the background magnetic field strength at this point by selecting **Manual Sampling** ().
Record the value in your data table.
- Turn on the power supply and adjust it to 10 A.
- Select **Manual Sampling** () to record the magnetic field strength at this point. Record the value in the data table.
- Now position the edge of the magnetic probe on the 2 cm mark of the ruler, keeping the probe perpendicular to the table edge. Select **Manual Sampling** () again and record the value in the data table.
- Move the sensor along the ruler in 1 cm steps. Each time taking a reading manually by selecting **Manual Sampling** ().
- Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.

Data Table

Background magnetic field = _____


mT = _____ T

Distance from Wire (cm)	Reciprocal of Distance (1/m)	Magnetic Field with Background (mT)	Magnetic Field without Background (T)
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			



Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop**

- Select **Export** () from the **Graph** toolbar to export the data as a csv file.
- Open the exported data file with an appropriate spreadsheet or graphing program.
- Plot a graph of the magnetic field without background (y-axis) vs. the distance from wire (x-axis).
- Discuss the graph.
- Plot a graph of the magnetic field without background (y-axis) vs. the reciprocal of the distance from the wire (x-axis).
- Fit a straight line that passes through the data points. What are the units of the slope?
- Use the slope of the straight line fit to calculate μ_0 (the permeability of free space or magnetic constant). Record the result.
- Compare your results with the known value: $\mu_0 = 4\pi \cdot 10^{-7} \text{ T} \cdot \text{m/A}$.



Further Suggestions

1. Explore the magnetic field as a function of the current.
2. Explore the magnetic field of two parallel long conductive wires carrying current in opposite directions.
3. Explore the magnetic field of two parallel long conductive wires carrying current in the same direction.

Chapter 37

The Magnetic Field of a Solenoid

Part A: Measuring B vs. I

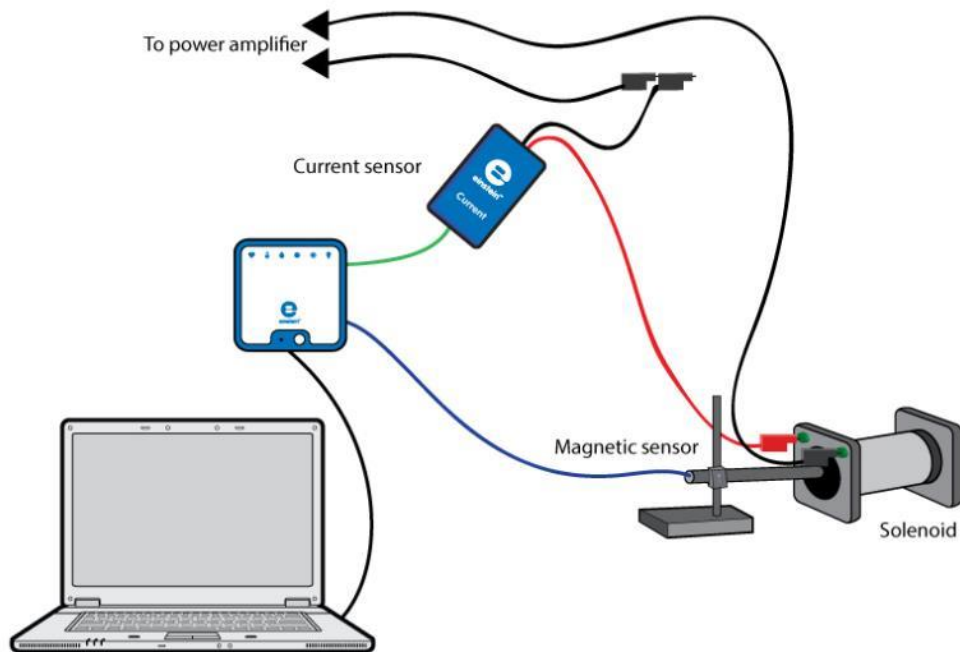


Figure 1



Introduction

A solenoid is a type of electromagnet created by winding a wire into a tight helix. When a current runs through a wire, the current creates a magnetic field around the wire. When a current is passed through the solenoid's coiled wire, it generates a magnetic field in the center of the solenoid coil. In this experiment we will explore the relationship between the magnetic field in the center of a solenoid and the current passing through the solenoid's helically wound wire.

The magnetic field in the center of a solenoid will be measured with the help of the Magnetic Field sensor. At the same time, the current through the solenoid will be measured with the Current sensor.

We will use a signal generator to sweep through a range of currents, so that we can produce a live graph of magnetic field (B) vs. current (I).

In the case of a long solenoid, the magnetic field in the center of the solenoid is given by:

$$B = \frac{\mu_0 N I}{\ell} \quad (1)$$

Where:

μ_0 = The permeability of free space (the magnetic constant)

N = The number of turns of the wound coil

I = The current through the solenoid

ℓ = The length of the solenoid




Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Magnetic Field sensor
- Current sensor (± 2.5 A)
- Solenoid
- Stand to hold the Magnetic Field sensor
- Signal generator with power amplifier



Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect the Magnetic Field sensor to one of the ports on the einstein™LabMate.
3. Connect the Current sensor to one of the ports on the einstein™LabMate.
4. Assemble the equipment as shown in Figure 1.
5. Place the Magnetic Field sensor so that its end can be placed at the center of the solenoid.
6. Set the signal generator to triangular waveform and its frequency to 0.1 Hz.
7. Set the output level so that the current won't exceed 2.5 A.
8. Set the sensor switch to the low sensitivity range.
9. Use the pull down menu in the **Current Setup Summary** window to select the Magnetic Field sensor.
10. In the window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Magnetic Field and Current sensors are selected under **Measurements**.




Current Setup Summary

Program the sensors to log data according to the following setup:


Sensor:	Magnetic Field ± 10 mT
Measurements:	Magnetic (mT)
Sensor:	Current (± 2.5 A)
Measurements:	Current (A)
Current Reading:	Set (sets as zero)
Rate:	100 samples per second
Samples:	2000
Duration:	20 seconds



Procedure

1. Place the Magnetic Field sensor so that its end is in the center of the solenoid.
2. Turn on the signal generator.
3. Select **Run** () to begin recording data.
4. The data logger will graph the data from the two sensors. The graph will show both the magnetic field and the current as a function of time, each in a separate color (Figure 2). Check that both the magnetic

field and the current appear to follow the same trend. Change the direction of the current in the solenoid and repeat the experiment if the trend is not the same.

5. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.

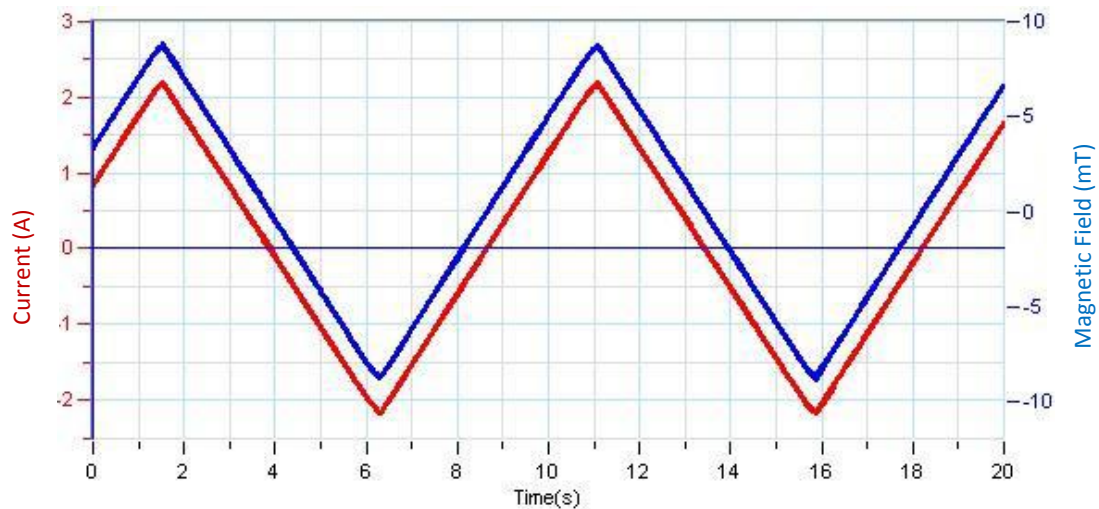


Figure 2



Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop.**

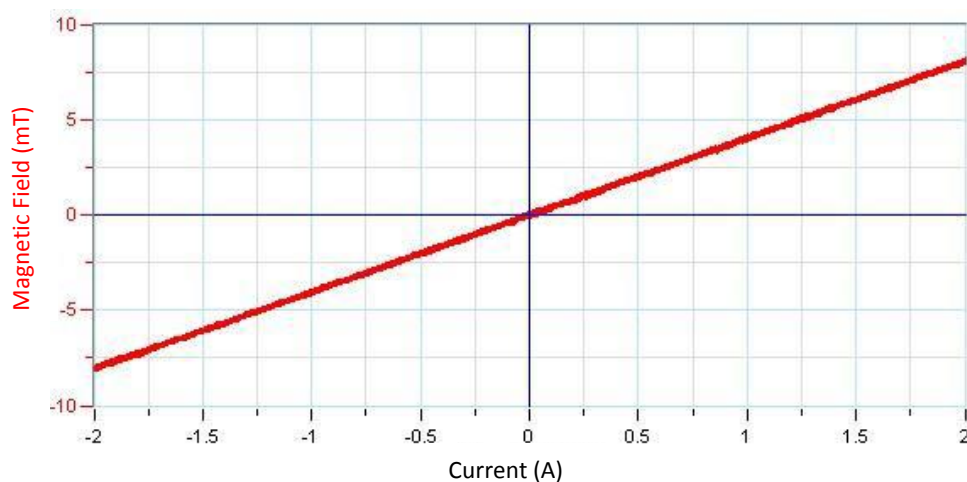



Figure 3

1. Create a graph of magnetic field vs current by selecting the down arrow (▼) from the **Graph** toolbar and choosing Current as your x-axis measure (Figure 3).
2. Apply a linear fit to the graph:
 - a. Select **Curve fit** () from the **Analysis** window on the upper menu bar.
 - b. In the **Curve fit** window which opens, choose **Linear** from the **Curve fit** drop down menu.
 - c. The fit equation will be displayed next to the second cursor.
3. Use the slope of the linear regression to calculate μ_0 , the permeability of free space (the magnetic constant). Write it down in your notebook.

Compare your result with the known value: $\mu_0 = 4\pi \cdot 10^{-7} \text{ T} \cdot \text{m/A}$.

Chapter 38

The Magnetic Field of a Solenoid

Part B: Measuring B vs. x

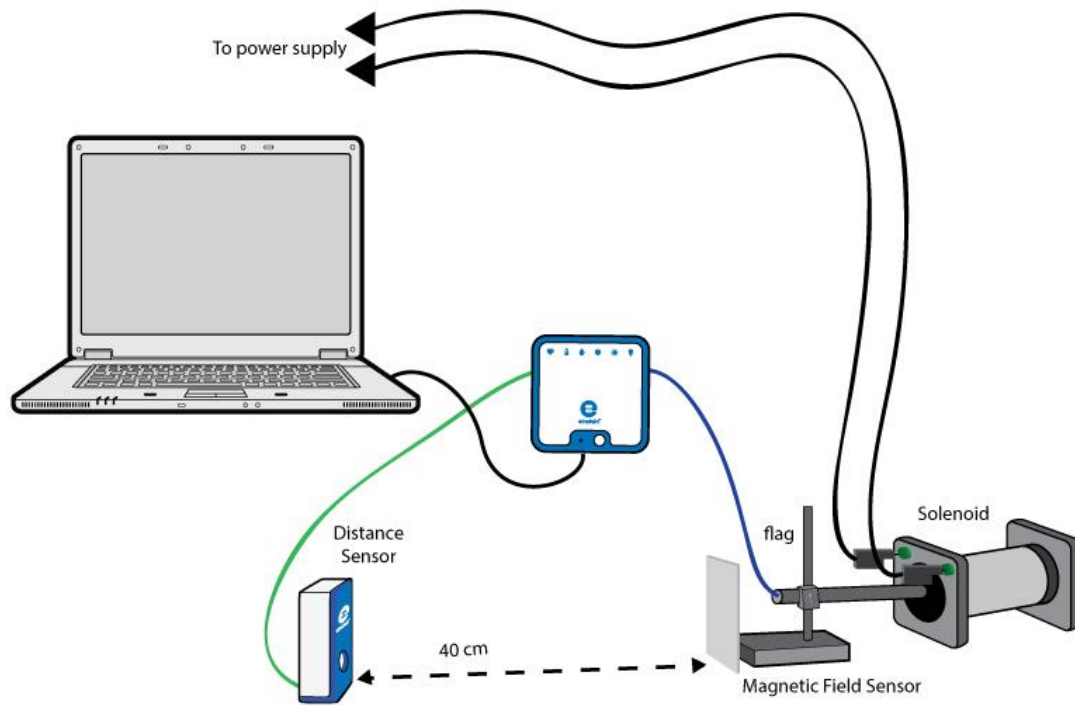


Figure 1

Introduction

A solenoid is a type of electromagnet created by winding a wire into a tight helix. When a current runs through a wire, the current creates a magnetic field around the wire. When a current is passed through the solenoid coiled wire, it generates a magnetic field in the center of the solenoid coil. In this experiment we will map the strength of the magnetic field along the length of a solenoid. This will create a picture of the magnetic field generated by the electromagnetic solenoid.

