



# Experiments in Physics

for MiLAB™



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# Experiments by Sensor



## Charge

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## Sound

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## Temperature

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## Voltage

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# Preface

This book contains 31 Physics experiments for students designed for use with MiLAB and einstein™ sensors. MiLAB comes pre-installed on the einstein™Tablet or can be installed on any Android or iOS tablet and paired with a einstein™LabMate. The most recent version of MiLAB can be downloaded from the FOURIER Education website [einsteinworld.com](http://einsteinworld.com).

For your convenience we have added an index in which the experiments are sorted according to sensor.

## einstein™Tablet+ and einstein™LabMate Devices

### einstein™ Tablet+

The einstein™Tablet includes the following:

#### 8 built-in sensors:

- Heart Rate: 0-200 bpm
- Light: 0-600 lux, 0-6000 lux, 0-150 klux
- Relative Humidity: Range: 0-100%
- Temperature: -30°C to 50°C
- UV: 10 W/m<sup>2</sup>, 200 W/m<sup>2</sup>, UV wavelength 290-390 nm
- GPS
- Microphone (sound)
- g-sensor (accelerometer)

#### + 4 ports for external sensors

### einstein™LabMate

The einstein™LabMate includes the following:

#### 6 built-in sensors:

- Heart Rate: 0-200 bpm
- Temperature: -30°C to 50°C
- Relative Humidity: Range: 0-100%
- Pressure: 0-400 kPa
- UV: 10 W/m<sup>2</sup>, 200 W/m<sup>2</sup>, UV wavelength 290-390 nm
- Light: 0-600 lux, 0-6000 lux, 0-150 klux

#### + 4 ports for external sensors

External sensors can be connected to either of these devices by inserting the sensor cable into one of their sensor ports.

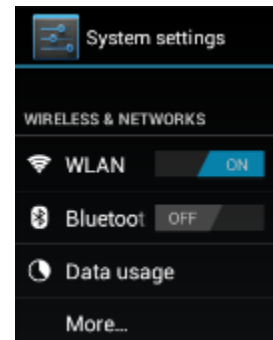
## Using the einstein™LabMate

To use MiLAB on a non-einstein™ device, one must first pair with an einstein™LabMate via Bluetooth.

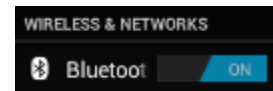
### Pairing with an Android device

1. Make sure the einstein™LabMate is on and not paired with any other device.

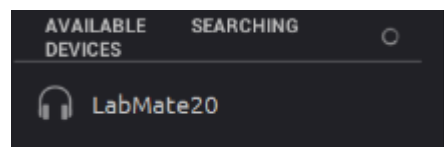
2. On your tablet select the Main Menu button and then the System Settings icon.



3. Select the Bluetooth OFF/ON to turn the Bluetooth ON.

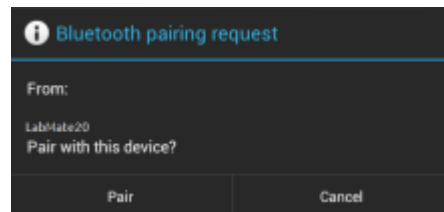


4. Once the Bluetooth setting is ON, the device will begin searching for Bluetooth devices.



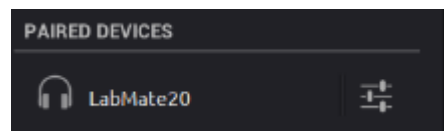
5. Once the einstein™LabMate is discovered, it will appear in the list of discoverable devices.

6. Select the einstein™LabMate to connect. Your device will show a quick pairing message, followed by a Bluetooth pairing request.



7. Select Pair to approve the pairing process.

8. Once successfully paired, the einstein™LabMate will appear under paired devices.

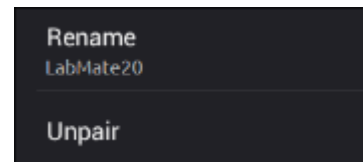
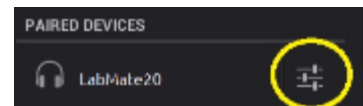


9. NOTE: Please be patient. As every device is different, the pairing time can vary from a few seconds to a few minutes.



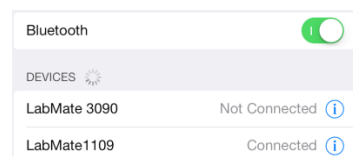
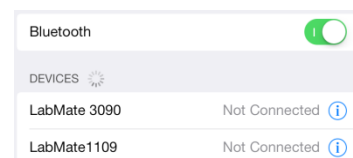
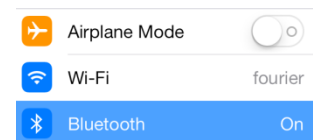
## Unpairing

1. On the Android device, select the Main Menu button > System Settings icon > Bluetooth.
2. Select the icon next to einstein™LabMate that is listed under Paired Devices.
3. A new window will appear showing, Rename and Unpair. Select Unpair.



## Pairing with an iOS device

1. Make sure the einstein™LabMate is on and not paired with any other device.
2. Select Settings.
3. Select the Bluetooth OFF/ON to turn the Bluetooth ON.
4. Once the Bluetooth setting is ON, the device will begin searching for Bluetooth devices.
5. Once the einstein™LabMate is discovered, it will appear in the list of discoverable devices.
6. Select the einstein™LabMate to connect.
7. Once successfully paired, the word Connected will appear next to the einstein™ Lab Mate.



## Unpairing

1. Select Settings.
2. Select the paired einstein™LabMate.

## Working with Graphs in MiLAB

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

## Understanding Graphs

In general graphs in MiLAB represent the data from one or more sensors along the  $y$  (or vertical) axis vs. time along the  $x$  (horizontal) axis.

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

To zoom in on one part of the graph touch the screen and spread 2 fingers.

To zoom back out pinch two fingers together.



Pinch to Zoom out



Spread to Zoom in

**Note:** You can also spread and pinch along the  $x$  or  $y$ -axis to zoom in or out on these axes.

Double tap on the graph to return to the original auto scale graph.

You can also move the graph or axes by touching and dragging them.

## Analyzing a Graph

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

To analyze a graph:

- Run an Experiment.
- In order to use MiLAB's analysis functions you must select at least one point on the graph – this is known as a cursor. Many functions require two cursors.

**Note:** If you are using more than one sensor, both points must be on the same plot line.

## Working with Cursors

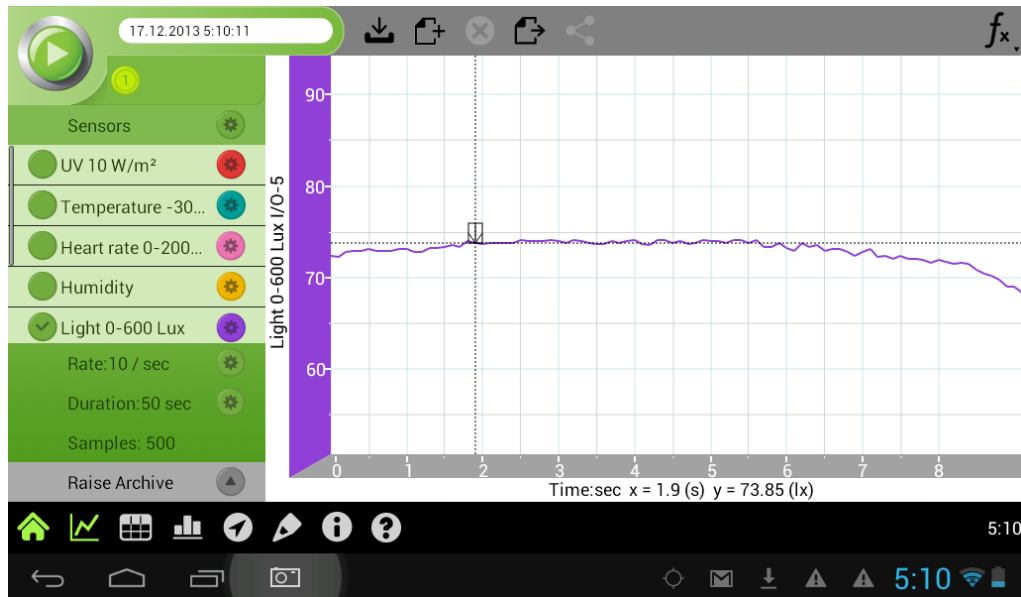
You can display up to two cursors on a graph simultaneously.

Use one cursor to display individual data recording values, to select a curve or, if you are using three or more sensors, to reveal a hidden y-axis.

Use two cursors to analyze the data in the graph.

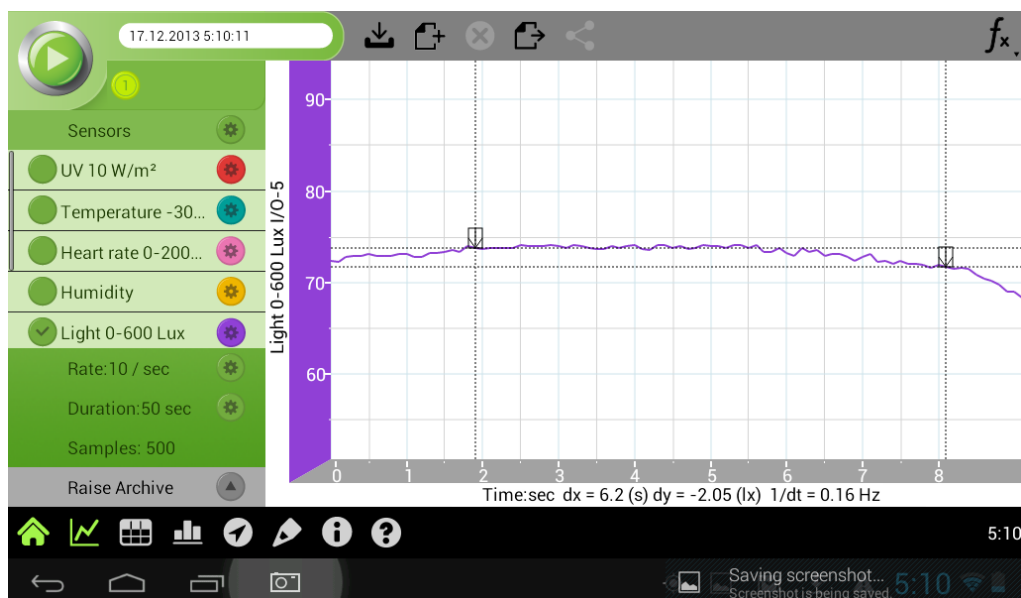
### To display the first cursor:

In graph view, tap any point on a plot line. MiLAB will now display the coordinate values.



### To display the second cursor:

Once the first cursor is placed, tap any point on the same plot line.



When there are 2 data points selected; the differences between the x and y values of the two points will appear at the bottom of the graph window.

- $dx$  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

- Touch and hold a cursor then drag it left and right on a single plot line.
- Tap the plot line of a different sensor to move the cursor to that plot line.

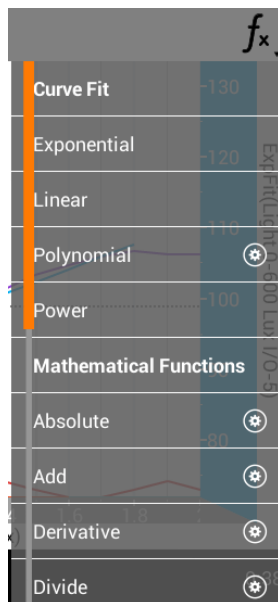
#### To remove a cursor:

- Tap and hold a cursor, flick it quickly off the screen in any direction.  
The cursor will disappear from the plot line.

## Working with Functions

Once you have selected a cursor, this will activate the **Function** button ( $f_x$ ).

Tap the **Function** button to access the list of tools available to you.

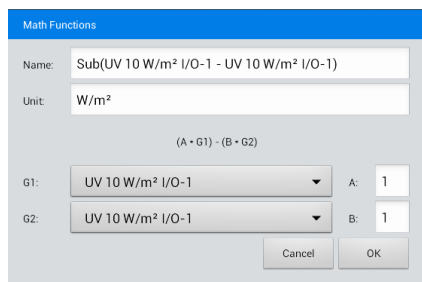


Tap one of these to apply the function.