In this experiment we are mapping the magnetic field along the axis of the solenoid. The magnetic field is measured with the help of the Magnetic Field sensor. At the same time the position of the Magnetic Field sensor is measured with the Distance sensor, so that we can produce a graph of the magnetic field along the length of the solenoid.




Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Magnetic Field sensor
- Distance sensor
- Stands to hold the Magnetic Field sensor
- 10x10 cm piece of cardboard or plastic to use as a flag
- D.C. power supply

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Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect the Magnetic Field sensor to one of the ports on the einstein™LabMate.
3. Connect the Distance sensor to one of the ports on the einstein™LabMate.
4. Assemble the equipment as shown by Figure 1:
 - a. Mount the Magnetic Field sensor on the stand.
 - b. Attach the flag to the stand on the opposite side of the sensor.
 - c. Place the Magnetic Field sensor so that its end is 4 cm in front of the solenoid.
 - d. Place the Distance sensor at least 40 cm away from the flag.
5. Set the output level of the power supply so that the current won't exceed the maximum continuous current of the solenoid.
6. Set the sensor switch to the low sensitivity range.
7. Use the pull down menu in the **Current Setup Summary** window to select the Magnetic Field sensor.
8. In the window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Magnetic Field and Distance sensors are selected under **Measurements**.




Current Setup Summary

Program the sensors to log data according to the following setup:


Sensor:	Magnetic Field ± 10 mT
Measurements:	Magnetic (mT)
Sensor:	Distance
Measurements:	Distance (m)
Rate:	10 samples per second
Samples:	200
Duration:	20 seconds



Procedure

1. Select **Run** () to begin recording data.
2. Move the stand so that the Magnetic sensor is pointing toward the center of the solenoid. Move slowly. You have 10 seconds before the sampling stops.
3. The data logger will graph the data from the two sensors. The graph will show both the magnetic field strength and the position of the magnetic field sensor as a function of time, each in a separate color (Figure 2, already zoomed). When the magnetic sensor is moved along the length of the solenoid in

smooth even steps, the graph of the position as a function of time will appear as a straight line (Figure 2). If you suspect that the motion was not smooth enough or if you didn't succeed in reaching the far end of the solenoid, repeat the experiment.

4. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.

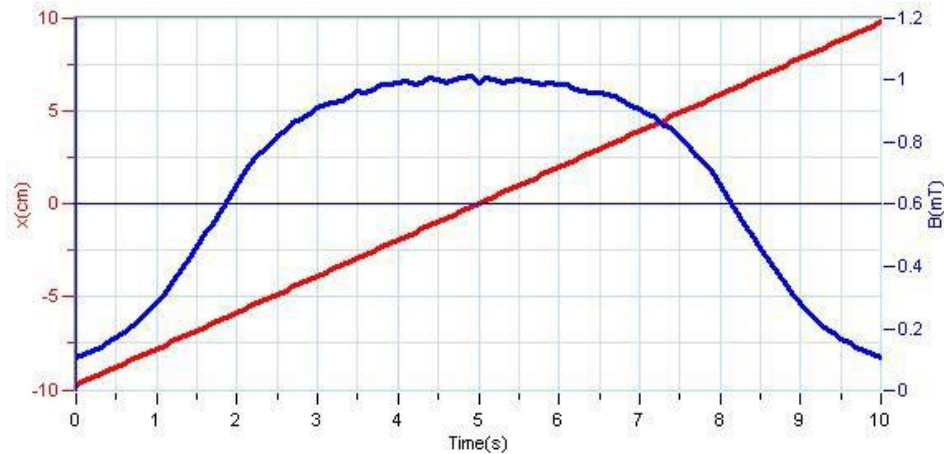


Figure 2

Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop**.

1. Create a graph of magnetic field vs. position by selecting the down arrow (▼) from the **Graph** toolbar and choosing Distance as your x-axis measure (Figure 3).

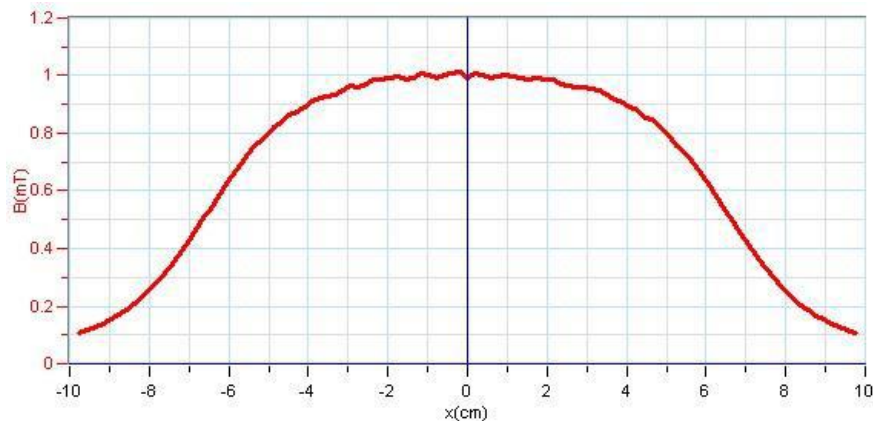


Figure 3

2. Discuss the graph.
3. Use the cursor to read the value of the magnetic field in the center of the solenoid. Write it down in your notebook.
4. Use the cursor to read the value of the magnetic field at the end of the solenoid. Write it down in your notebook. It should be half the of the center value.

Chapter 39

Magnetic Field of Helmholtz Coils

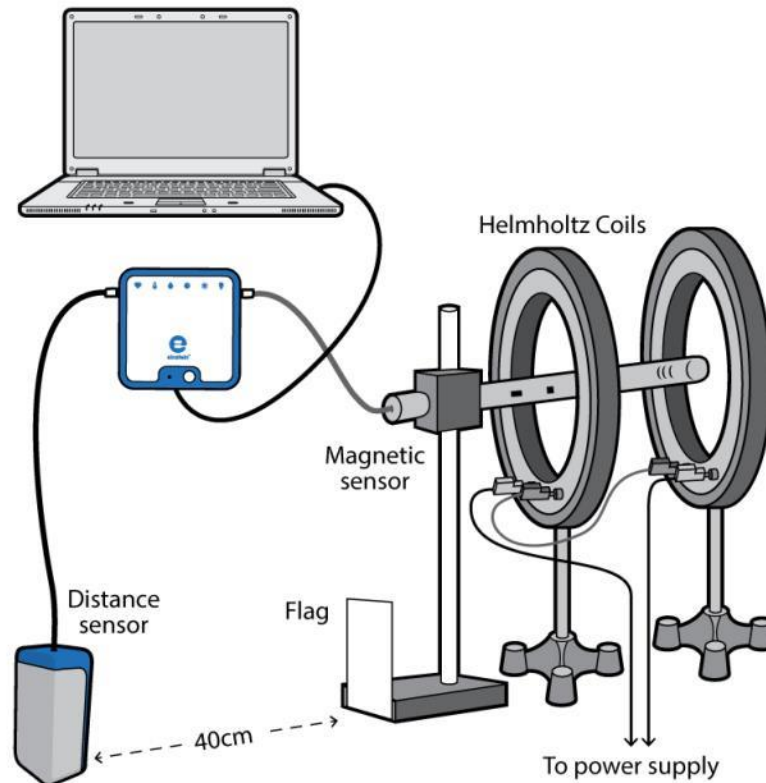


Figure 1



Introduction

Helmholtz coils are a pair of two circular wound wire coils having the same radius - R , the same number of wound turns - N and both carrying the same current - I . When two such identical coils are placed parallel to each other and separated by a distance equal to their radius, the result is a very uniform magnetic field between the two coils.

The strength of the magnetic field B in the center of the Helmholtz pair is given by:

$$B = \frac{8\mu_0 NI}{R\sqrt{125}} \quad (1)$$

Where:

μ_0 = The permeability of free space (the magnetic constant) = $4\pi \cdot 10^{-7} \text{ T}\cdot\text{m/A}$

N = The number of turns of the wound coil

I = The current through the solenoid

R = The radius of the coils

In this experiment we will explore the uniformity of the magnetic field between the pair of coils and how it is dependent on the distance between the coils.

The magnetic field will be measured with the Magnetic Field sensor. At the same time, the position of the Magnetic Field sensor will be measured with the Distance sensor, so that we will be able to create a graph of magnetic field strength - B as a function of position.




Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Magnetic Field sensor (± 10 mT)
- Distance sensor
- Pair of Helmholtz coils
- Stand to hold the Magnetic Field sensor
- 10x10 cm piece of cardboard or plastic to use as a flag
- D.C. power supply



Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect the Magnetic Field sensor to one of the ports on the einstein™LabMate.
3. Connect the Distance sensor to one of the ports on the einstein™LabMate.
4. Assemble the equipment as shown in Figure 1.
 - a. Mount the Magnetic Field sensor on the stand.
 - b. Attach the flag to the stand on the opposite side of the sensor.
 - c. Place the Magnetic Field sensor so that its end is 4 cm in front of the first coil.
 - d. Place the Distance sensor at least 40 cm away from the flag.
5. Set the output level of the power supply so that the current won't exceed the maximum continuous current of the coils.
6. Set the sensor switch to the low sensitivity range.
7. Use the pull down menu in the **Current Setup Summary** window to select the Magnetic Field sensor.
8. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Magnetic Field and Current sensors are selected under **Measurements**.




Current Setup Summary

Program the sensors to log data according to the following setup:

Sensor:	Magnetic Field ± 10 mT
Measurements:	Magnetic (mT)
Sensor:	Current (± 2.5 A)
Measurements:	Current (A)
Current Reading:	Set (sets as zero)
Rate:	10 samples per second
Samples:	200
Duration:	20 seconds



Procedure

1. Select **Run** () to begin recording data.

2. Move the stand so that the Magnetic sensor is pointing toward the center of the coils. Move slowly. You have 20 seconds before the sampling stops.
3. The data logger will graph the data from the two sensors. The graph will show both the magnetic field strength and the position of the magnetic field sensor as a function of time, each in a separate color (Figure 2). When the magnetic sensor is moved along the length of the axis of the Helmholtz coils in smooth even steps, the graph of the position as a function of time will appear as a straight line (Figure 2). If you suspect that the motion was not smooth enough or if you didn't succeed in reaching the far end of the solenoid, repeat the experiment.

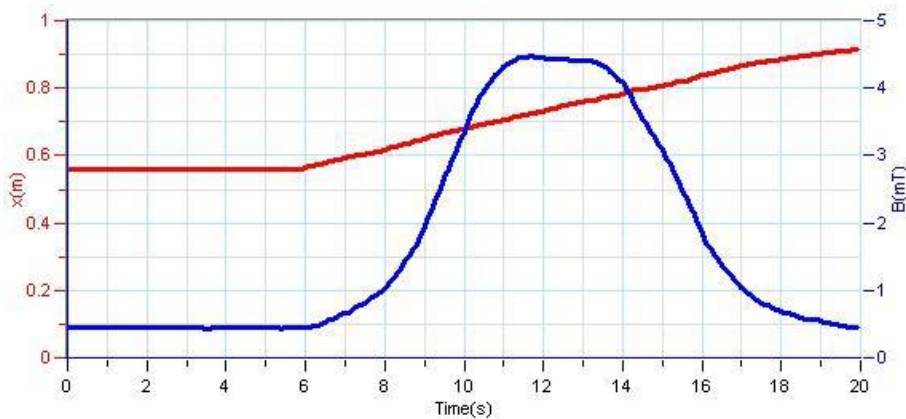


Figure 2



Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop.**

1. Create a graph of magnetic field vs. position by selecting the down arrow (▼) from the **Graph** toolbar and choosing Distance as your x-axis measure (Figure 3).