After you select a function a new plot line will appear on the graph displaying the results.

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

- Place two cursors on one of the plot lines.
- Tap the **Function** button ( $f_x$ ).
- Tap the Setup button (⚙️) next to the desired function.
- In the Setup menu **G1** will be the plot line you selected.



- Use the **G2** dropdown menu to select the plot line you would like to compare it to.
- Tap **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.

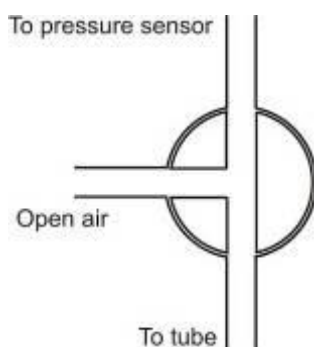
**Note:** To ensure a tight seal you may need to use a material such as modeling clay to seal any openings.

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

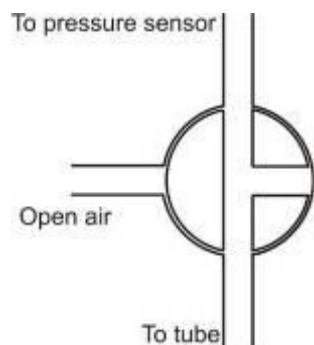
Once you have sealed the flask or test tube, you can test the seal.

1. Tap **Play** (  ) 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.

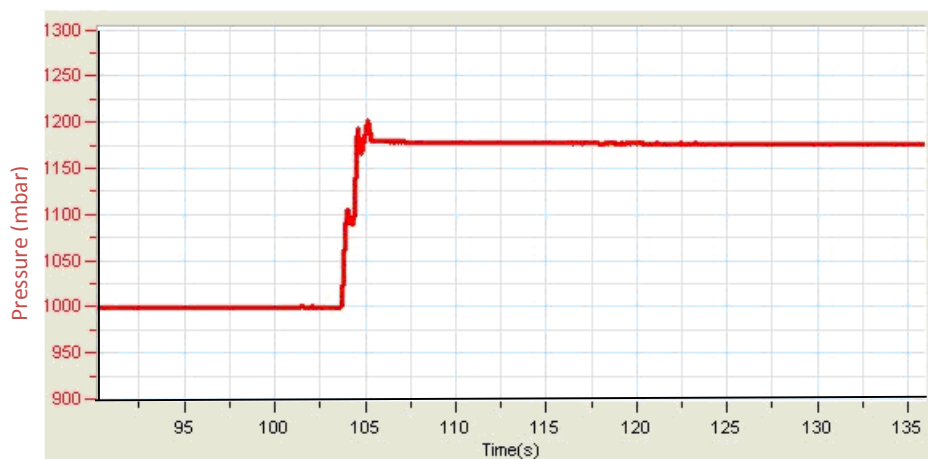
The readings should now indicate the atmospheric pressure.



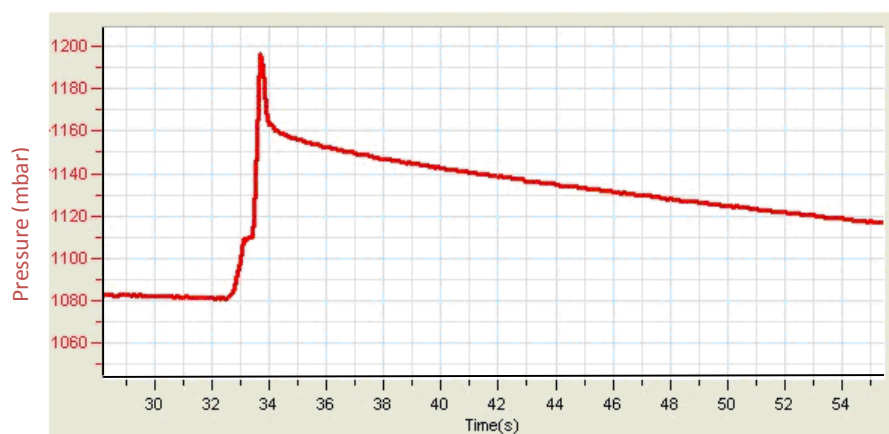
3. (If your setup includes three-way valves) Turn the three-way valves to seal the system from the surrounding air.




Press the stoppers. The pressure should rise a little and then remain constant.



4. If the pressure drops (see Figure below) 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.



5. After you are satisfied that the containers are sealed, tap **Stop** (  ).



## Experimental Layout

Each experiment includes the following parts:

- **Introduction:** A brief description of the concept and theory
- **Equipment:** The equipment needed for the experiment
- **Equipment Setup Procedure:** Illustrated guide to assembling the experiment
- **Experimental Setup:** Recommended setup
- **Procedure:** Step-by-step guide to executing the experiment
- **Data Analysis**
- **Questions**
- **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

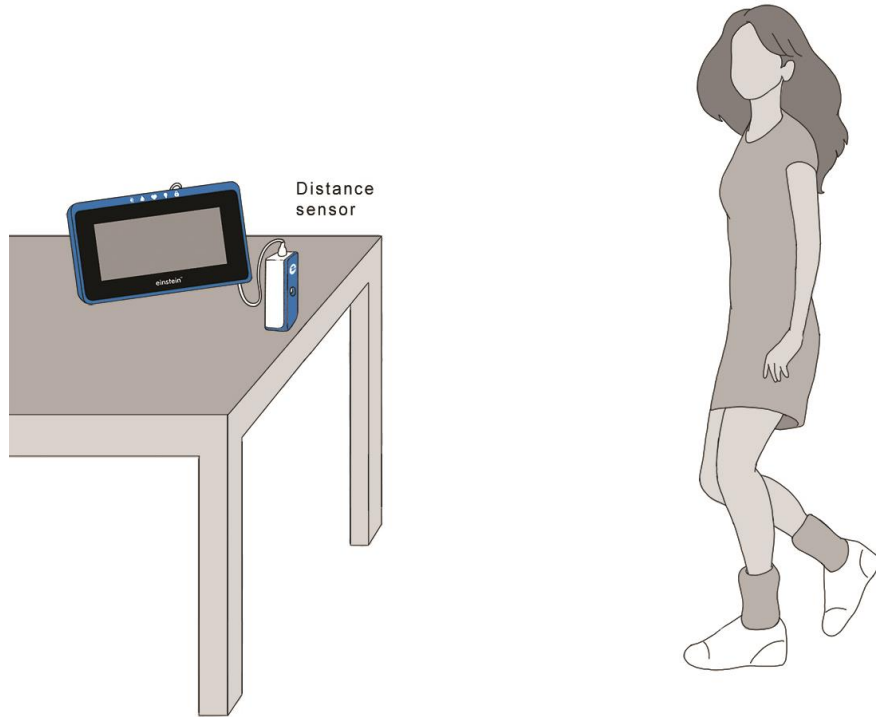


Figure 1



### 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™Tablet+ with MiLAB or Android/iOS Tablet with MiLAB and einstein™LabMate
- Distance sensor
- Distance adaptor
- Masking tape



## 123 Equipment Setup Procedure

**Note:** Ensure that the AC/DC adapter is connected as the Distance sensor consumes relatively high current

1. Launch MiLAB (.
2. Connect the Distance sensor with the Distance adaptor to one of the ports on the einstein™Tablet+ or einstein™LabMate.
3. Make sure that only the Distance sensor is selected.

### Position versus Time Graph Matching:






## Experimental Setup

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

Distance sensor	Distance (outgoing) (m)
Rate:	10/sec
Duration:	2 Min



## 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 tap **Run** () to begin recording data. Walk slowly away from the Distance sensor.
4. When you reach the 3 m mark, ask you partner to tap **Stop** (.
5. Tap **Save** () to save your data.
6. Repeat steps 3 to 5 to match the following graph (Figure 2):

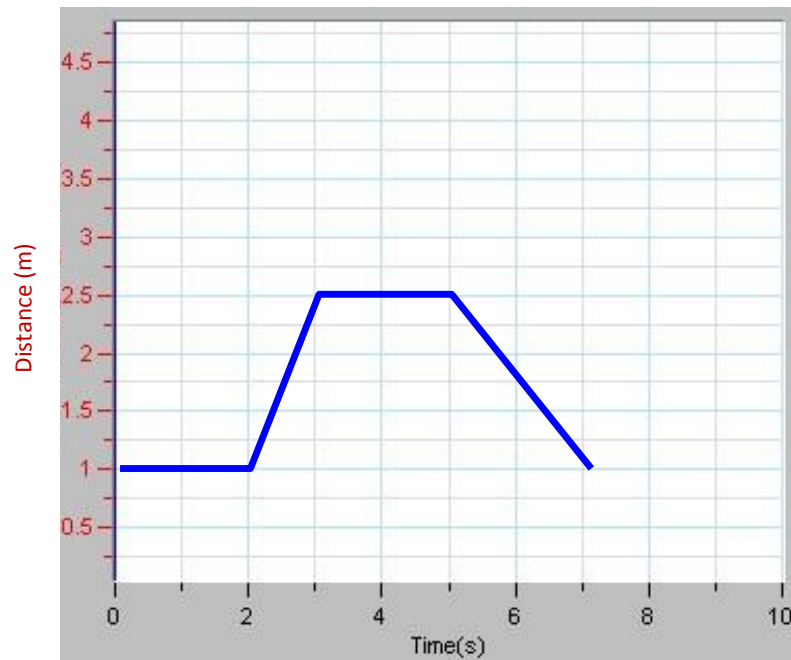


Figure 2: Position vs. Time graph

## Velocity versus Time Graph Matching:






### Experimental Setup

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

Distance sensor	Velocity (outgoing) (m/s)
Rate:	10/sec
Duration:	2 Min



### 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. Tap **Save** (  ) to save your data.
6. Repeat steps **Error! Reference source not found.**3 to 5**Error! Reference source not found.****Error! Reference source not found.** to match the following graph (Figure 3):

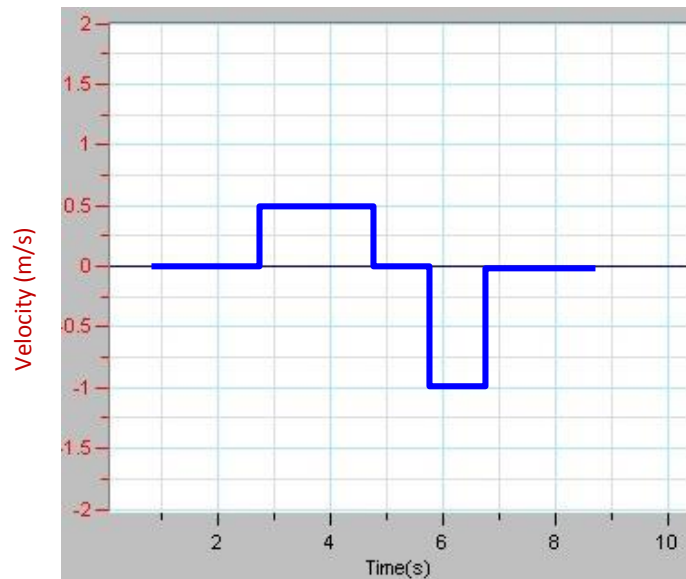


Figure 3: Velocity vs. Time graph



## Data Analysis

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

1. Describe how you walked for the graph that you matched.
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

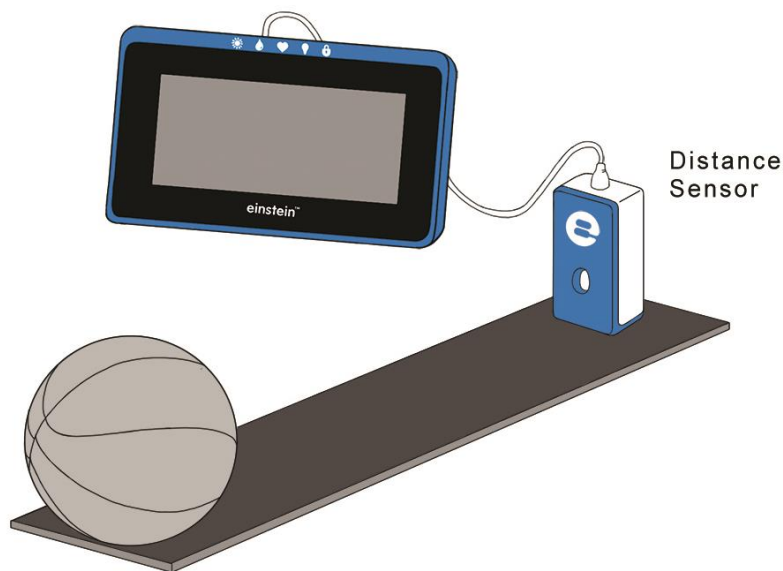


Figure 1



### 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:

$\Delta x$  = The displacement

$\Delta t$  = The time elapsed


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



### Equipment

- einstein™Tablet+ with MiLAB or Android/iOS Tablet with MiLAB and einstein™LabMate
- Distance sensor
- Distance adaptor
- Basketball or other round ball

## 123 Equipment Setup Procedure




1. Launch MiLAB (.
2. Connect the Distance sensor with the Distance adaptor to one of the ports on the einstein™Tablet+ or einstein™LabMate.
3. Make sure only the Distance sensor is selected.