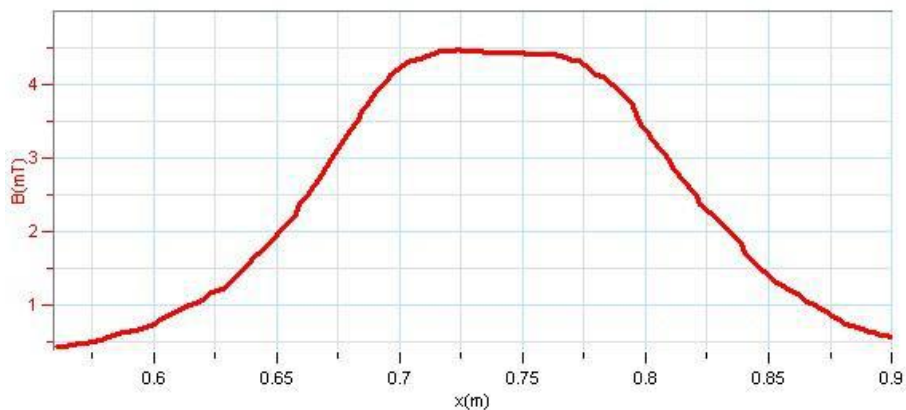


Figure 3

2. Use the cursor to read the value of the magnetic field at the center of the Helmholtz coils.
3. Write the value down in your notebook and compare it to the theoretical value (refer to the Introduction).
4. Discuss the uniformity of the magnetic field.



Further Suggestions

1. Reduce the distance between the coils by a centimeter or two and repeat the experiment. Discuss the uniformity of the magnetic field in this case (see Figure 4).

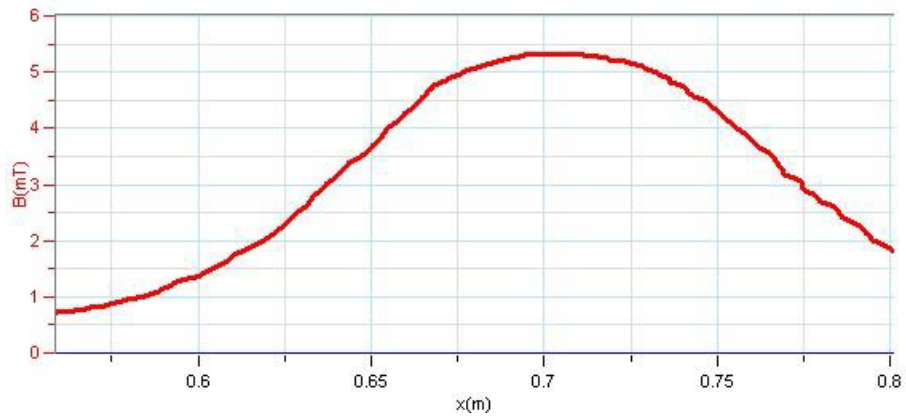


Figure 4

2. Change the distance between the coils to a centimeter or two more than the radius and repeat the experiment. Discuss the uniformity of the magnetic field in this case (see Figure 5).

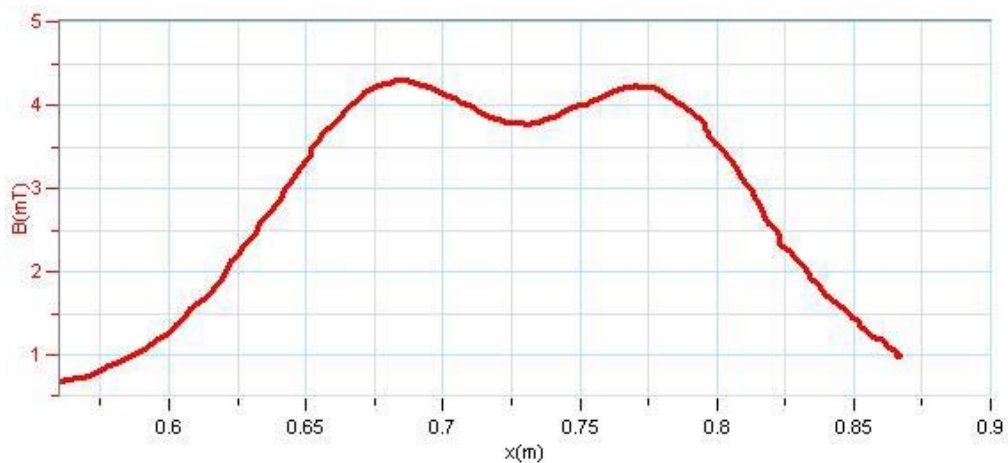


Figure 5

Chapter 40

The Magnetic Field of the Earth

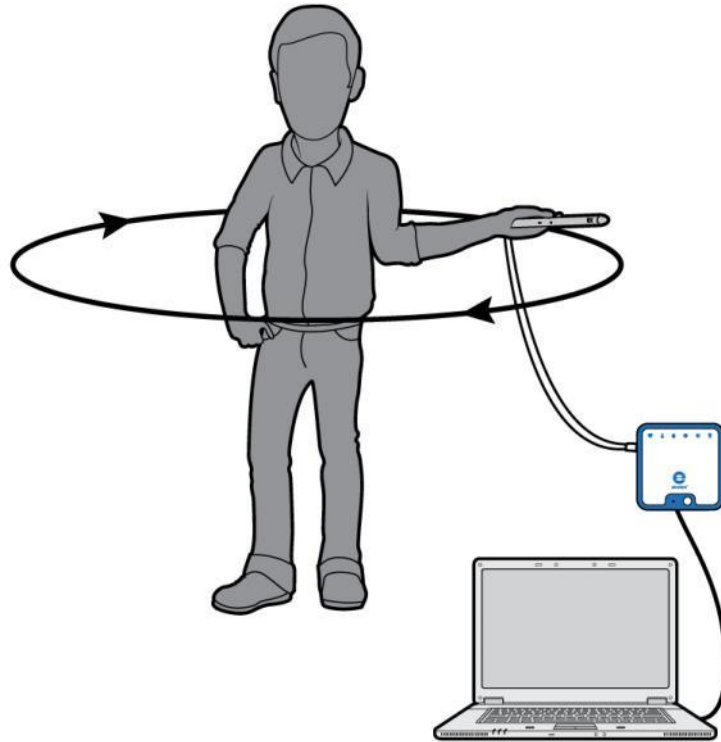


Figure 1



Introduction

In this experiment we explore the magnetic field of the Earth.


We determine the magnitude and the direction of Earth's magnetic field, and its inclination.



Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Magnetic Field sensor
- Compass
- Protractor
- Plumb (or level)

123 Equipment Setup Procedure


1. Launch MiLAB Desktop ().
2. Connect the Magnetic Field sensor to one of the ports on the einstein™ LabMate.
3. Set the sensor switch to the high sensitivity range.
4. Use the pull down menu in the **Current Setup Summary** window to select the Magnetic Field sensor.
5. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Magnetic Field sensor is selected under **Measurements**.

Current Setup Summary

Program the sensors to log data according to the following setup:

Sensor:	Magnetic Field ± 0.2 mT
Measurements:	Magnetic (mT)
Rate:	10 samples per second
Samples:	500
Duration:	50 seconds

Procedure

1. Find a place in your laboratory as far from ferromagnetic materials and magnetic fields as possible. You will need enough space to rotate your body 360 degrees with your arm outstretched.
2. Select **Run** () to begin recording data.
3. Hold the sensor in your hand and extend your arm to fully outstretched. Rotate your body and the sensor, making a full circle staying within a horizontal plane. Make sure to hold the sensor so that you maintain a constant distance from the ground.
4. Find the angle for which the readings are maximal and remain in this position (see Figure 2). Now rotate the sensor a full circle in a vertical plane.

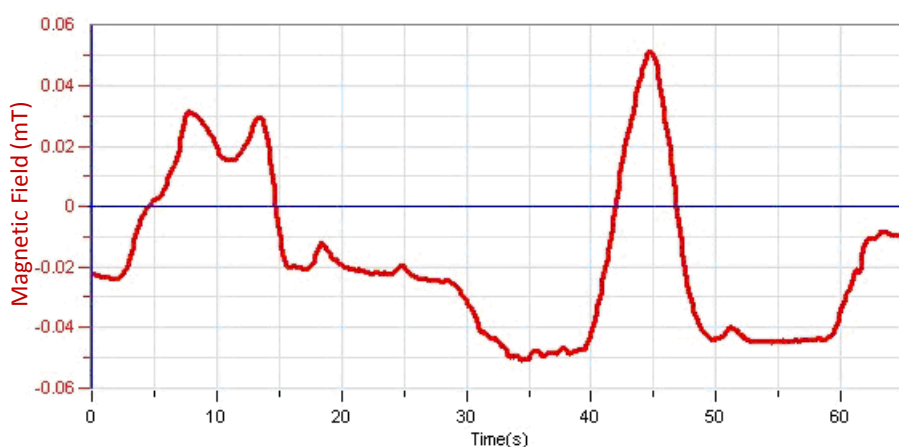






Figure 2

Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop**.

1. Zoom in on the data acquired during the vertical circling using the **Zoom** tool () on the **Graph** toolbar.
2. Use **two cursors** () from the **Graph** toolbar to select the maximum and minimum in this part of the graph. The difference between these points will be now displayed in the information bar in the graph window. That should be twice the magnitude of the vertical component of the magnetic field of the Earth.
3. Write this value down in your notebook.
4. Zoom in on the data acquired during the horizontal circling using the **Zoom** tool () on the **Graph** toolbar.
5. Use **two cursors** () from the **Graph** toolbar to select the maximum and minimum in this part of the graph. This difference between these points will be now displayed in the information bar in the graph window. That should be twice the magnitude of the horizontal component of the magnetic field of the Earth.
6. Write this value down in your notebook.
7. Use these two results to find the angle of inclination of the magnetic field of the Earth.
8. Write the angle down in your notebook.

Chapter 41

Induction Current and Electromotive Force

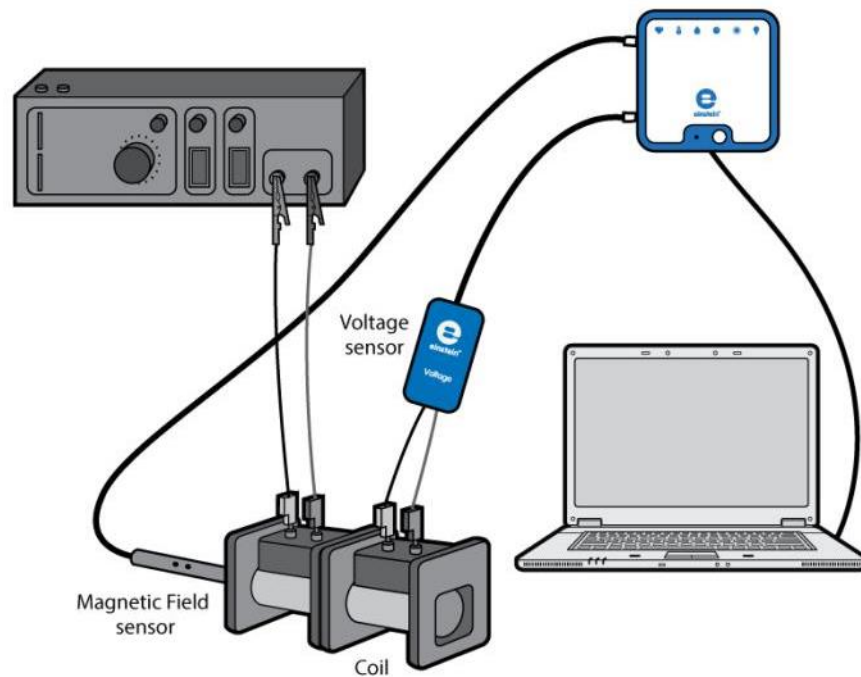


Figure 1

Introduction

Electromagnetic induction is the production of an electrical potential difference (voltage) across a conductor situated in a changing magnetic field. Michael Faraday was the first to describe this phenomenon mathematically. He found that the electromotive force (EMF) produced along a closed path is proportional to the rate of change of the magnetic flux through any surface bounded by that path. In practice, this means that an electrical current will flow in any closed conductor, when the magnetic flux through a surface bounded by the conductor changes. This applies whether the field itself changes in strength or the conductor is moved through it.

The mathematical expression of Faraday's Law is given by:

$$\varepsilon = \frac{\Delta\Phi}{\Delta t} \quad (1)$$

Where:

ε = The electromotive force (EMF) produced along a closed path

Φ = The magnetic flux through any surface bounded by that path

In this experiment we will investigate this relationship.




Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Voltage sensor (± 2.5 V)
- Magnetic Field sensor
- Two coils with the same physical dimensions. One with about 500 turns and the other with about 10,000 turns
- Signal generator with power output
- Connecting wires

123

Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect the Magnetic Field sensor to one of the ports on the einstein™LabMate.
3. Connect the Voltage sensor to one of the ports on the einstein™LabMate.
4. Assemble the equipment as shown in Figure 1.
 - a. Place the coils on the table and orient them so that they are end to end.
 - b. Connect the low turn coil (primary coil) to the power supply.
 - c. Connect the high turn coil (secondary coil) to the Voltage sensor.
 - d. Insert the Magnetic Field sensor into the low turn coil.
 - e. Set the sensor switch to the high sensitivity range.
5. Use the pull down menu in the **Current Setup Summary** window to select the Magnetic Field sensor.
6. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Magnetic Field and Voltage sensors are selected under **Measurements**.






Current Setup Summary

Program the sensors to log data according to the following setup:

Sensor:	Magnetic Field ± 0.2 mT
Measurements:	Magnetic (mT)
Sensor:	Voltage (± 2.5 V)
Measurements:	Voltage (V)
Current Reading:	Set (sets as zero)
Rate:	100 samples per second
Samples:	1000
Duration:	10 seconds




Procedure

1. Turn on the signal generator.
2. Adjust the signal generator to a frequency of 1 Hz and a triangular waveform.
3. Select **Run** () to begin recording data.
4. Wait for 20 s then select **Stop** ().
5. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.
6. Change the signal generator's frequency to 2 Hz and repeat steps 3 to 6.
7. Return to frequency of 1Hz and change the signal generator's waveform to sinusoidal, then repeat steps 3 to 6.



Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop**

1. Select **Graph Window** () from the **Work Space** menu bar to open a new **Graph Window**. Drag the data folder from the first experiment to this window in order to display the first graph you have produced.
2. Discuss the graph in view of Faraday's Induction Law (Equation (1)).
3. Drag the data folder from the second experiment to this window to display the second graph you have produced.
4. Discuss the graph in view of Faraday's Induction Law. What was the effect of doubling the frequency?
5. Drag the data folder from the third experiment to this window to display the third graph you have produced.
6. Discuss the graph in view of Faraday's Induction Law. Does the induced voltage graph fit the derivative of the magnetic field function?

Chapter 42

The Transformer

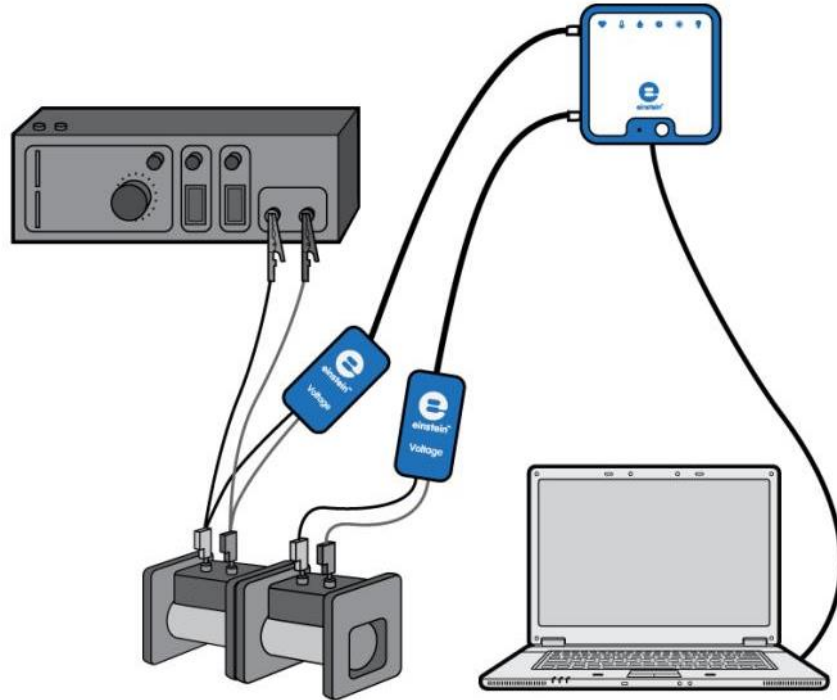


Figure 1



Introduction

When an alternating current is passed through a coil, a changing magnetic field is produced. This magnetic field is proportional to the number of turns of the coil. For an infinite solenoid the magnetic field B is given by:

$$B = \frac{\mu_0 N I}{\ell} \quad (1)$$

Where:

μ_0 = The permeability of free space (the magnetic constant)

N = The number of turns of the wound coil

I = The current through the solenoid

ℓ = The length of the solenoid

If we have two coils with different numbers of turns, N_1 and N_2 , we can pass a current through one coil and use the resulting fluctuating magnetic field to induce an electromotive force in the second coil by placing it in the vicinity of this magnetic field. Using Faraday's Law the resulting electromotive force is equal to:

$$\varepsilon = -N \frac{\Delta \Phi}{\Delta t} \quad (2)$$

Where:

N = The number of turns of the coil

ε = The electromotive force (EMF) induced in the coil

Φ = The magnetic flux through the coil

Assuming that all the magnetic flux created by the first (primary) coil flows through the second (secondary) coil we get the transformer equation:

$$\frac{\varepsilon_1}{\varepsilon_2} = \frac{N_1}{N_2} \quad (3)$$

Where ε_1 and N_1 are the electromotive force and number of turns of the primary coil, through which the current is passed. ε_2 and N_2 are the electromotive force and number of turns of the secondary coil, in which the electromotive force is induced.

In this activity we will investigate Equation (3).




Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Voltage sensor (± 25 V)
- Voltage sensor (± 2.5 V)
- Signal generator
- Power supply
- Coil (400 turns)
- Coil (1600 turns)
- Armature
- U core with armature
- Banana cord (2)



Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect the ± 2.5 Voltage sensor to one of the ports on the einstein™LabMate then connect it to the 400 turns coil (primary coil).
3. Connect the ± 25 Voltage sensor to one of the ports on the einstein™LabMate then connect it to the 1600 turns coil (secondary coil).
4. Assemble the equipment as shown in Figure 1.
 - a. Use the banana cords to connect the 400 turns coil (primary coil) to the power output of the signal generator.
 - b. Place the 1600 turns coil (secondary coil) next to the primary coil.
5. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the two Voltage sensors are selected under **Measurements**.








Current Setup Summary

Program the sensors to log data according to the following setup:

Sensor:	Voltage (± 2.5 V)
Measurements:	Voltage (V)
Current Reading:	Set (sets as zero)
Sensor:	Voltage (± 25 V)
Measurements:	Voltage (V)
Current Reading:	Set (sets as zero)
Rate:	100 samples per second
Samples:	2000
Duration:	20 seconds



Procedure

- Turn on the signal generator and set it to:
 Output voltage: ~ 2 V
 Frequency: 5 Hz
 Waveform: Sinusoidal
- Select **Run** () to begin recording data.
- After a couple of seconds select **Stop** ().
- Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.
- Use the **first** () and **second** () cursors to measure the voltage drops across the primary and secondary coils. Record the values in your notebook.
- Insert the armature to both the coils and repeat steps 2 to 5.
- Mount the coils on the U core and close it with the armature.
- Repeat steps 2 to 5.
- Set the signal generator's frequency to 50 Hz and increase the data logger's recording rate to 1000 samples per second.
- Repeat steps 2 to 5.



Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop**.

- How did the readings change after inserting the armature?
- What was the effect of mounting the coils on the U core?
- Explain the role of the core.
- Compare the functioning of the transformer at 5 Hz to its functioning at 50 Hz.
- Do your results agree with Equation (3)? Explain.

Chapter 43

Capacitor in Alternating Current

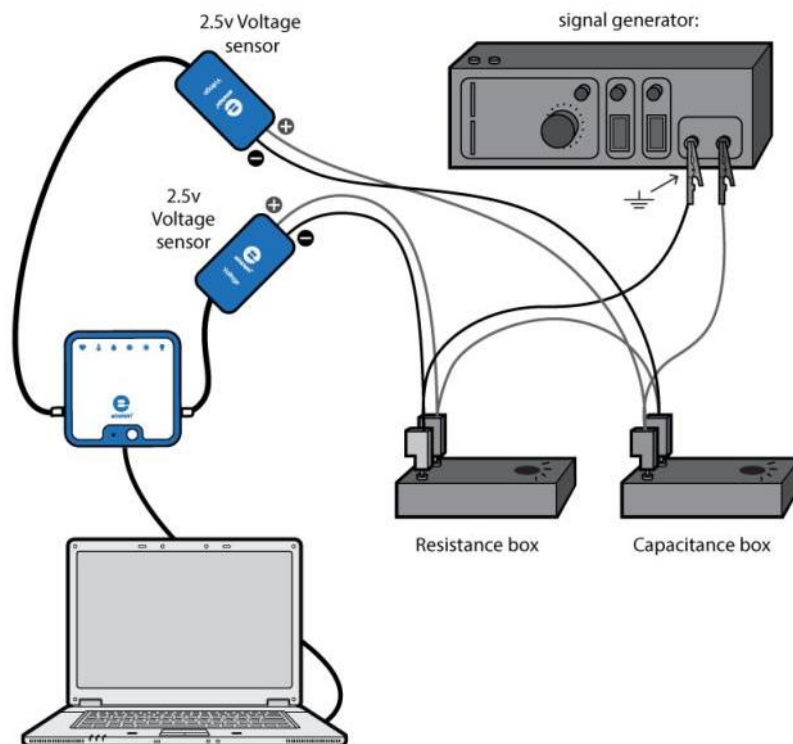


Figure 1



Introduction

When a capacitor C and a resistor R are connected in series with an AC voltage source the reactance of the capacitor, X_c is defined as:

$$X_c = \frac{V_{c,max}}{I_{c,max}} \quad (1)$$

Where:

$V_{c,max}$ = The maximum value of the potential difference across the capacitor

$I_{c,max}$ = The maximum value of the current

The reactance, X_c , can be shown to equal:

$$X_c = \frac{1}{2\pi fC} \quad (2)$$

Where:

f = The frequency

There is a phase difference of $\pi/2$ between V_c , the potential difference between the terminals of the capacitor and the current I_c .

There is also a phase difference ϕ between the voltage of the signal generator and the current. This phase difference is given by:

$$\tan \phi = \frac{1}{2\pi fRC} \quad (3)$$

In this experiment these formulas are explored and verified.

The Data Analysis section is divided into four independent parts. You may perform only some of them.



Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Voltage sensors ± 2.5 V (or ± 25 V) (2)
- Box of capacitors
- Box of resistors
- Signal generator

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Equipment Setup Procedure



1. Launch MiLAB Desktop ().
2. Connect the Voltage sensors to ports on the einstein™LabMate.
3. Assemble the electric circuit as shown by Figures 1 and 2.
4. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the two Voltage sensors are selected under **Measurements**.

Note: The polarity of the sensors is very important when it comes to measuring the relative phase of the current and the voltage.

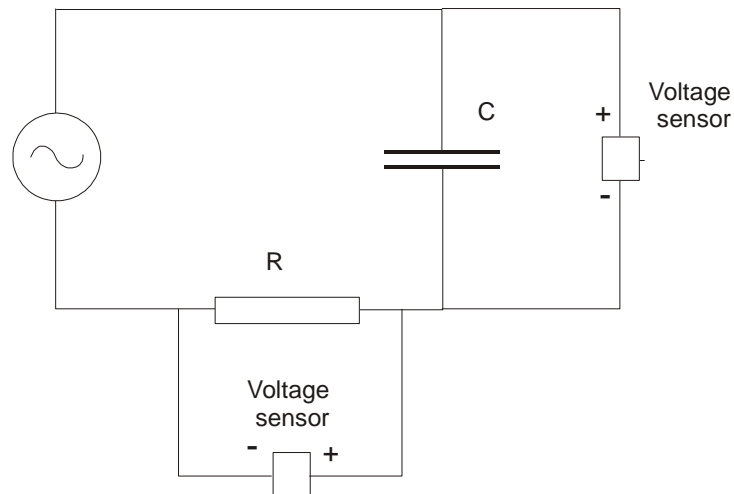


Figure 2





Current Setup Summary

Program the sensors to log data according to the following setup:

Sensor:	Voltage (± 2.5 V) or (± 25 V)
Measurements:	Voltage (V)
Current Reading:	Set (sets as zero)
Sensor:	Voltage (± 2.5 V) or (± 25 V)
Measurements:	Voltage (V)
Current Reading:	Set (sets as zero)
Rate:	1000 samples per second
Samples:	2000
Duration:	2 seconds



Procedure

1. Turn on the signal generator. Select a frequency of 100 Hz.
2. Select a capacitor of $1\mu\text{F}$ and a resistor of $1000\ \Omega$.
3. Select **Run** () to begin recording data.
4. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.