## Experimental Setup

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

Distance sensor	Distance (outgoing) (m)
Rate:	10/sec
Duration:	2 Min


## 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. Tap **Run** () on the upper toolbar 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, tap **Stop** (.
6. Save your data by tapping **Save** () on the upper toolbar.

## Data Analysis

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

Look at the graph and answer the following questions:

1. Does the slope of the graph change over time?
2. Use Equation (1) 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. Tap the **Function** button (.
5. Select **Derivative** from the **Mathematical Functions** menu to calculate a velocity vs time graph. Discuss the graph.
6. Compare the results to the velocities you calculated using Equation (1).

## Chapter 3

# Motion on an Inclined Plane

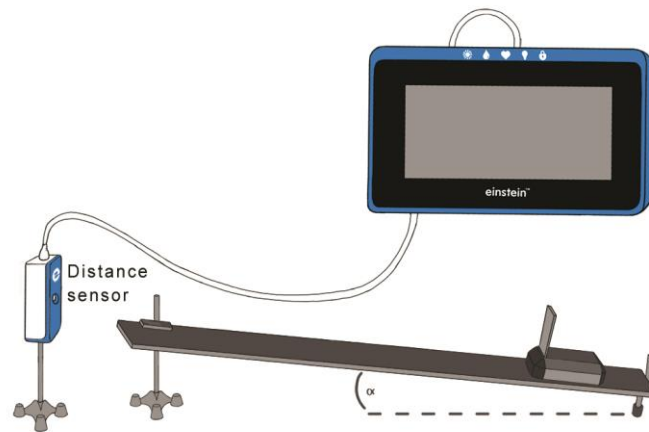


Figure 1



### 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™Tablet+ with MiLAB or Android/iOS Tablet with MiLAB and einstein™LabMate
- 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

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### Equipment Setup Procedure

1. Launch MiLAB ()
2. Connect the Distance sensor with the Distance adaptor to one of the ports on the einstein™Tablet+ or einstein™LabMate.
3. Assemble the equipment as shown in Figure 1.

4. Place the Distance sensor at the upper end of the inclined plane.
5. Place a stopper at the bottom of the plane.
6. The starting distance between the cart and the Distance sensor should be at least 50 cm.
7. Make sure that only the Distance sensor is selected.






## Experimental Setup

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

Distance sensor	Distance (outgoing) (m)
Rate:	10/sec
Duration:	10 Sec



## Procedure

1. Set the height of the inclined plane at ~5 cm. Record the height in your data table.
2. Hold the cart at the top of the inclined plane.
3. Tap **Run** (  ) to begin recording data.
4. Release the cart when you hear the clicking of the sensor.
5. When the cart reaches the bottom of the inclined plane, tap **Stop** (  ). The cart may jump several times before the end of the measurement as it bounces away from the stopper.
6. Repeat steps 3 to 5 **Error! Reference source not found.** two more times. Record all data in the data table.
7. Change the height of the incline to 15 cm and repeat steps 3 to 5. Record all data in the data table.
8. Change the height of the incline to 20 cm and repeat steps **Error! Reference source not found.** 3 to 5. Record all data in the data table.
9. Save your data by tapping **Save** (  ) on the upper toolbar.

## Data Table

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

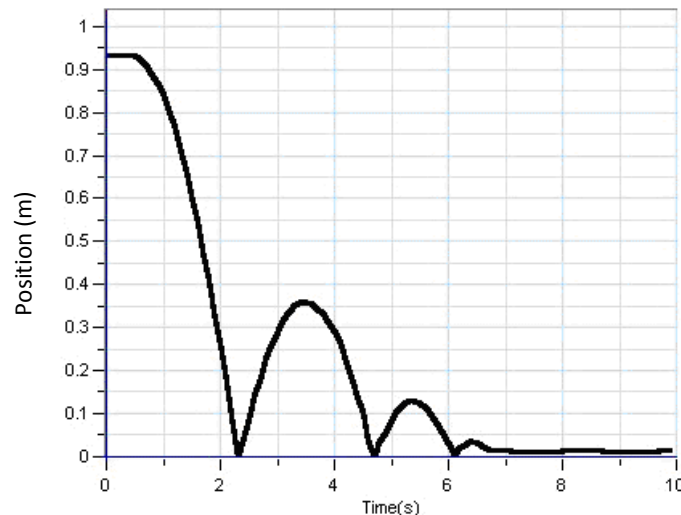


Figure 2



## Data Analysis

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

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. Tap the **Function** button ( $f_x$ ).
3. Tap the Setup button ( $\otimes$ ) next to the **Derivative** function from the **Mathematical Functions** menu.
4. In the **Math Functions** window which opens, select the Distance data from the **G1** drop down menu.
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. Tap the **Function** button ( $f_x$ ).
8. Tap the **Linear** function from the **Curve Fit** menu.
9. The linear fit to the data selection will appear on the 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. Tap the **Function** button ( $f_x$ ).
  - c. Tap the Setup button ( $\otimes$ ) next to the **Polynomial** function from the **Curve Fit** menu.
  - d. In the **Math Functions** window which opens, choose **2** from the **Order** drop down menu and the Distance data from the **G1** 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  $\alpha$  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 4

# Friction Coefficient

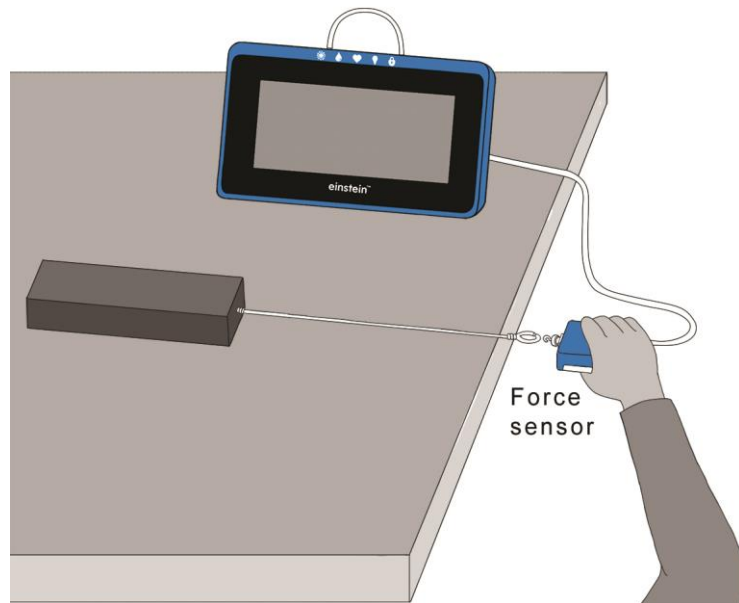


Figure 1



## 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

$\mu_s$  = 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

$\mu_k$  = The kinetic friction coefficient

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



## Equipment

- einstein™Tablet+ with MiLAB or Android/iOS Tablet with MiLAB and einstein™LabMate
- 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 ().
2. Connect the Force sensor to one of the ports on the einstein™Tablet+ or einstein™LabMate.
3. Assemble the equipment as shown in Figure 1.
4. Attach one end of the string to the block.
5. 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.
6. Make sure that only the Force sensor is selected.



## Experimental Setup

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

Force sensor	Force, Pull – positive ( $\pm 10$ or $\pm 50$ N) (N)
Set As Zero	ON
Rate:	10/sec
Duration:	2 Min



## 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 tapping **Save** ( ) on the upper toolbar.
7. Repeat the experiment with different materials. Remember to save the data from each experiment with a unique name.

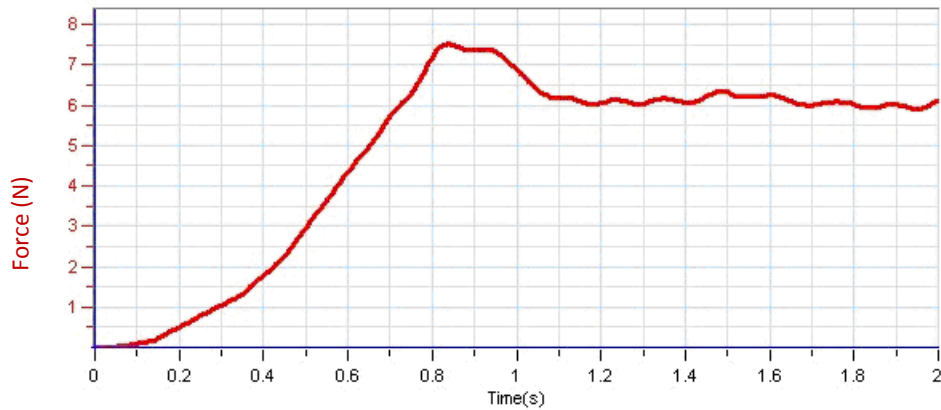


Figure 2



## Data Analysis

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

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  $\mu_s$ , 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. Calculate the average value of the force for this portion of the graph and write it down.
3. Use the average value of the force and Equation **Error! Reference source not found.**(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 5

# Newton's Third Law

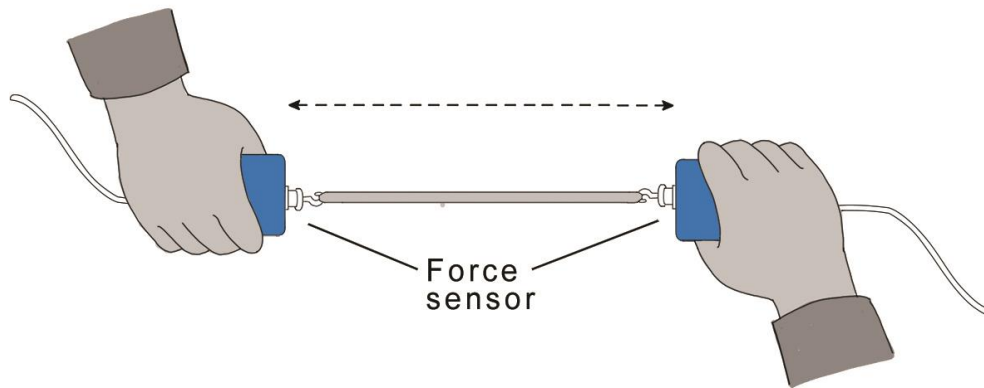


Figure 1



### 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 of Motion.




### Equipment

- einstein™Tablet+ with MiLAB or Android/iOS Tablet with MiLAB and einstein™LabMate
- Force sensors (2)
- String
- Rubber band



### Equipment Setup Procedure

1. Launch MiLAB ().
2. Connect the Force sensors to ports on the einstein™Tablet+ or einstein™LabMate.
3. Make sure that only the Force sensors are selected.







## Experimental Setup

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

<b>Force sensor</b>	Force, Pull – positive ( $\pm 50$ N) (N)
Set As Zero	ON
Rate:	10/sec
Duration:	50 Sec



## 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 you can pull on each other (see Figure 1).
2. Tap **Run** (  ) on the upper toolbar 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. Save your data by tapping **Save** (  ) on the upper toolbar.
5. Repeat the experiment with different materials. Remember to save the data from each experiment with a unique name.
6. What would happen if you used the rubber band instead of the string? Make a prediction using the **Predict** tool.
  - a. Open the **Setup** window (  ) from the **Sensor Control Panel**.
  - b. Turn on the **Predict** tool and close the setup window. Tap the **Predict** tool (  ) and follow the instruction to sketch a prediction on the graph.
  - c. Repeat steps 2-4 **Error! Reference source not found.** using the rubber band instead of the string.



## Data Analysis

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

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 your Force sensors have the same positive direction? What impact does your answer have on the analysis of the force pair?
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 and repeat the experiment. 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 6

# The Impact of Constant Force on a Moving Body

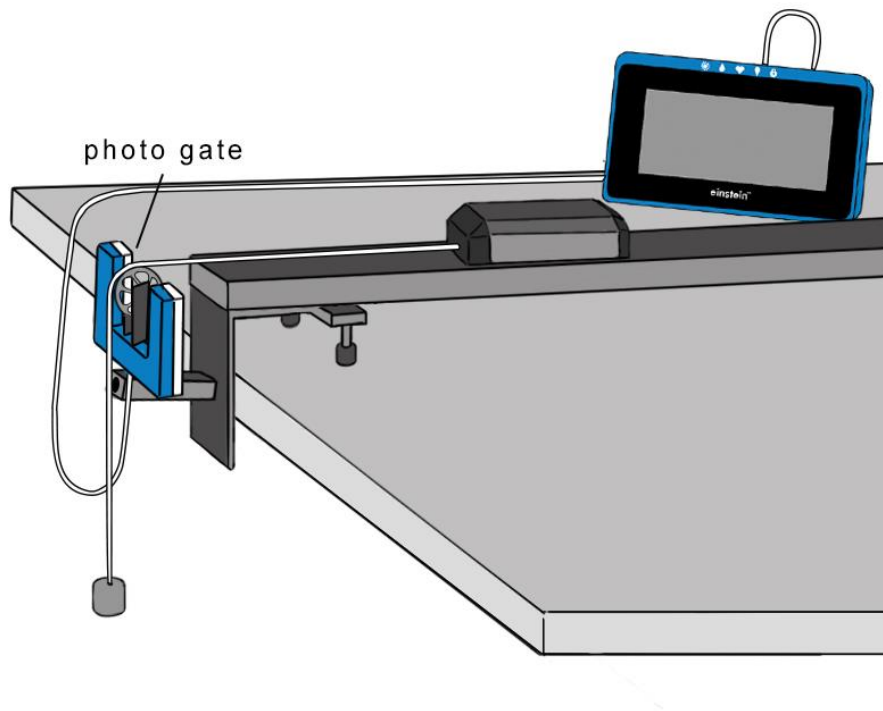


Figure 1



### Introduction

In this experiment you will explore the impact of constant force on 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, applying a constant force to a body yields a motion with constant acceleration.

The cart's velocity will be monitored using the Smart Pulley sensor.




### Equipment

- einstein™Tablet+ with MiLAB or Android/iOS Tablet with MiLAB and einstein™LabMate
- Smart Pulley sensor
- Dynamic Track
- Dynamic Cart
- Weight (~100 g)
- String



## 123 Equipment Setup Procedure

1. Launch MiLAB (.
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™Tablet+ or 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. Make sure that only the Smart Pulley sensor is selected.

## Experimental Setup




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

### Smart Pulley Sensor

Rate:	25/sec
Duration:	4 Sec

**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. Tap **Run** () on the upper toolbar.
3. Release the cart.
4. Tap **Stop** () on the upper toolbar as the hanging mass reaches the floor.
5. Save your data by tapping **Save** () on the upper toolbar.

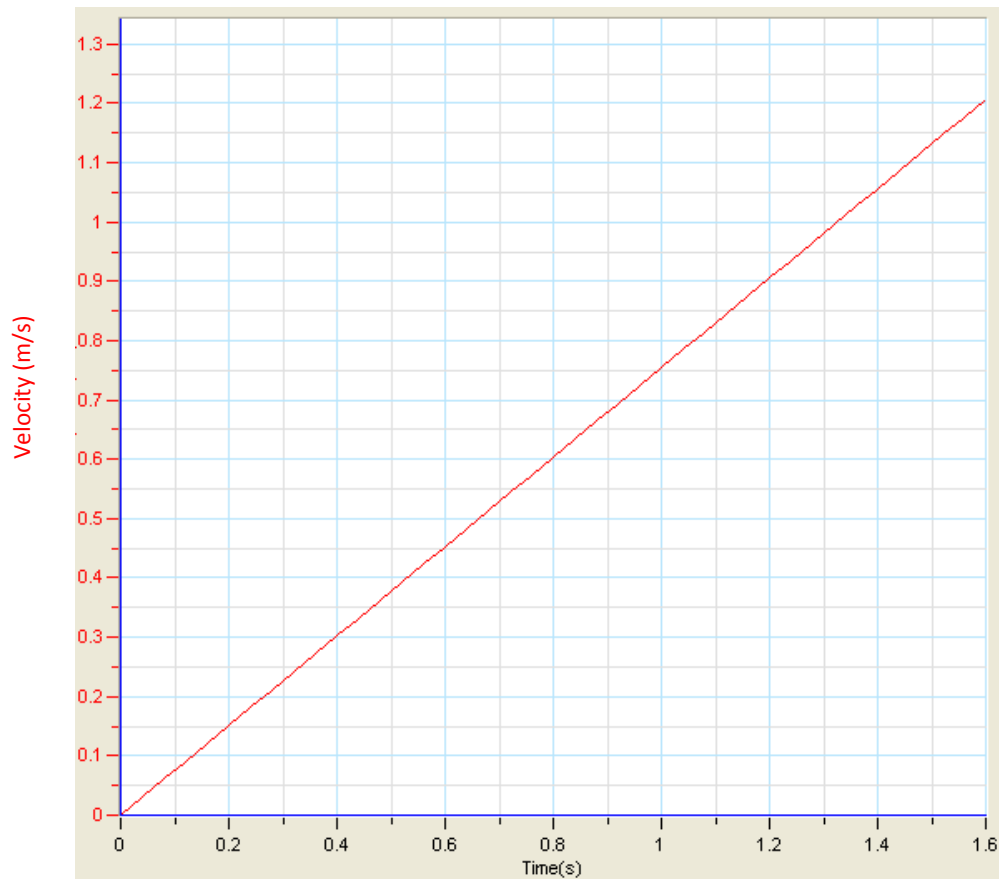


Figure 2



## Data Analysis

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

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. Tap the **Function** button ( $f_x$ ).
  - b. Tap the **Linear** function from the **Curve Fit** menu.
  - c. The linear fit to the data selection will appear on the graph and the fit equation will be displayed below the x-axis.
  - d. The slope of the linear fit line represents the acceleration of the cart.

## Chapter 7

# Newton's Second Law

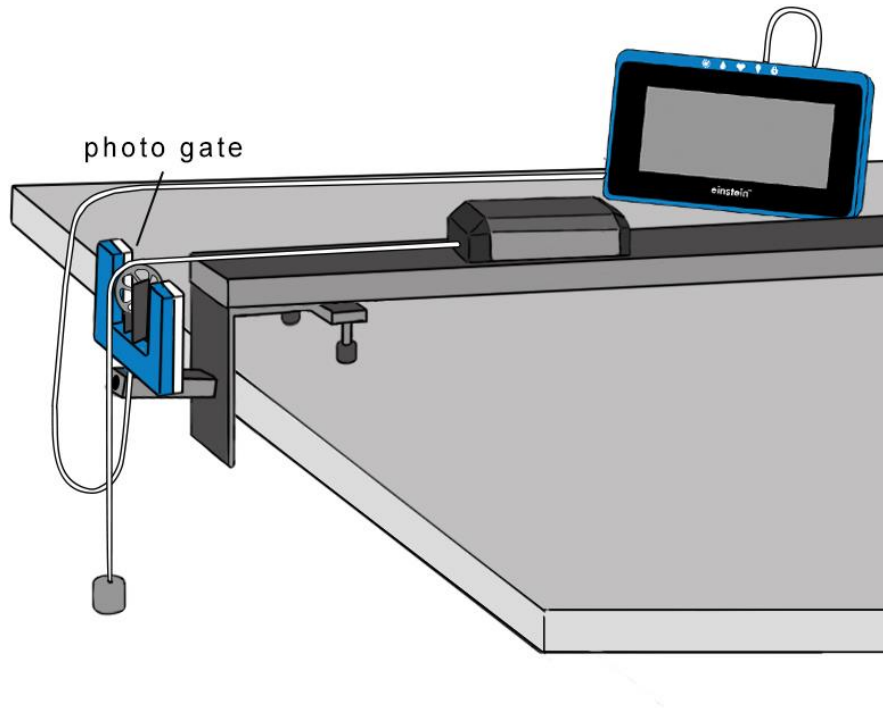


Figure 1



### 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 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 Rotary Motion sensor.




### Equipment

- einstein™Tablet+ with MiLAB or Android/iOS Tablet with MiLAB and einstein™LabMate
- 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 (.
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+ or einstein™LabMate.
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. Make sure that only the Smart Pulley sensor is selected.



## Experimental Setup




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

Smart Pulley Sensor	Velocity (m/s)
Rate:	25/sec
Duration:	20 Sec

**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. Tap **Run** () to begin recording data.
4. Release the cart.
5. Tap **Stop** () as the hanging mass reaches the floor.
6. Save the results by tapping **Save** (.
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 1 to 6 with hanging weights of 30 g, 40 g and 50 g.

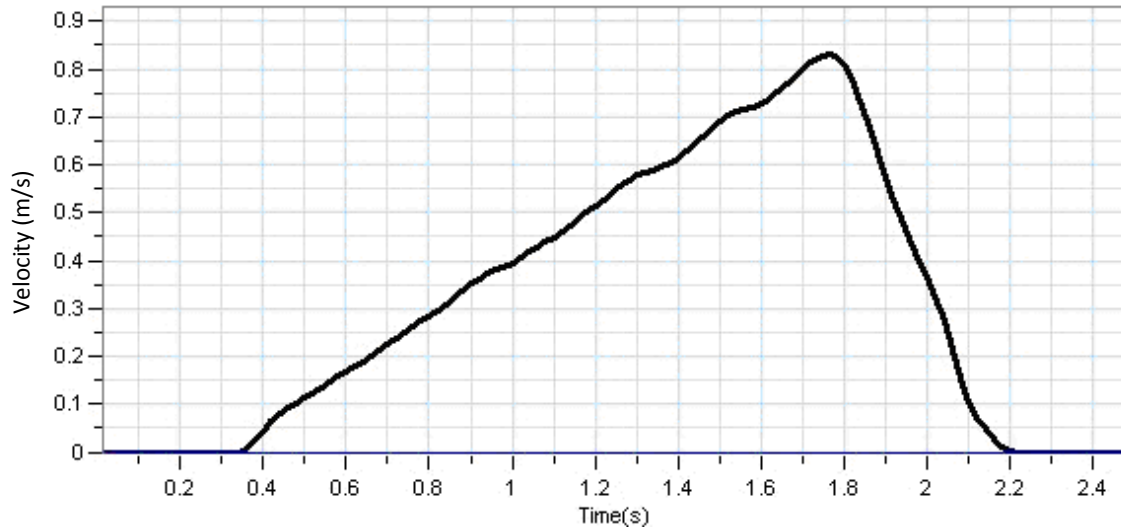


Figure 2



## 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.**

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 in velocity.
2. Use the cursors to select the linear range of the graph.
3. Tap the **Function** button ( $f_{x,y}$ ).
4. Tap the **Linear** function from the **Curve Fit** menu.
5. The linear fit equation will be displayed below the x-axis.
6. The slope of the linear fit line represents the acceleration of the cart.
7. Prepare a data table:

## Data Table

$m_{\text{weight}}$ (g)	$a$ (m/s <sup>2</sup> )	$F = m_{\text{weight}}g$ (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 8

# Energy of a Tossed Ball

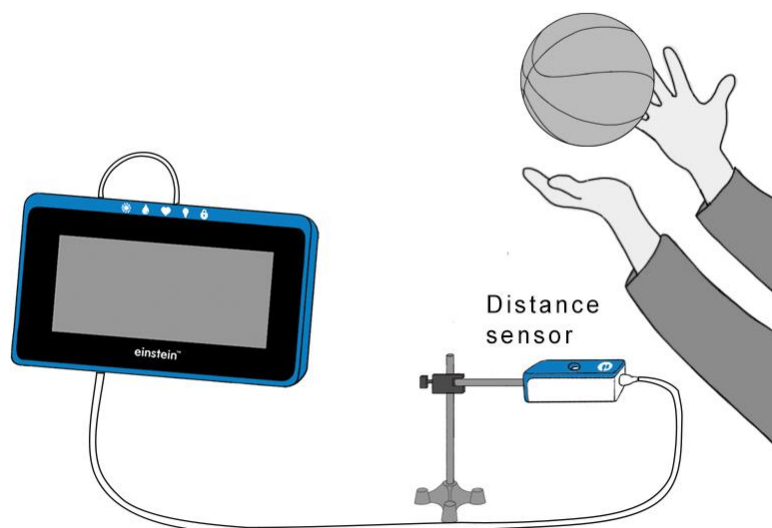


Figure 1



### 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™Tablet+ with MiLAB or Android/iOS Tablet with MiLAB and einstein™LabMate
- 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 ()
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. Make sure that only the Distance sensor is selected.