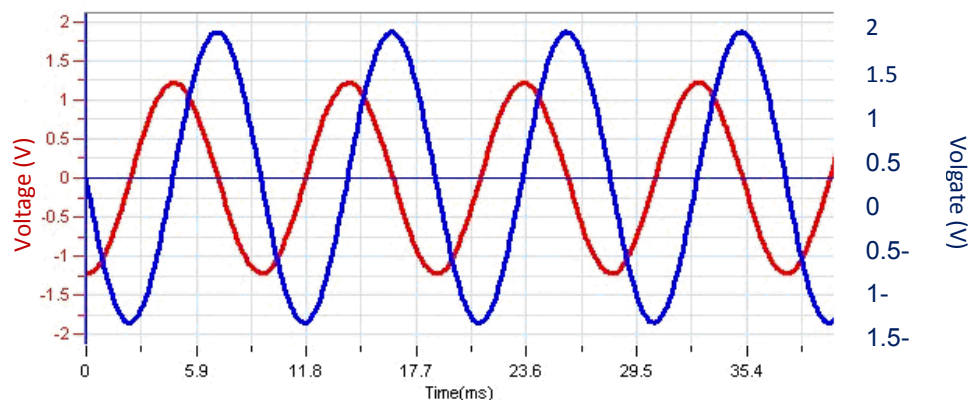





Figure 3





Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop.**

Explore the phase differences between the voltage drop across the capacitor and the voltage drop across the resistor:

1. Use **Zoom** () tool from Graph toolbar to display one or two periods of the voltage.
2. Use the first () and second () cursors to measure the Period τ and the frequency f . Record these values in your notebook.
3. Does the voltage drop across the capacitor lead or lag that of the resistor?
4. What is the phase difference between the two curves?

Explore the power and the effective current:

- Use the graph of the Voltage vs. Time for the resistor to produce a graph of the Current vs. Time:
 - Select **Math functions** () from the **Analysis** toolbar.
 - In the **Math function** window which opens, select **Linear** from the dropdown **Functions** menu. This will perform the operation: **A*G1 + B**.
 - In the **A** edit box, enter the value of $1/R$ for the resistor you used in the experiment ($1000\ \Omega$) and enter 0 in the **B** edit box.
 - From the **G1** dropdown menu, choose the voltage data from the resistor measured in this experiment.
 - In the **Name** edit box, enter Current, I , in the **Unit** edit box, enter A, and then select **OK**.
- Produce a graph of the power dissipated by the capacitor by multiplying the current by the capacitor's voltage:
 - Select **Math functions** () from the **Analysis** toolbar.
 - In the **Math function** window which opens, select **Multiply** from the dropdown **Functions** menu. This will perform the operation: **(A*G1) * (B*G2)**.
 - From the **G1** dropdown menu, choose the current data calculated above. From the **G2** dropdown menu, choose the voltage data from the capacitor measured in this experiment.
 - In the **A** and **B** edit box enter a value of 1.
 - In the **Name** edit box, enter Power, in the **Unit** edit box enter W and then select **OK**.

From the resulting graph it should be clear that the average value of the power of the capacitor is zero.
- In the same way produce a graph of the power of the resistor.
The average power consumption is given by:

$$\bar{P} = \frac{1}{\tau} \int_0^{\tau} P(t) dt \quad (4)$$

- To evaluate the average power consumption of the resistor, use the cursors to select one period of the power curve, then select **Statistics** from the **Analysis** toolbar. Record the area in your notebook and divide it by the period τ to calculate the average power.
- The effective value of the current is defined by:

$$I_{eff} = \sqrt{\frac{\bar{P}}{R}} \quad (5)$$

- Use your previous results to calculate this value and compare it to the maximum value of the current.
The theoretical relation is:






$$I_{eff} = \frac{I_m}{\sqrt{2}} \quad (6)$$

The reactance as a function of frequency:

- Select a capacitor of $5\ \mu\text{F}$ and a frequency of 40 Hz and repeat the experiment.
- Use the cursors to measure the maximum values of the resistor's voltage V_R and the capacitor's voltage V_C . Record these values in your notebook.
- Calculate I_m the maximum value of the current ($I_m = V_R/R$), and X_C the value of the reactance ($X_C = V_C/I_m$).
- Repeat the experiment with different values of the frequency: 40 Hz, 80 Hz, 120 Hz, 160 Hz and 200 Hz. Calculate X_C for each frequency by following the steps above.
- Create a graph of X_C vs. $1/f$ using an appropriate spreadsheet or graphing program.
- Fit a line to your graphed data and determine the slope of the line.
- Compare the slope with the expected theoretical value:

$$\text{slope} = \frac{1}{2\pi C} \quad (7)$$

The phase as a function of frequency:

1. Detach the Voltage sensor from the terminals of the capacitor and connect them to the terminals of the signal generator (points A and B in Figure 1). The negative terminal (black) of the Voltage sensor should be attached to point A and the positive terminal (red) should be attached to point B. Leave the other Voltage sensor connected to the terminals of the resistor.
2. Select **Run** () to begin recording data.
3. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.
4. Use **Zoom** () from the **Graph** toolbar to display only one period of the voltage of the resistor.
5. Measure the phase difference between the signal generator's voltage and the current (the current is represented by the voltage of the resistor):
 - a. Use the **First cursor** () and **Second cursor** () to measure the period τ .
 - b. Use the cursor to measure t_1 , the time at which one period of the resistor's voltage begins.
 - c. Use the cursor to measure t_2 , the time at which one period of the signal generator's voltage begins.
6. Calculate the phase difference ϕ .

$$\phi = 2\pi \frac{t_1 - t_2}{\tau} \quad (8)$$

7. Calculate $\tan(\phi)$. Remember that ϕ is given in radians.
8. Repeat the experiment with different values of the frequency: 40 Hz, 80 Hz, 120 Hz, 160 Hz and 200 Hz. Calculate $\tan(\phi)$ for each frequency by following steps b-e.
9. Create a graph of $\tan(\phi)$ vs. $1/f$. Apply a linear fit to this graph and compare the slope with the expected theoretical value:

$$\text{slope} = \frac{1}{2\pi RC} \quad (9)$$



Further Suggestions

1. Display a graph of the voltage drop across the capacitor vs. the voltage drop across the resistor. The result will be an ellipse whose axes are the x- and y-axes. This proves that the phase difference between the voltage V_C and the current (represented by the voltage on the resistor) is indeed $\pi/2$.
2. You may wish to explore X_C and ϕ as a function of the capacity: repeat the experiments described above with different values of capacitance.

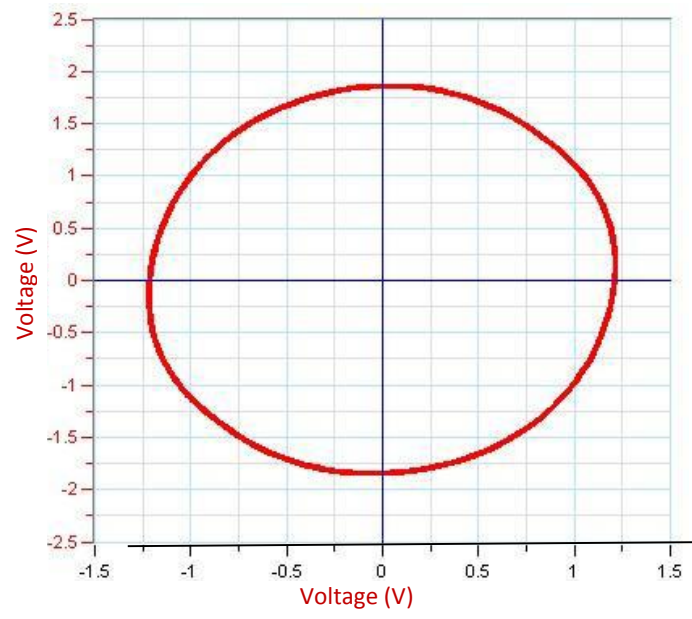


Figure 4

Chapter 44

RLC Resonance

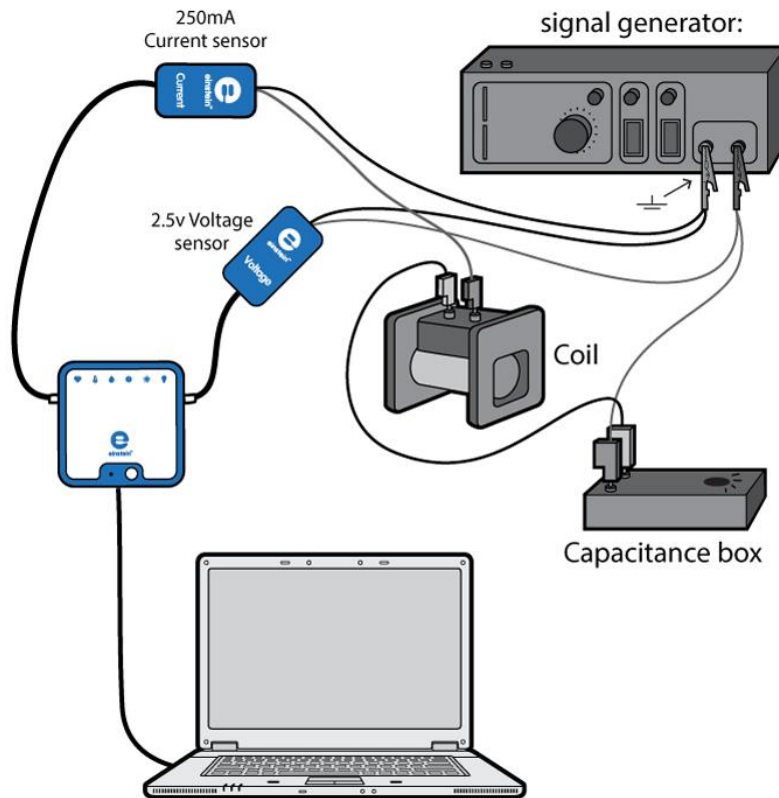


Figure 1



Introduction

When a capacitor, a solenoid and a resistor are connected in series with an AC voltage source the impedance Z of the circuit is given by the following formula:

$$Z = \sqrt{R^2 + (2\pi fL - \frac{1}{2\pi fC})^2} \quad (1)$$

Where

$R =$ The resistance of the circuit

$f =$ The frequency

$L =$ The inductance

$C =$ The capacitance

The impedance is minimal when the frequency is:

$$f_o = \frac{1}{2\sqrt{LC}} \quad (2)$$

$f_o =$ The resonance frequency

At the resonance frequency the current and the voltage are in phase and the power dissipated by the resistor is maximal.

The width of the resonance Δf is defined as the difference between the frequencies f_1 and f_2 at which power dissipation drops to half its maximum value.

The quality factor of the circuit is defined as:

$$Q = \frac{f_o}{\Delta f} \quad (3)$$

And can be shown to be equal to:

$$Q = \frac{2\pi f_o L}{R} \quad (4)$$

In this experiment these formulas are explored and verified.




Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Voltage sensor (± 2.5 V)
- Current sensor ± 250 mA (if you don't have the appropriate current sensor you can use a $10\ \Omega$ resistor and measure the potential difference between its terminals with a second voltage sensor)
- Solenoid coil ($L \sim 20$ mH, R as low as possible)
- Box of capacitors
- Box of resistors
- Signal Generator with power output and continuous frequency control



Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect the Voltage sensor to one of the ports on the einstein™LabMate.
3. Connect the Current sensor to one of the ports on the einstein™LabMate.
4. Assemble the electric circuit as shown by Figures 1 and 2.
5. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Voltage sensor and the Current sensor are selected under **Measurements**.

Note: The polarity of the sensors is very important when it comes to measuring the relative phase of the current and the voltage.

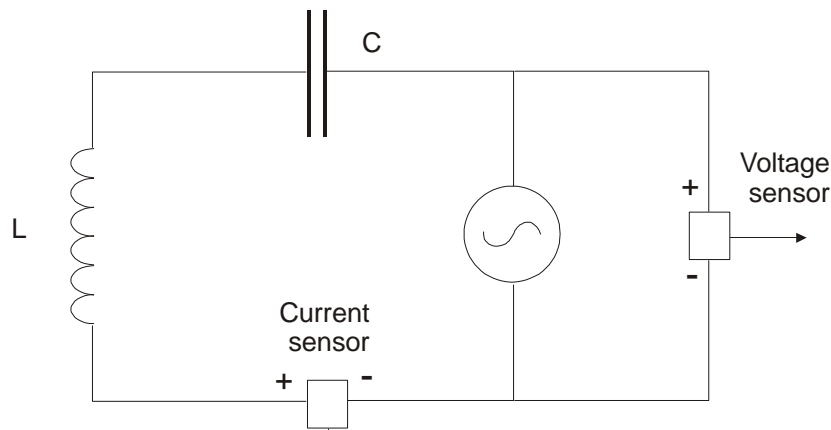


Figure 2





Current Setup Summary

Program the sensors to log data according to the following setup:

Sensor:	Voltage (± 2.5 V) or (± 25 V)
Measurements:	Voltage (V)
Current Reading:	Set (sets as zero)
Sensor:	Current (± 250 mA) (or $10\ \Omega$ resistor + Voltage sensor in parallel)
Measurements:	Current (mA)
Current Reading:	Set (sets as zero)
Rate:	1000 samples per second
Samples:	1000
Duration:	1 seconds



Procedure

1. Turn on the signal generator.
2. Select a capacitor of $\sim 2\ \mu\text{F}$.
3. Estimate, using Equation (2), the value of the resonance frequency (1 kHz depending on the solenoid and the capacitor you selected).
4. Select the signal generator's frequency range that contains this frequency. Set the frequency to the lowest value in the selected range.
5. Select **Run** () to begin recording data.
6. Sweep the frequency range from the lowest value to the highest value. Notice that the duration of data acquisition is very short and you have to perform a complete scanning of the frequency range in this time.
7. You may want to repeat the experiment several times until you get satisfactory results. The voltage and the current will be displayed in the same window; we show them separately in Figures 3 and 4.
8. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.

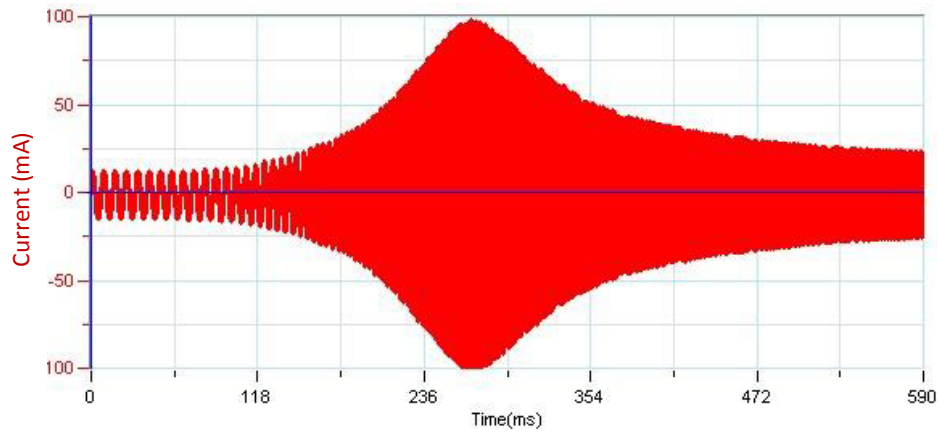


Figure 3

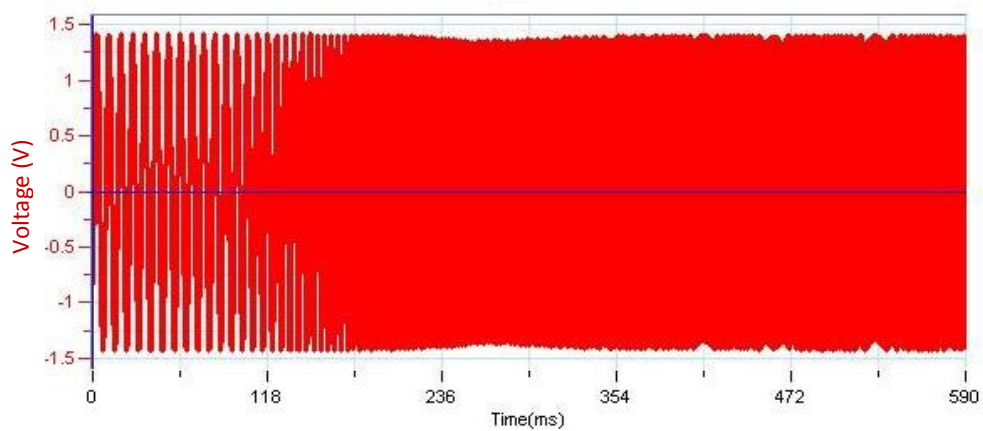


Figure 4

Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop.**

1. Apply a Fourier Transform to the current:
 - a. Select **Math functions** (f_{∞}) from the **Analysis** toolbar.
 - b. In the **Math function** window which opens, select **Fourier transform** from the dropdown **Functions** menu.
 - c. From the **G1** dropdown menu, choose the current data.
2. Use the quality factor Q you have calculated and Equation (4) to calculate the resistance R of the circuit.
3. Explore the influence of the resistance on the resonance:
 - a. Add a resistor to the circuit in series with the Current sensor.
 - b. Repeat the experiment.
 - c. Repeat step 1 of the Data Analysis and compare the new values with the values you recorded before.
4. Use the new value of Q to estimate the new resistance of the circuit and compare this value to the value of the resistance that you added to the circuit.
5. Remove the resistor you added to the circuit.

6. Explore the influence of the capacitance on the resonance frequency:
 - a. Change the value of the capacitor.
 - b. Repeat the experiment.
 - c. Repeat steps 2 and 2 of the Data Analysis.
7. Repeat this procedure with five different values of capacitance.
8. Create a graph of f^2 vs. $\frac{1}{C}$. The graph should be linear and the slope should equal:

$$\text{slope} = \frac{1}{4\pi^2 L}$$

9. Use the value of the slope to calculate the inductance of the circuit.



Further Suggestions

1. You can repeat the experiment with different solenoids.
2. In the original graphs of the Voltage and the Current vs. Time you can zoom in on different parts of the graph and observe the relative phase of the current and the voltage at different frequencies. At the resonance frequency the current and the voltage are in phase.

Chapter 45

Damped Oscillations

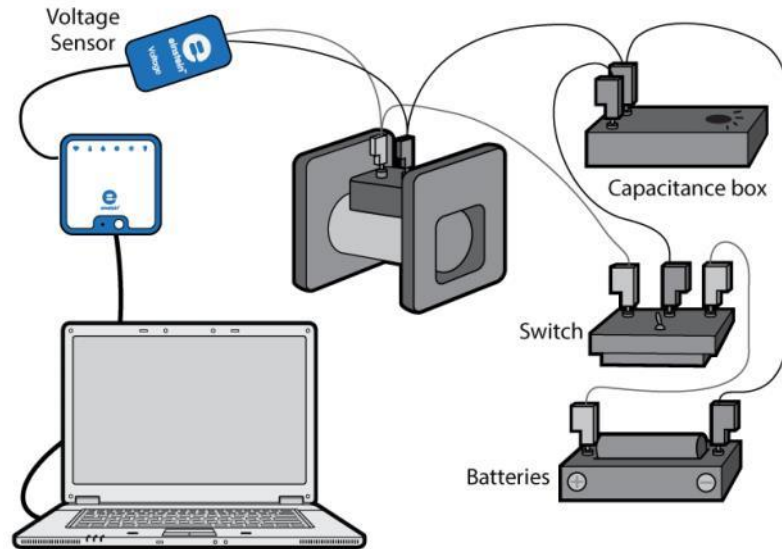


Figure 1



Introduction

When a charged capacitor is discharged through a solenoid and a resistor, the voltage and the current oscillate with gradually decreasing amplitudes. The voltage between the terminals of the capacitor is given by:

$$V = V_0 e^{-\frac{R}{2L}t} \cos \left(\sqrt{\frac{1}{LC} - \left(\frac{R}{2L}\right)^2} t \right) \quad (1)$$

Where:

- $V_0 =$ The initial voltage
- $R =$ The resistance of the circuit
- $L =$ The inductance
- $C =$ The capacitance
- $t =$ The time

In this experiment this formula is explored and verified.




Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Voltage sensor ± 2.5 V (or ± 25 V)
- Coil ($L \sim 20$ mH, R as low as possible)
- Capacitor ($C \sim 20$ μ F, the expected frequency should be approximately 300 Hz)
- 1.5 V battery with battery holder
- Switch with one pole and two Terminals (1P2T)

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Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect the Voltage sensor to one of the ports on the einstein™LabMate.
3. Assemble the electric circuit as shown by Figures 1 and 2.
4. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Voltage sensor is selected under **Measurements**.

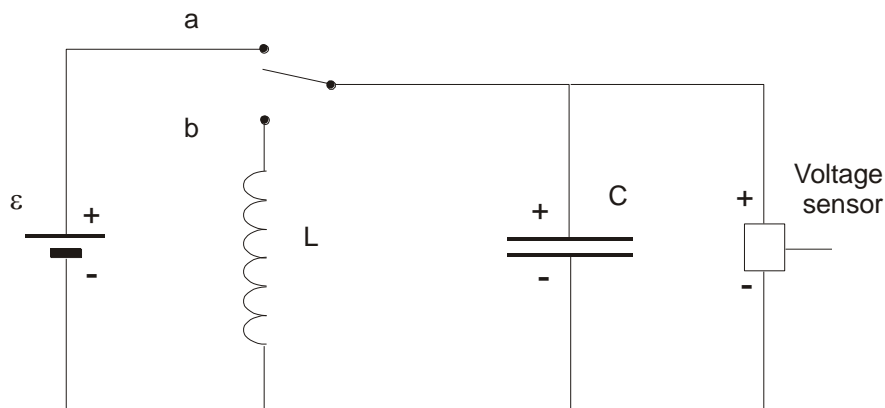


Figure 2





Current Setup Summary

Program the sensors to log data according to the following setup:

Sensor:	Voltage (± 2.5 V) or (± 25 V)
Measurements:	Voltage (V)
Current Reading:	Set (sets as zero)
Trigger	Set
Start Sampling When:	Above level 0.78 V
Rate:	10000 samples per second
Samples:	5000



Procedure

1. Move the switch to the “a” position (see Figures 1 or 2) and wait a few seconds for the capacitor to be charged. The potential difference should reach a level higher than the trigger level (0.78 V). Make sure the trigger is set in the **Current Setup Summary**.
2. Select **Run** () to begin recording data.
3. Data collection will not start before the voltage exceeds the trigger level. The message Trigger run appears on the MiLAB Desktop display.
4. Switch to the “b” position; the capacitor will begin to discharge and data collection will automatically begin.
5. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.

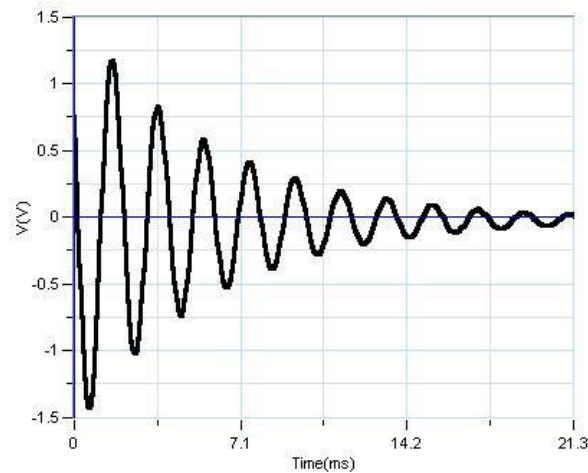




Figure 4



Data Analysis


For more information on working with graphs see: **Working with Graphs in MiLAB Desktop**.

1. Use the **First cursor** () and the **Second cursor** () to measure the frequency of the damped oscillations and compare to the expected value:

$$f = \frac{1}{2\pi} \sqrt{\frac{1}{LC} - \left(\frac{R}{2L}\right)^2} \quad (2)$$

2. Explore the exponentially damping amplitude:

$$V(t) = V_0 e^{-\frac{R}{2L}t} \quad (3)$$

3. Use the cursor to select the graph.
4. Select **Math functions** () from the **Analysis** toolbar.
5. In the **Math function** window which opens, select **Envelope (upper)** from the dropdown **Functions** menu and then select **OK**.