## Experimental Setup

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

Distance Sensor	Distance (m)
Rate:	25/sec
Duration:	20 Sec

## 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. Tap **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. Tap **Stop** ()
6. Save the results by tapping **Save** ()

## Data Analysis

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

## Graph the Kinetic Energy

1. Display a graph of the **Velocity** by taking the derivative of the distance vs time graph:
  - a. Tap the **Function** button ( $f_x$ ).
  - b. Tap the Setup button ( $\otimes$ ) next to the **Derivative** function from the **Mathematical Functions** 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. Tap the **Function** button ( $f_x$ ).
  - b. Tap the Setup button ( $\otimes$ ) next to the **Square** function from the **Mathematical Functions** menu.
  - c. In the **Math Functions** window which opens, select the calculated velocity data from the **G1** drop down menu.

- d. In the **A** edit box, enter half 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. Tap the **Function** button (  $f_x$  ).
  - b. Tap the Setup button (  $\otimes$  ) next to the **Linear** function from the **Mathematical Functions** menu.
  - c. In the **Math Functions** window which opens, select the Distance data from the **G1** drop down menu.
  - d. In the **A** edit box, enter the result of the mass of the ball multiplied by the free fall acceleration ( $9.8 \text{ m/s}^2$ ).
  - 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. Export the data (  $\rightarrow$  ) as a .csv file.
2. Create a plot of Potential Energy vs Kinetic Energy.
3. Discuss the graph in terms of the transitions between potential and kinetic energy and conservation of energy.

## Chapter 9

# Hooke's Law: Finding the Spring Constant

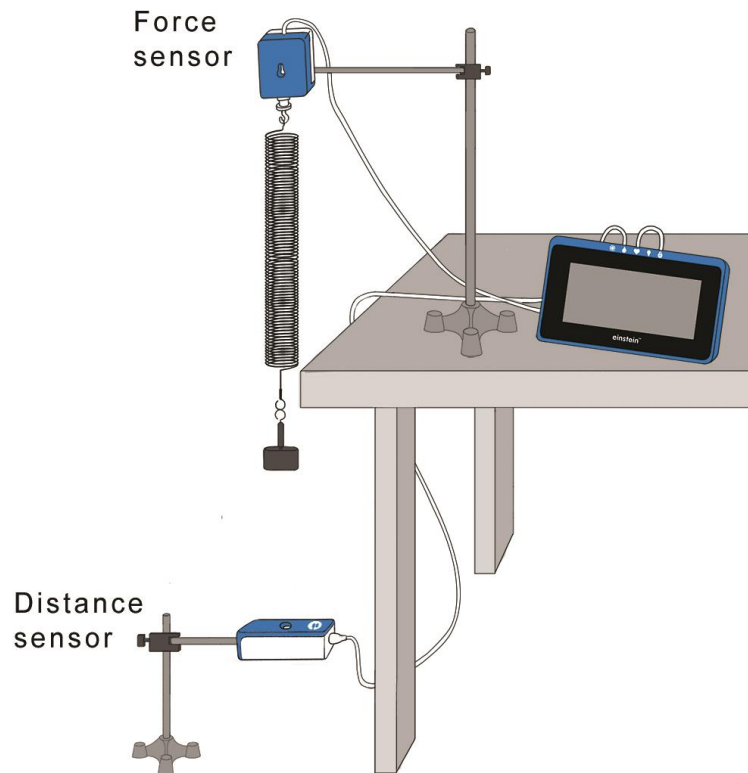


Figure 1

### 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
- $x$  = The spring's extension
- $k$  = The spring constant

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™Tablet+ with MiLAB or Android/iOS Tablet with MiLAB and einstein™LabMate
- 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

123

## Equipment Setup Procedure

1. Launch MiLAB ().
2. Connect the Distance sensor with the Distance adaptor to one of the ports on the einstein™Tablet+ or einstein™LabMate.
3. Connect the Force sensor to one of the ports on the einstein™Tablet+ or einstein™LabMate.
4. 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. Make sure that the Distance sensor and the Force sensor are the only sensors selected.



## Experimental Setup

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

Distance Sensor	Distance (m)
Force Sensor	Force, Pull - positive ( $\pm 10$ N) (N)
Set As Zero	ON
Rate:	10 samples/ sec
Duration:	2 Min



## Procedure

1. Make sure that the hanging mass is at rest.
2. Tap **Run** ()) on the upper toolbar 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 again a 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. Tap **Stop** ().
7. Save your data by tapping **Save** ()) on the upper toolbar.
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)
100		
150		
200		
250		
300		
350		
400		



## Data Analysis

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

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 10

# Simple Harmonic Motion

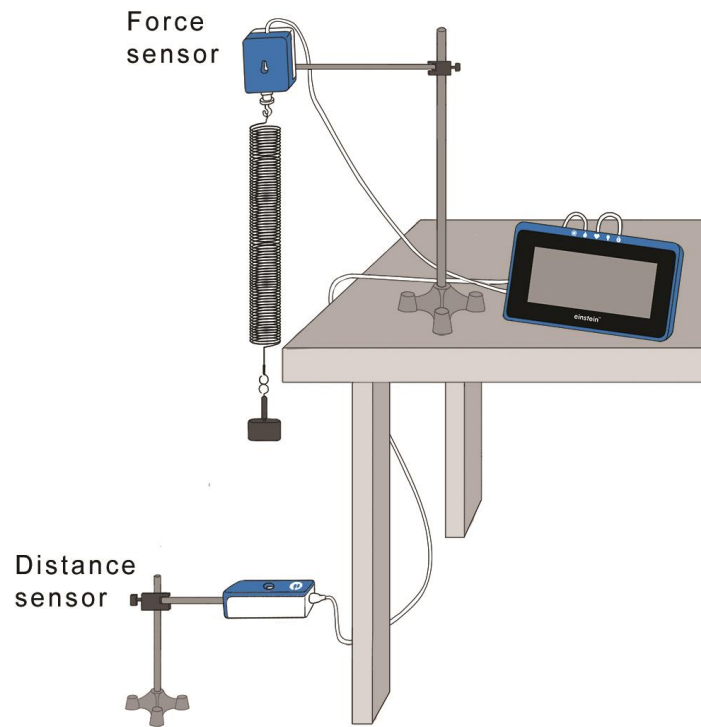


Figure 1

### 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:

$$x = A \cos 2\pi ft \quad (2)$$

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™Tablet+ with MiLAB or Android/iOS Tablet with MiLAB and einstein™LabMate
- 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

123

## Equipment Setup Procedure

1. Launch MiLAB .
2. Connect the Force sensor to one of the ports on the einstein™Tablet+ or einstein™LabMate.
3. Connect the Distance sensor to one of the ports on the einstein™Tablet+ or 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. Make sure that only the Force and Distance sensors are selected.



## Experimental Setup

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




<b>Force Sensor</b>	Force, Pull - positive ( $\pm 50$ N) (N)
Set As Zero	ON
<b>Distance Sensor</b>	Distance (m)
Rate:	25/sec
Duration:	40 Sec



## Procedure

- Using a meter stick and two known masses, measure the spring constant  $k$ :
  - Place a 1 kg mass at 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,  $\Delta F$ , 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  $\Delta F$  by the change in displacement,  $\Delta x$ , 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.
  - Tap **Run** (  ) to begin recording data.
  - After about 15 oscillations, tap **Stop** (  ).
  - Save your data by tapping **Save** (  ) on the upper toolbar.




## Data Analysis

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

- Working with either the Force curve or the Distance curve, measure the period of oscillation by using two cursors. Put the first cursor on the first peak and the second cursor on the 11th peak. Record the value of  $\Delta t$ , which will appear in the text box on the graph as  $dx$ . 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.
- Export the data (  ) as a .csv file.



5. Create a plot of force vs distance.
6. Fit a straight line to the resulting graph. From Equation (1), the slope of this graph is the spring constant  $k$ .
7. Compare this value of  $k$  with those calculated previously.

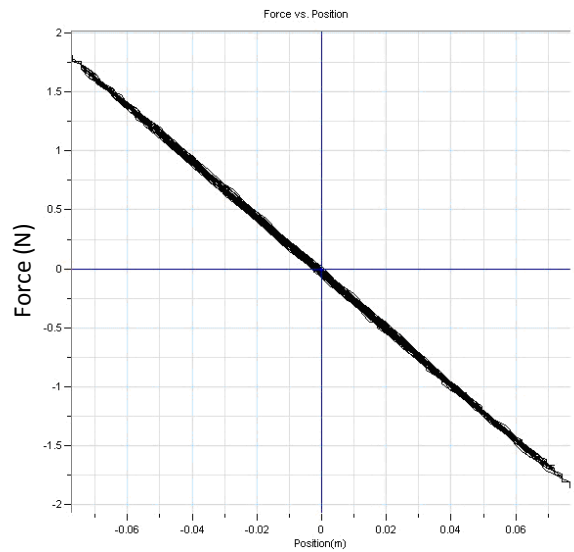


Figure 2



### Further Suggestions

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

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

## Chapter 11

# Energy in Simple Harmonic Motion

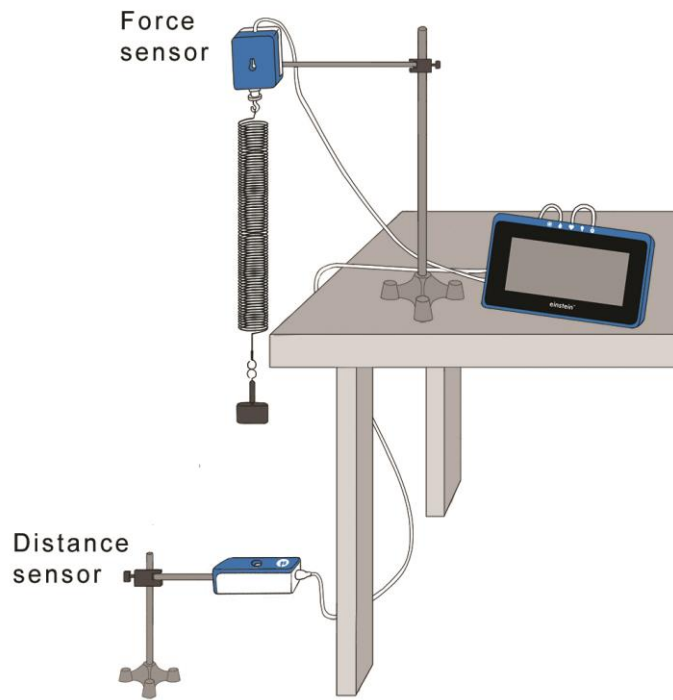


Figure 1

### 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™Tablet+ with MiLAB or Android/iOS Tablet with MiLAB and einstein™LabMate
- 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 ()
2. Connect the Distance sensor to one of the ports on the einstein™Tablet+ or 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. Make sure that only the Distance sensor is selected.



## Experimental Setup



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


<b>Distance Sensor</b>	<b>Distance (m)</b>
Rate:	10/sec
Duration:	4 Min



## Procedure

### The Spring Constant

1. Make sure that the hanging mass is at rest.
2. Tap **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 tap **Stop** ().