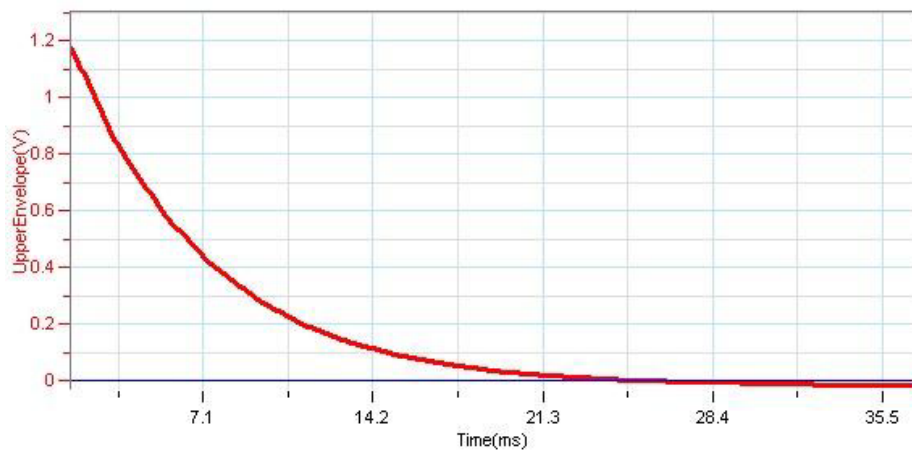


Figure 5

6. Use the cursors to select the part of the envelope where the values are above zero.
7. Select **Math functions** (f_{xy}) from the **Analysis** toolbar.
8. In the **Math function** window which opens, select **Exponential** from the dropdown **Functions** menu and then select **OK**.
9. Verify that your results fit the theory by comparing the exponent to its predicted value:

$$\text{exponent} = -\frac{R}{2L} \cdot x \quad (4)$$



Further Suggestions

1. You can repeat the experiment with different solenoids and capacitors.
2. You may want to add a resistor to the circuit and see what resistance will cause the complete damping of the oscillations.
3. You can repeat the experiment during the charging of the capacitor. You then have to connect the solenoid in series with the capacitor.
4. You may use a Current sensor simultaneously with the Voltage sensor. You then have many options:
 - a. Compare the time constants of the two sensors.
 - b. Compare the derivative of the voltage to the current. The potential difference between the terminals of the capacitor is proportional to the charge on the capacitor, and since the current is the derivative of the charge it is expected that the voltage derivative will be proportional to the current.

Chapter 46

Measuring the Speed of Sound

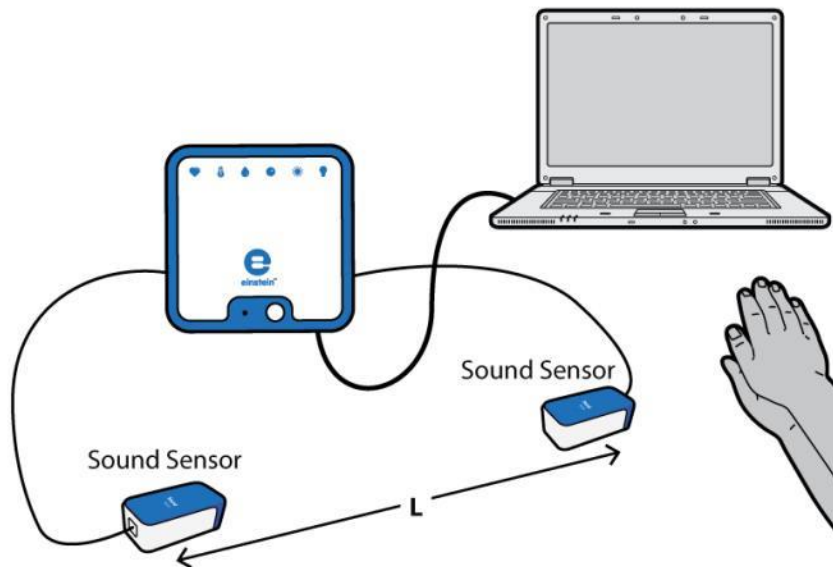


Figure 1



Introduction

In this experiment we measure the time it takes a sharp sound to travel the distance between two microphones. The speed of sound is then calculated by dividing the distance between the microphones by the time it took the sound to travel the distance between them. In this manner the speed of sound in air, wood and metal can be measured.




Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Microphone sensor (2)
- Hammer
- Optional:
 - Long iron bar (2 m at least)
 - Long aluminum bar (2 m at least)
 - Long wooden surface (a 2 m long table will work well)

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Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect the Microphone sensors to two of the ports on the einstein™LabMate.
3. Place the two microphones at least 2m apart, both facing the sound source (see Figure 1).
4. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Microphone sensors are selected under **Measurements**.



Current Setup Summary


Program the sensor to log data according to the following setup:

Sensor:	Microphone
Measurements:	Microphone (V)
Rate:	1000 samples per second
Samples:	2000
Duration:	2 seconds





Procedure

Measuring the speed of sound in the air:

1. Measure the distance between the microphones and record this value in your notebook.
2. Select **Run** () to begin recording data.

Note: You have about two seconds to complete the experiment.

3. Produce a sharp sound. The sound must be sharp (must have a sudden beginning), short and loud. A clap of hands is one possibility. Hitting a metallic object with a hammer is another. Perform several experiments before you decide what option best suits you.
4. Select **Stop** () to stop the experiment.
5. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.

Measuring the speed of sound in wood and metal:

Position the microphones on a long bar of the desired material facing down (see Figure 2). The distance between the microphones should be as large as possible (more than 3 m is best).

Note: Use adhesive tape to hold the microphones facing down.

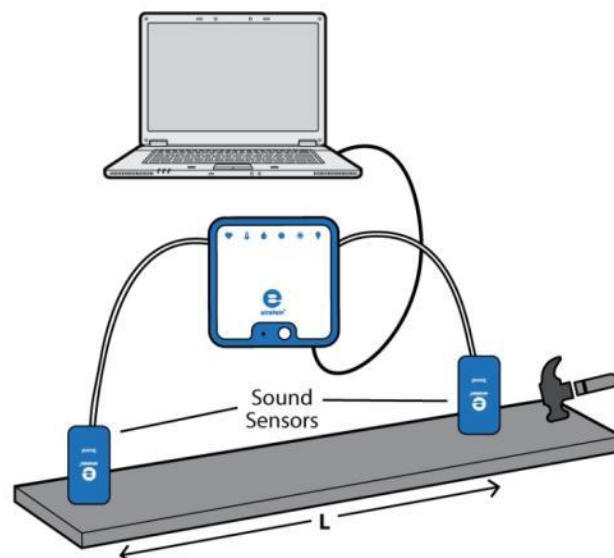


Figure 2

1. After setting up the next experiment, repeat steps 1 to 4 of the previous section (Measuring the speed of sound in the air). Remember to save each experiment. Also, when measuring the speed of sound in materials such as aluminum or wood, the sharp sound should be emitted from the material (hitting the aluminum or wooden bar with a hammer will work well).

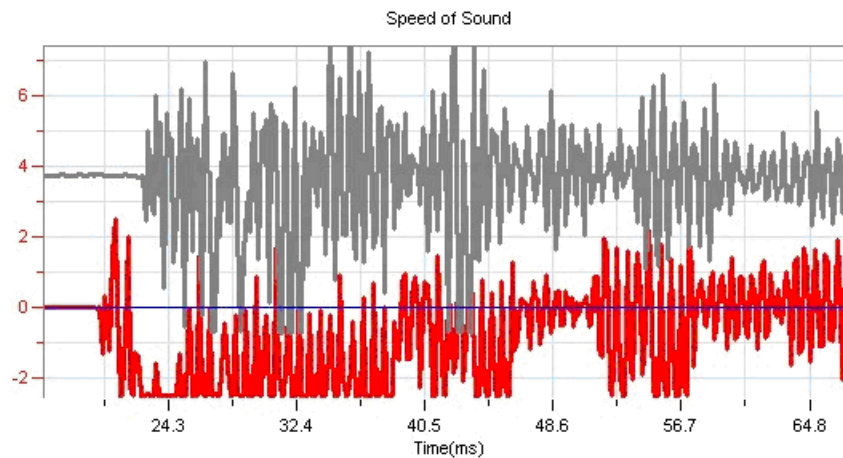




Figure 3



Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop.**

1. Zoom in on the graph using the **Zoom** tool () on the **Graph** toolbar to show the part of the graph when the sound reached the microphones.
2. Use the cursor () to measure the time when the sound reached the first microphone and then move the cursor and place it on the second microphone's graph to measure the time the sound took to reach it.
3. Calculate the speed of sound:

$$v = \frac{\ell}{t_2 - t_1} \quad (1)$$

Where:

v = The speed of sound

ℓ = The length of the medium

t = The time

4. Repeat the same procedure for each material.
5. Compare your results from the various materials, and compare them to their real values: try to speculate on the reasons for the deviation (if there is one).

Chapter 47

Sound Beats

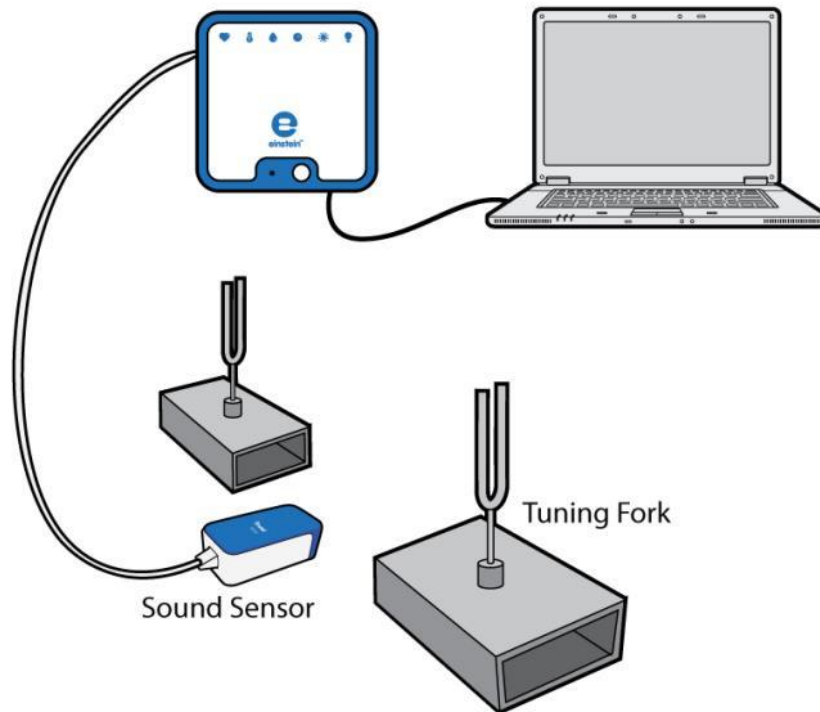


Figure 1

Introduction

When two sound waves with different but close frequencies interfere with each other what is heard is a sound whose frequency is the average of the two original frequencies. This sound varies in intensity and the variations in intensity have a frequency that is equal to the difference between the two original frequencies.

If the original waves are given by:

$$y_1 = A \sin(2\pi f_1 t) \quad (1)$$

$$y_2 = A \sin(2\pi f_2 t) \quad (2)$$

Where f_1 , and f_2 are the frequencies. The composite wave will be of the form:

$$y = 2A \cos(2\pi(f_1 - f_2)t) \sin(2\pi(f_1 + f_2)t) \quad (3)$$


In this experiment we explore the form of the composite wave by viewing the readings of a microphone and by looking at the Fourier Transform of those readings.

Equipment

- einstein™ LabMate and a computer with MiLAB Desktop

- Microphone sensor
- Two tuning forks mounted on sounding boxes. The tuning frequencies should be close, i.e. 440 Hz and 435 Hz (you can use instead two signal generators with power amplifiers and loudspeakers)
- Rubber hammer to excite the tuning forks

123 Equipment Setup Procedure




1. Launch MiLAB Desktop ().
2. Connect the Microphone sensor to one of the ports on the einstein™LabMate.
3. Position the sounding boxes facing each other about 20-30 cm apart.
4. Change the distance between them and excite the forks with the hammer to find out the best position. The louder the beat sounds, the better.
5. Place the Microphone half way between the sounding boxes (see Figure 1).
6. In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Photogate sensor is selected under **Measurements**.

Current Setup Summary

Program the sensor to log data according to the following setup:

Sensor:	Microphone
Measurements:	Microphone (V)
Rate:	10000 samples per second
Samples:	10000
Duration:	1 second

Procedure

1. Hit one of the tuning forks with the rubber hammer. Wait a few seconds for the high pitched harmonies to subside.
2. While the fork is still sounding, select **Run** () to begin recording data.
3. After a few seconds select **Stop** ().
4. Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.
5. Repeat steps 1 to 4 with the other tuning fork.
6. Repeat steps 1 to 4 while sounding both forks simultaneously.

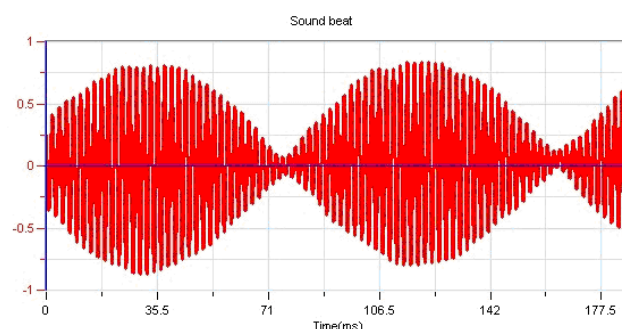







Figure 2

Data Analysis

For more information on working with graphs see: **Working with Graphs in MiLAB Desktop**.