5. Save your data by tapping **Save** (  ) on the upper toolbar.
6. Use two cursors 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:

$\Delta l$  = 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. Tap **Run** (  ) to begin recording data.
3. Lift the mass about 5 cm above the equilibrium position and release.
4. After 20 seconds tap **Stop** (  ).



## Data Analysis

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

### 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. Tap the **Function** button (  ).
  - b. Tap the Setup button (  ) next to the **Linear** function from the **Mathematical Functions** menu.
  - c. In the **Math Functions** window which opens, select the Distance data from the **G1** drop down menu.
  - 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. Tap the **Function** button (  ).
  - b. Tap the Setup button (  ) next to the **Square** function from the **Mathematical Functions** menu.
  - c. In the **Math Functions** window which opens, select the displacement data which you calculated in the previous step from the **G1** drop down menu.
  - d. In the **A** edit box, enter  $\frac{1}{2}k$ , that is, half the value of the spring constant.
  - e. In the **B** edit box 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. Create a graph of the velocity of the spring,  $v$ , as it changes over time with the oscillations:
  - a. Tap the **Function** button (  ).
  - b. Tap the Setup button (  ) next to the **Derivative** function from the **Mathematical Functions**

- menu.
- c. In the **Math Functions** window which opens, select the Distance data from the **G1** drop down menu.
  - d. Enter *Velocity* in the **Name** edit box and *m/s* in the **Unit** edit box.
2. Create a graph of the kinetic energy as it changes over time with the oscillations:
- a. Tap the **Function** button ( $f_x$ ).
  - b. Tap the Setup button ( $\otimes$ ) next to the **Square** function from the **Mathematical Functions** menu.
  - c. In the **Math Functions** window which opens, select the calculated velocity data from the **G1** drop down menu.
  - d. In the **A** edit box, enter half the value of the mass of the weight, *m*.
  - e. Type *KE* in the **Name** edit box; type J in the **Unit** edit box.

## Create Graphs of Kinetic Energy and Potential Energy as a Function of Position

1. Export the data ( $\rightarrow$ ) as a .csv file.
2. Plot Potential Energy and Kinetic Energy as a function of position.
3. Calculate the total energy (*PE+KE*) of the system and plot this value on the graph as well.
4. Discuss the graph in terms of the transitions between potential and kinetic energy and conservation of energy.

## Chapter 12

# Specific Heat

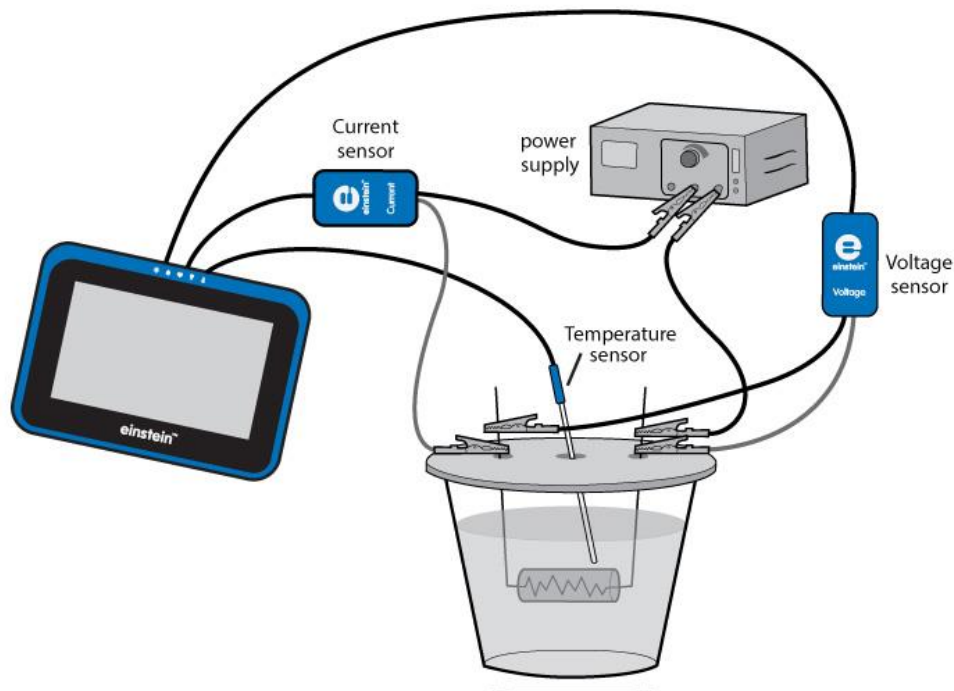


Figure 1

### 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

$\Delta T$  = 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 of the substance.

In this experiment you will determine the specific heat of water. You will heat the water by passing current through an electric resistor. The energy dissipated by the resistor is given by:

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

Where:

$V$  = The voltage drop across the resistor

$I$  = The current through the resistor

$\Delta t$  = The heating time

The known value of the specific heat of water is  $1 \text{ calorie/gram } ^\circ\text{C} = 4.186 \text{ joule/gram } ^\circ\text{C}$




## Equipment

- einstein™Tablet+ with MiLAB or Android/iOS Tablet with MiLAB and einstein™LabMate
- Temperature sensor ( $-40\text{ }^\circ\text{C}$  to  $140\text{ }^\circ\text{C}$ )
- Current sensor ( $\pm 2.5\text{ A}$ )
- Voltage sensor ( $\pm 25\text{ V}$ )
- 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 ( $6\text{ V}$ ,  $2\text{ A}$ )
- Resistor ( $5\ \Omega$ ,  $10\text{ W}$ )
- Two alligator clips
- Wires



## Equipment Setup Procedure

1. Launch MiLAB (.
2. Connect the Temperature sensor to one of the ports on the einstein™Tablet+ or einstein™LabMate.
3. Connect the Current sensor to one of the ports on the einstein™Tablet+ or einstein™LabMate.
4. Connect the Voltage sensor to one of the ports on the einstein™Tablet+ or einstein™LabMate.
5. Fill the polystyrene cup with  $40\text{ mL}$  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. Make sure that only the Temperature sensor, Voltage sensor and Current sensor are selected.

Assemble the setup as shown in Figure 1:

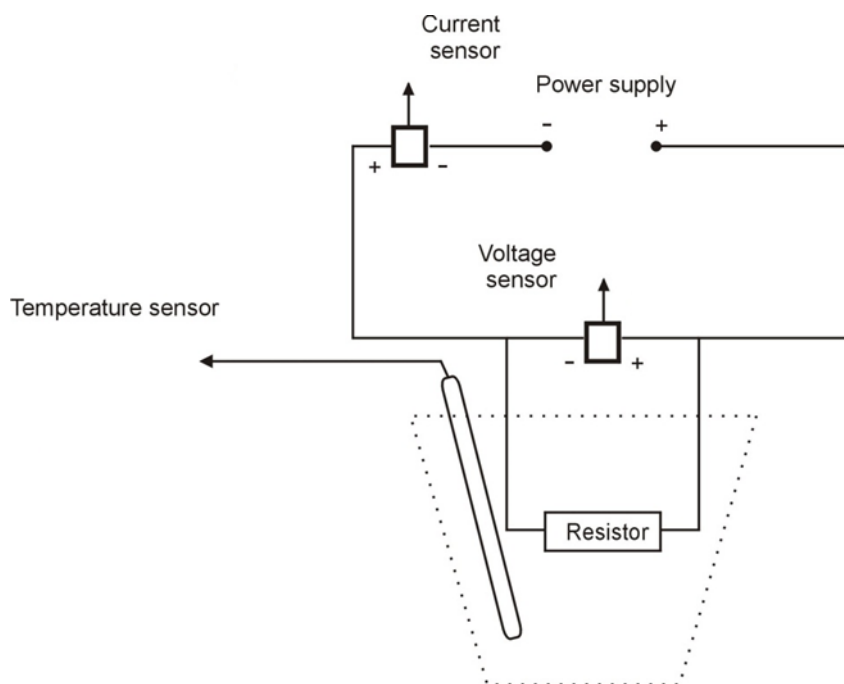


Figure 2



## Experimental Setup

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

Temperature Sensor (-40 °C – 140 °C)	Temperature (°C)
Current Sensor ( $\pm 2.5$ A)	Current (A)
Set As Zero	ON
Voltage Sensor ( $\pm 25$ V)	Voltage (V)
Set As Zero	ON
Rate:	1/sec
Duration:	8 Min 20 Sec

**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. Tap **Run** (🎮) on the main toolbar to begin recording data.
2. Switch the power supply to 6V DC and turn it on.
3. Observe the graph.
4. After 6 minutes tap **Stop** (⏏).
5. Save your data by tapping **Save** (💾).





## Data Analysis

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

1. What is the mass of water in 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 the value in your notebook.
3. Use the cursor to read the value of the current. Record the 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 in the region 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 the value in your notebook.
7. Use Equation (1) to calculate the specific heat of water. Record the 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 13

# Charge Produced by Friction

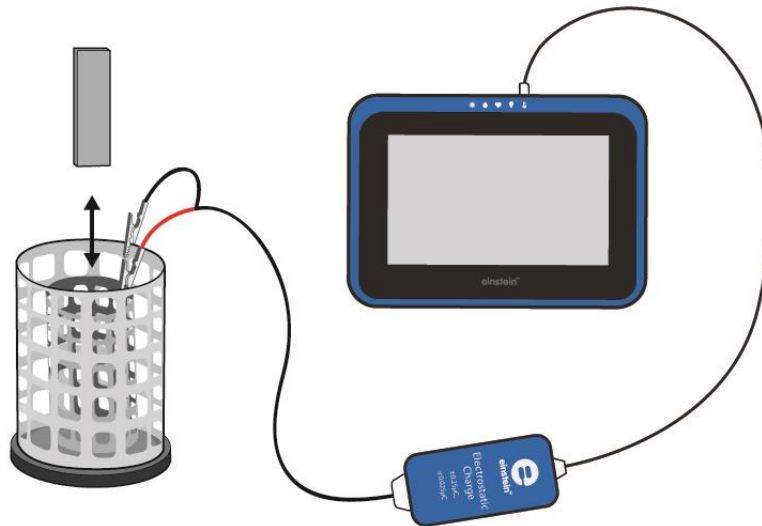


Figure 1



### 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™Tablet+ with MiLAB or Android /iOS Tablet with MiLAB and einstein™LabMate
- 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

123

### Equipment Setup Procedure

1. Launch MiLAB ()
2. Connect the Electrostatic Charge sensor to one of the ports on the einstein™Tablet+ or einstein™LabMate.
3. Connect the test leads to the Electrostatic Charge sensor.

- Make sure that only the Electrostatic Charge sensor is selected.



## Experimental Setup

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

Electrostatic Charge Sensor	Charge, 25 nC (nC)
Set As Zero	ON
Rate:	10/sec
Duration:	2 Min



## Procedure

- 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).

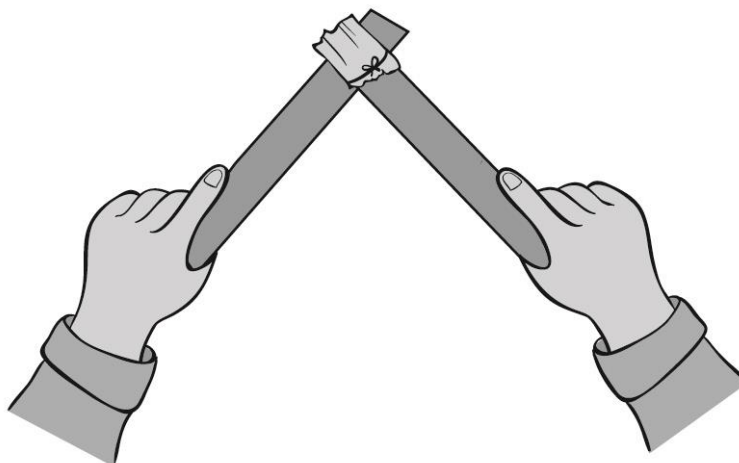


Figure 2

- Short circuit the two leads of the Electrostatic charge sensor. To short circuit the sensor, connect the positive (red) and negative (black) leads.
- Tap **Run** (▶) to begin recording data.
- Rub the woolen cloth along the length of a strip of PVC plastic (see Figure 2).
- 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).
- Tap **Stop** (■) to stop collecting data.
- Tap **Save** (⬇) to save data.
- Remove the strip from the Faraday pail.
- Short circuit the two leads of the Electrostatic charge sensor.
- Next, insert the woolen cloth into the pail and record the readings.
- Repeat steps 3 to 8 with other pairs of materials, rubbing cloth against a strip or rod.



## Questions

- What happens when you rub a woolen cloth against PVC plastic?

2. Are the objects that have been rubbed together always charged equally and opposite in charge, when you measure them? Explain.
3. Which of the pairs of materials that you have rubbed together give off electrons more easily?

## Chapter 14

# Electrification by Contact

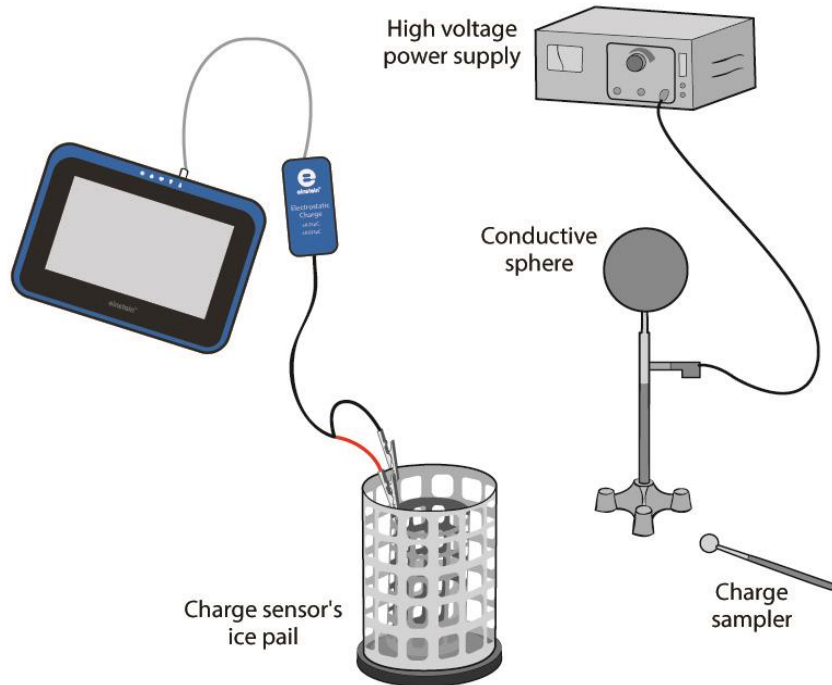


Figure 1



## 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™Tablet+ with MiLAB or Android/iOS Tablet with MiLAB and einstein™LabMate
- 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 .
2. Connect the Electrostatic Charge sensor to one of the ports on the einstein™Tablet+ or 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. Make sure that only the Electrostatic Charge sensor is selected.

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











## Experimental Setup





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

<b>Electrostatic Charge Sensor</b>	Charge, 25 nC (nC)
Set As Zero	ON
Rate:	10/sec
Duration:	2 Min



## 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. Tap **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. Tap **Stop** () to stop collecting data.
7. Tap **Save** () to save data.
8. Short circuit the two leads of the Electrostatic charge sensor.
9. Tap **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. Tap **Stop** () to stop collecting data.
12. Tap **Save** () to save data.
13. Short circuit the two leads of the Electrostatic charge sensor.
14. Tap **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. Tap **Stop** () to stop collecting data.

17. Tap **Save** (  ) to save data.
18. Short circuit the two leads of the Electrostatic charge sensor.
19. Tap **Run** (  ) to begin recording data.
20. Now ground the charge sampler to remove any residual charge from it, then repeat step 7. Explain the changes in the graph.
21. Tap **Stop** (  ) to stop collecting data.
22. Tap **Save** (  ) to save data.



## 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 15

# Charge Produced by Induction

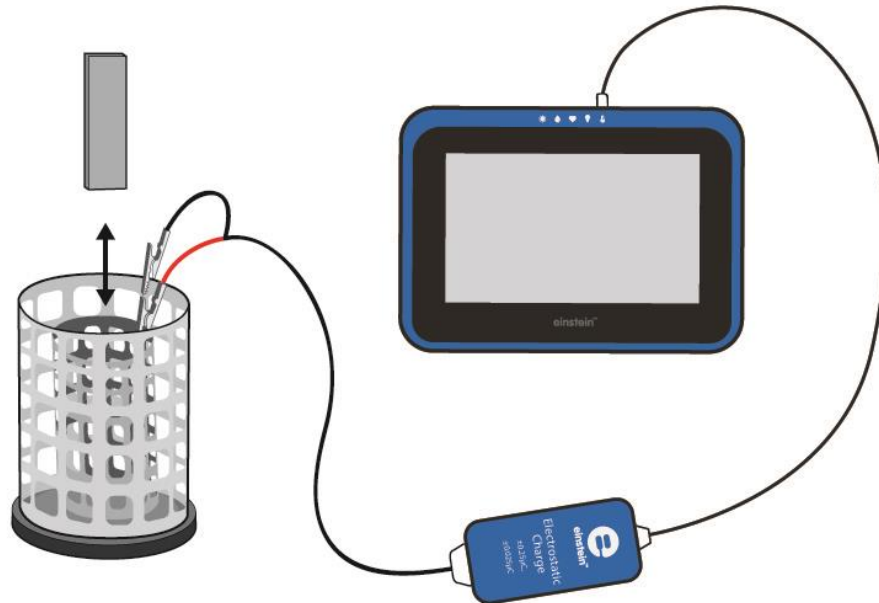


Figure 1



### Introduction

In this experiment you 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™Tablet+ with MiLAB or Android/iOS Tablet with MiLAB and einstein™LabMate
- 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



## 123 Equipment Setup Procedure

1. Launch MiLAB .
2. Connect the Electrostatic Charge sensor to one of the ports on the einstein™Tablet+ or 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. Make sure that only the Charge sensor is selected.

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



## Experimental Setup

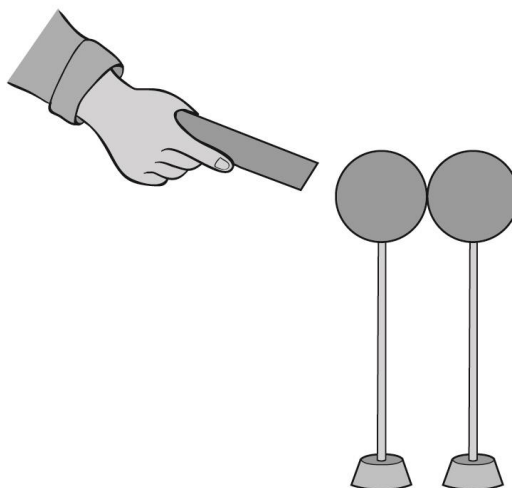
Program the sensor to log data according to the following setup:

<b>Electrostatic Charge Sensor</b>	Charge, 25 nC (nC)
Set As Zero	ON
Rate:	10/sec
Duration:	2 Min






## 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. Tap **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 pail, while not letting it touch the pail.
8. Tap **Stop** (  ) to stop collecting data.
9. Tap **Save** (  ) to save your data.
10. Remove the sphere.
11. Short circuit the two leads of the Electrostatic charge sensor.
12. Now repeat steps 6 to 10, 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 16

# Conductive and Insulating Materials

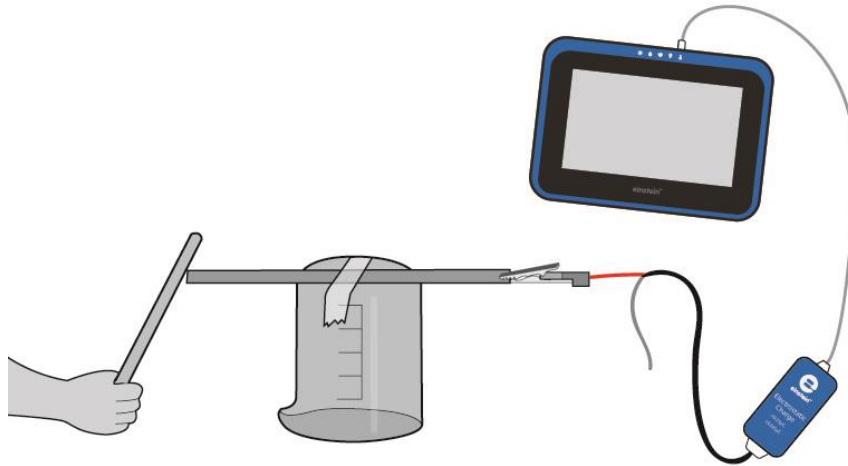


Figure 1



## 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™Tablet+ with MiLAB or Android /iOS Tablet with MiLAB and einstein™LabMate
- 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 such as metals, graphite, plastic, wood, paper and others

123

## Equipment Setup Procedure

1. Launch MiLAB ()
2. Connect the Electrostatic Charge sensor to one of the ports on the einstein™Tablet or 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. Make sure that only the Electrostatic Charge sensor is selected.




## Experimental Setup

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

Electrostatic Charge sensor	Charge, 25 nC (nC)
Set As Zero	ON
Rate:	10/sec
Duration:	2 Min



## 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. Tap **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 material and a list of insulating materials.

## Chapter 17

# Voltage Measurements

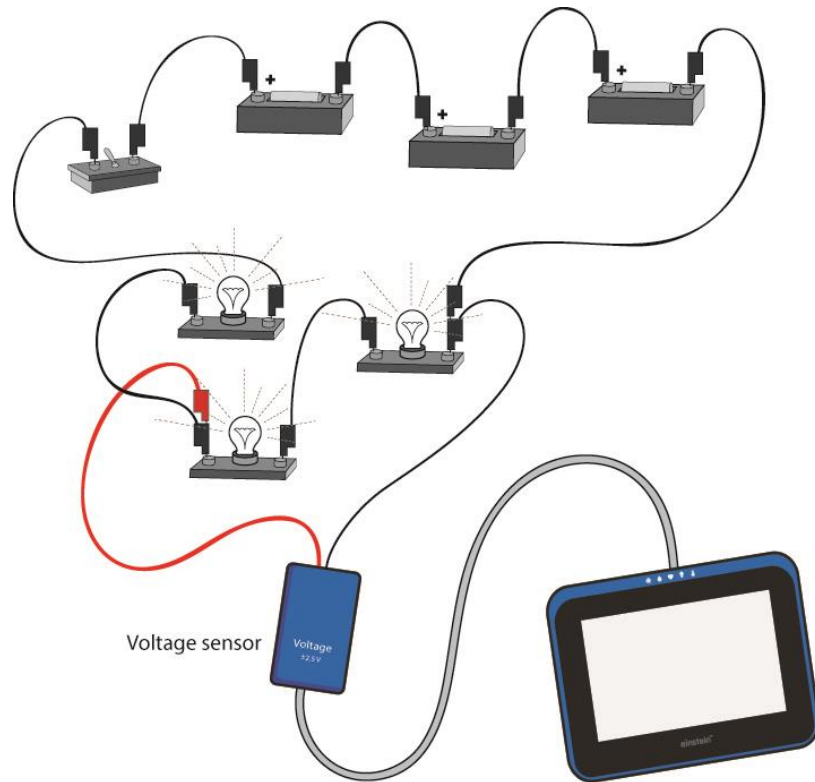


Figure 1



### Introduction

A voltmeter is an instrument used to measure the voltage drop between two points. A digital voltmeter displays 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 you will use the voltage sensor to measure voltage drops across several points in a basic electrical circuit. You will also learn the various display options.



### Equipment

- einstein™Tablet+ with MiLAB or Android/iOS Tablet with MiLAB and einstein™LabMate
- Voltage sensor ( $\pm 25$  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 (.
2. Connect the Voltage sensor to one of the ports on the einstein™Tablet+ or 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.