1. Display the first graph, containing data from a single tuning fork.
2. Use the **Zoom** () from the **Graph** toolbar to display two or three periods of the oscillation.
3. Use the cursors () to measure the frequency f_1 . The correct value is measured by positioning the cursors on two consecutive peaks of the wave. Note the frequency in your notebook.
4. Repeat steps 1 to 3 with the data from the second tuning fork. Note the second frequency f_2 in your notebook.
5. Display the third graph, containing data from the two forks simultaneously
6. Use the **Zoom** () from the **Graph** toolbar to display two or three beats.
7. Use the cursors () to measure the frequency of the beats.
8. Verify that the frequency accepted above is indeed the average of the original frequencies.
9. Select **Math functions** () from the **Analysis** toolbar.
10. In the **Math function** window which opens, select **Fourier Transform** from the dropdown **Functions** menu and then select **OK**. The Fourier Transform of the beats will be displayed.

Fourier Transform

Every periodic phenomenon that we sample can be transformed from the time domain (time along the x-axis) to the frequency domain (frequency along the x-axis). The Fourier transform presents the data as one or more peaks appearing at the frequency of the periodic phenomenon.

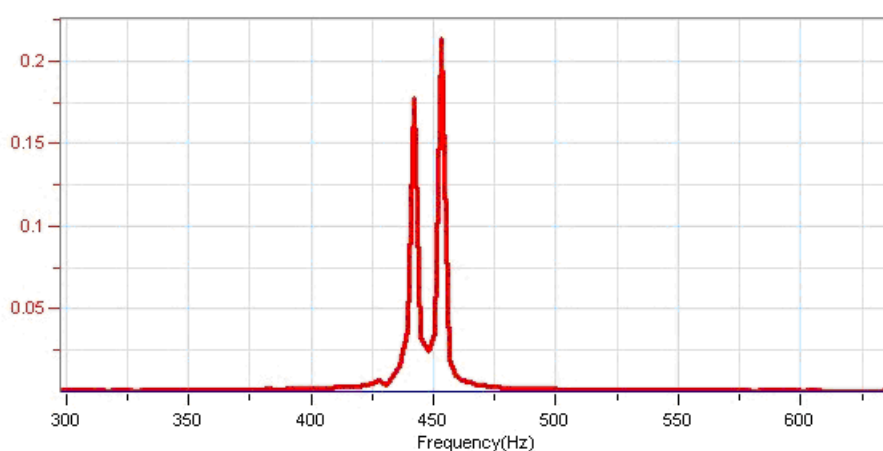




Figure 3

11. Use the cursors () to measure the two peaks from the Fourier transform and see that they match the two original frequencies. There is also a small peak at a frequency that is equal to the difference between the original frequencies

Further Suggestions

You can mathematically add the data from the two forks and see that the sum is similar to the beats:

1. Select **Math functions** () from the **Analysis** toolbar.
2. In the **Math function** window which opens, select **Add** from the dropdown **Functions** menu and then select the two individual frequency measurements as **G1** and **G2**. The sum will be displayed and you can compare it to the sound beats that you have measured.

Chapter 48

Diffraction and Interference of Light

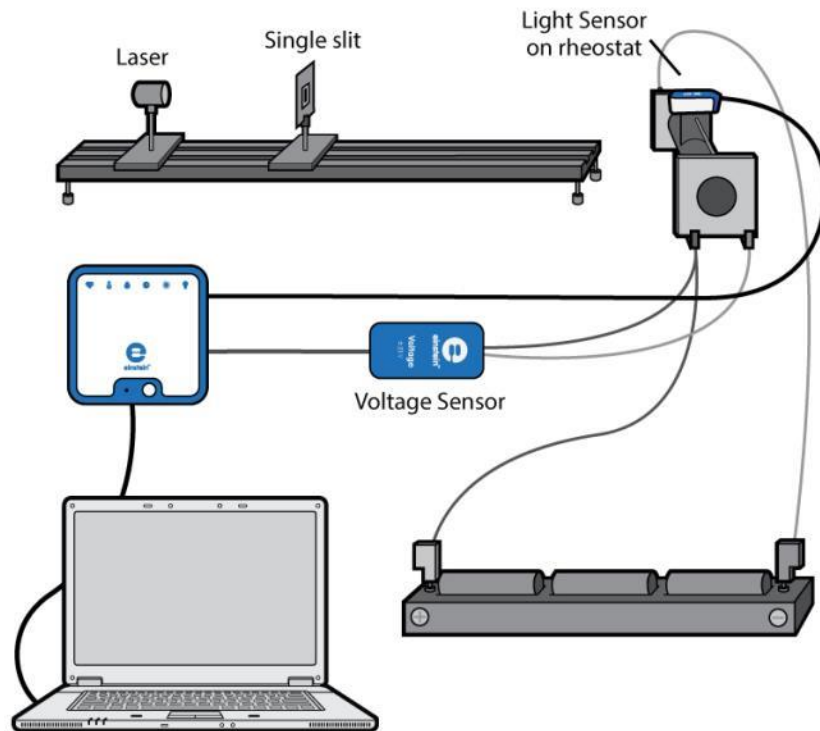


Figure 1



Introduction

When light passes through a narrow slit it is diffracted and a pattern of alternating dark and bright regions appear. The central region of light is twice as wide as the others and much brighter. The intensity of the light changes with the distance from the center of the pattern according to the following formula:

$$I = I_0 \left(\frac{\sin\left(\frac{\pi wx}{L\lambda}\right)}{\frac{\pi wx}{L\lambda}} \right)^2 \quad (1)$$

Where:

- $I =$ The intensity of the light
- $I_0 =$ The maximum intensity at the center of the diffraction pattern
- $w =$ The width of the slit
- $x =$ The distance from the center of the pattern
- $L =$ The distance from the slit to the screen
- $\lambda =$ The wavelength of the light

The minima of this pattern will be at:

$$x_n = n \frac{\lambda L}{w} \quad n = \pm 1, \pm 2, \dots \quad (2)$$

When light passes through two slits an interference pattern is superimposed on the diffraction pattern: narrow regions of light and darkness appear within each wider diffraction region. The formula that describes the light intensity is:

$$I = I_o \left(\frac{\sin\left(\frac{\pi wx}{L\lambda}\right)}{\frac{\pi wx}{L\lambda}} \right)^2 \cdot \cos^2\left(\frac{\pi dx}{L\lambda}\right) \quad (3)$$

Where:

d = The distance between the centers of the slits

The minima of this pattern will be at:

$$x_n = n \frac{\lambda L}{d} \quad n = \pm 1, \pm 2, \dots \quad (4)$$

In this experiment we use a laser as a light source and we move a light detector along the interference pattern. The position of the sensor is measured by placing the sensor on the sliding contact of a linear variable resistor.




Equipment

- einstein™LabMate and a computer with MiLAB Desktop
- Light sensor
- Voltage sensor ± 2.5 V
- Laser
- Slide with a single slit
- Slide with two slits (preferably of the same width as the single slit)
- Slide holder
- Linear sliding resistor (rheostat). Choose a rheostat where the voltage changes smoothly and without jumps
- Three 1.5 V batteries



Equipment Setup Procedure

1. Launch MiLAB Desktop ().
2. Connect the Light sensor to one of the ports on the einstein™LabMate.
3. Connect the Voltage sensor to one of the ports on the einstein™LabMate.
4. Assemble the equipment as shown in Figure 1. You should adjust distances according to the equipment available to you: the laser's wavelength, the width of the slits and the length of the rheostat.
5. Cover the aperture of the Light sensor with an opaque piece of paper, leaving open only a narrow slit of 0.3 to 0.4 mm. This slit should be narrower than the minimal width of an interference line.
6. Attach the Light sensor to the movable contact of the rheostat.
7. Place the slide holder with the slit in front of the laser.
8. Place a screen four meters away from the slit. The plane of the screen should be perpendicular to the laser beam. Adjust the distance of the screen from the laser so that the width of the diffraction pattern on the screen is smaller than but roughly equal to the length of your rheostat.
9. Replace the screen with the rheostat. Adjust the height of the rheostat so that the Light sensor is at the level of the diffraction pattern.
10. Connect the batteries to the fixed terminals of the rheostat.
11. Connect the Voltage sensor between one of the fixed terminals of the rheostat and the movable

terminal.

- In the **Current Setup Summary** window choose **Full Setup** and use the table below to set up the experiment. Make sure that only the Light sensor and the Voltage sensor are selected under **Measurements**.

Note: The light emitted from the computer screen might interrupt the experiment.




Current Setup Summary

Program the sensors to log data according to the following setup:

Sensor:	Light-600
Range:	0-600 lx
Measurements:	Light-600 (lx)
Sensor:	Voltage (± 2.5 V)
Measurements:	Voltage (V)
Current Reading:	Set (sets as zero)
Rate:	100 samples per second
Samples:	500
Duration:	5 seconds



Procedure

- Place the movable contact of the rheostat (with the Light sensor) at one end of its range.
- Select **Run** () to begin recording data.
- Move the sliding terminal of the rheostat with the Light sensor along the length of the rheostat. The sweep should last less than 5 seconds. A graph displaying the readings of both sensors will automatically appear.

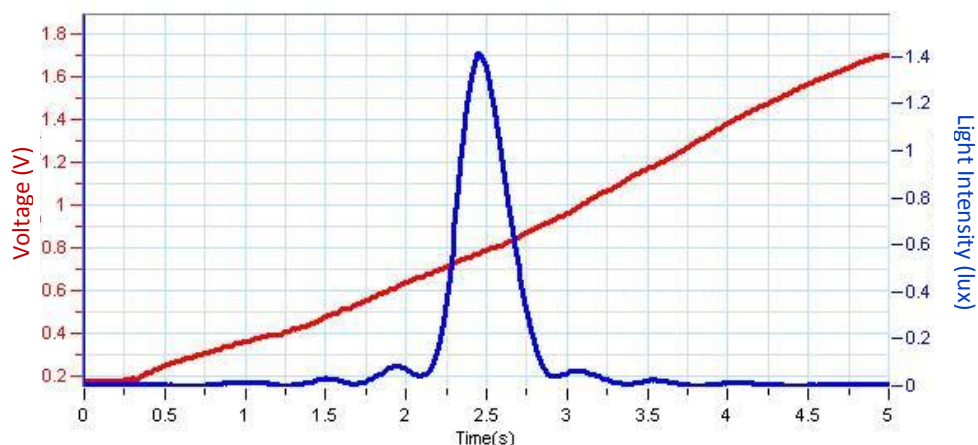



Figure 2


- Save your data by selecting **Save** () from the **Basic Tools** window on the upper menu bar.
- Repeat steps 2 to 4 with two slits.

6. Measure the distance L from the slide holder to the rheostat and record it in your notebook.
7. Measure the distance l_0 between the two extreme positions of the Light sensor and record this value in your notebook.




Data Analysis


For more information on working with graphs see: **Working with Graphs in MiLAB Desktop**

1. Display the first graph that you have saved.
2. To calibrate the voltage to represent distances perform the following:
3. Use the cursors () to determine the value of the voltage V_0 that corresponds to the maximum light intensity and ΔV the difference between the extreme values of the voltage.
4. The distance x from the center of the interference pattern will be given by:

$$x = \frac{l_0}{\Delta V} (V - V_0) = -\frac{l_0 V_0}{\Delta V} + \frac{l_0}{\Delta V} V \quad (5)$$


5. Use the cursor to select the voltage data set.
6. Select **Math functions** () from the **Analysis** toolbar.
7. In the **Math function** window which opens, select **Linear** from the dropdown **Functions** menu.
8. In the **A** and **B** edit boxes type in the following values:

$$C_1 = \frac{l_0}{\Delta V}, \quad C_2 = \frac{l_0 V_0}{\Delta V}$$

9. In the **Name** edit box type x , in the **Unit** edit box type m , and then select **OK**.
10. Create a graph of the Light Intensity vs. Position.
11. Below the x-axis of the graph, select the down arrow () and choose the calculated Linear function graph (x) as your x-axis measure.
12. Using the cursors you can measure the location of the minima of the light pattern and compare them with the theory.



Further Suggestions

1. If you use slits of the same width for both diffraction and interference you can display both graphs in the same window and compare the results.
2. Select **Math functions** () from the **Analysis** toolbar.
3. In the **Math function** window which opens, select **Envelope (upper)** from the dropdown **Functions** menu and observe the similarity to the diffraction pattern.
4. Compare the theoretical results with your real data.



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