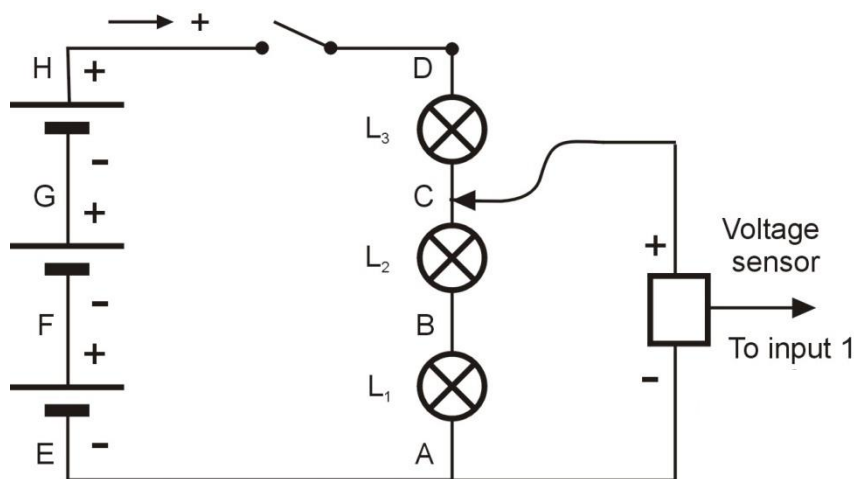


Figure 2

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™Tablet+ or einstein™LabMate.
6. Disconnect the two leads of the Voltage sensor.
7. Make sure that only the Voltage sensor is selected.





## Experimental Setup

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

Voltage Sensor ( $\pm 25$ V)	Voltage (V)
Set As Zero	ON
Rate:	10/sec
Duration:	2 Min



## Procedure

1. Make sure the switch is in the Off position.
2. Tap **Meter** () to view the results in meter format.
3. Tap **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, 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 to contact with point D on the circuit. Record the voltage

- value in your data table.
- Repeat step 8 with points C, B, A, E, F and G.
  - The **Meters** window has four different display options. Explore the **Analog** (🕒), **Bar** (📊), **Color** (🎨) and **Digital** (05.00) display options.
  - Save your data by tapping **Save** (💾) on the main toolbar.

## 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**.

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



## Chapter 18

# Resistance of a Wire

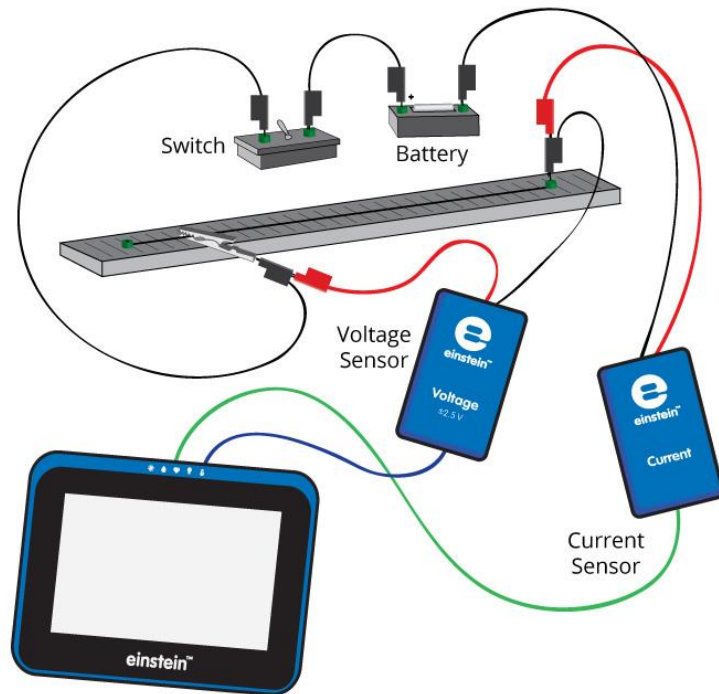


Figure 1

### 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:

$\rho$  = The specific electrical resistance of the material, resistivity

$\ell$  = The length of the wire

$A$  = The cross sectional area of the wire

In this experiment we will explore this equation.



## Equipment

- einstein™Tablet+ with MiLAB or Android/iOS Tablet with MiLAB and einstein™LabMate™ +
- Voltage sensor ( $\pm 2.5$  V)
- Current sensor ( $\pm 2.5$  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)
- Battery (1.5 V) and battery holder
- Connecting wires
- Alligator clip
- Switch (On/Off)
- Caliper

### 123

## Equipment Setup Procedure (Part 1)

1. Launch MiLAB ().
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. 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.

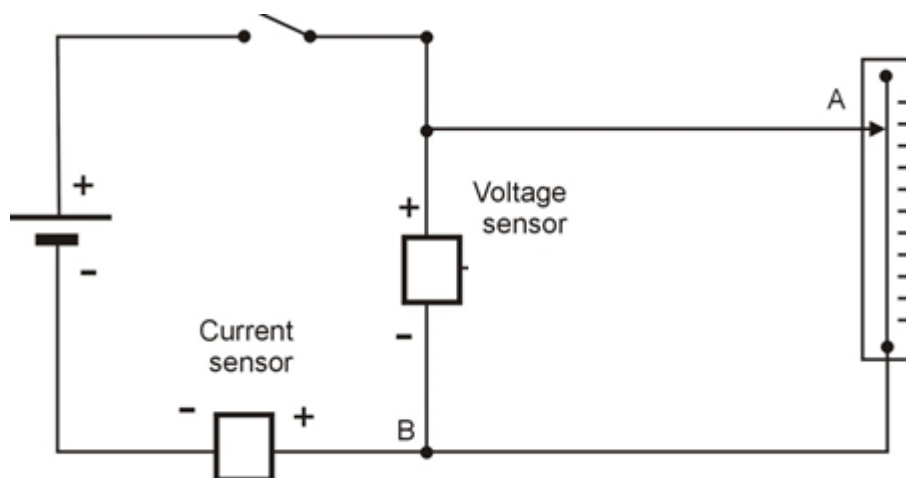


Figure 2

**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. Make sure that only the Current sensor and the Voltage sensor are selected.








## Experimental Setup

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

<b>Voltage Sensor (<math>\pm 2.5</math> V)</b>	Voltage (V)
Set As Zero	ON
<b>Current Sensor (<math>\pm 2.5</math> A)</b>	Current (A)
Set As Zero	ON
Rate:	10/sec
Duration:	5 Sec



## Procedure

1. Use the Caliper to measure the diameter of the resistance wire.
2. Clip the alligator clip to the resistance wire next to the 10 cm mark.
3. Tap **Meter** (  ) to view the results in meter format. Choose the **Digital** (  ) display option for the Current and Voltage sensors.
4. Tap **Run** (  ) to begin recording data. Record the voltage and current values in your data table.
5. Turn the switch to the On position.
6. Tap **Run** (  ) on the main toolbar each time you wish to record a data sample.
7. Record a data sample.
8. Tap **Stop** (  ) to stop collecting data.
9. Turn the switch to the Off position.
10. Clip the alligator clip to the resistance wire next to the 15 cm mark and repeat steps 4 to 9.
11. Increase the resistance wire length by measures of 5 cm until reaching 50 cm and repeat steps 4 to 9 for each length.

## Data Table

Diameter of the wire: \_\_\_\_\_ mm

Cross sectional area of the wire: \_\_\_\_\_ cm<sup>2</sup>

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



## Data Analysis

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

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 that passes through the origin to your data points.
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 19

# Resistors in Series

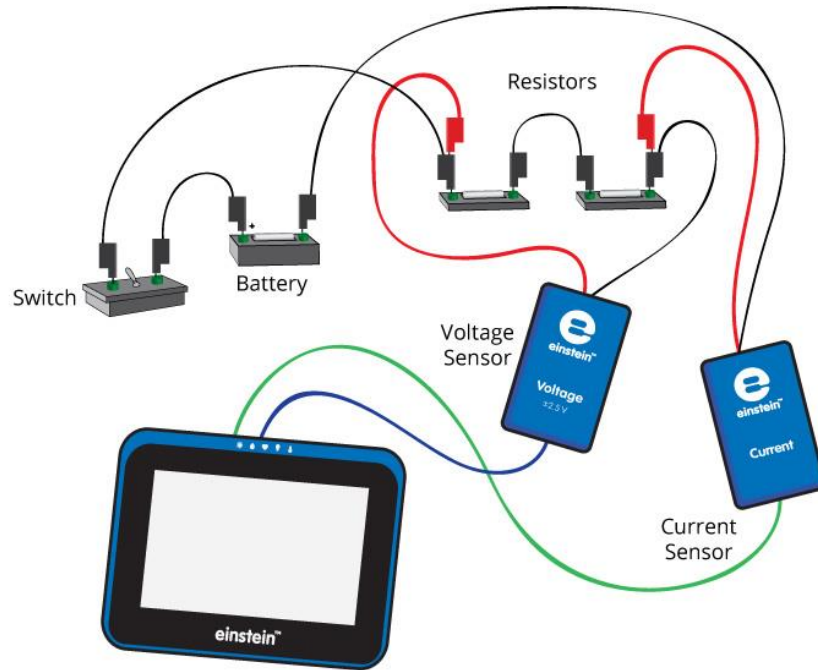


Figure 1



## 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 the same.

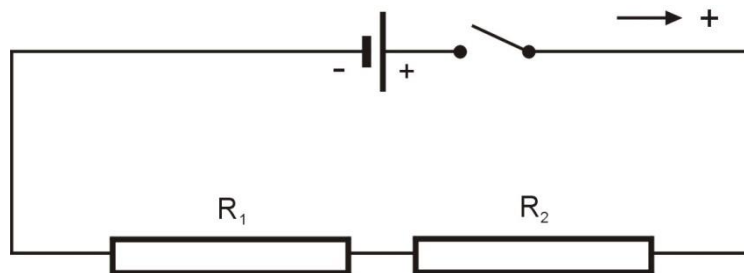


Figure 2

The voltage drop 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 resistors:

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


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



## Equipment

- einstein™Tablet+ with MiLAB or Android/iOS Tablet with MiLAB and einstein™LabMate
- Voltage sensor ( $\pm 2.5$  V)
- Current sensor ( $\pm 250$  mA)
- Resistor ( $10\ \Omega$ )
- Resistor ( $20\ \Omega$ )
- Battery (1.5 V) and battery holder
- Connecting wires
- Switch (On/Off)

## 123 Equipment Setup Procedure (Part 1)

1. Launch MiLAB (.
2. Connect the Voltage sensor to a port on the einstein™Tablet+ or einstein™LabMate.
3. Connect the Current sensor to a port on the einstein™Tablet+ or 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.

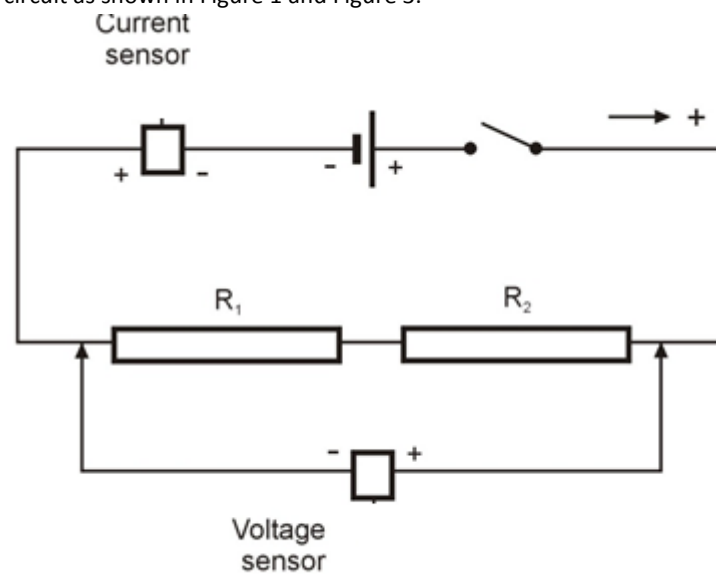


Figure 3

**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. Make sure that only the Voltage sensor and Current sensor are selected.








## Experimental Setup

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

<b>Voltage Sensor (<math>\pm 2.5</math> V)</b>	Voltage (V)
Set As Zero	ON
<b>Current Sensor (<math>\pm 250</math> mA)</b>	Current (mA)
Set As Zero	ON
Rate:	10/sec
Duration:	5 Sec



## Procedure

1. Turn the switch to the On position.
2. Tap **Meter** (  ) on the lower toolbar.
3. Choose the **Digital** (  ) display option for the Current and Voltage sensors.
4. Tap **Run** (  ) on the main toolbar each time you wish to record a data sample.
5. Connect the leads of the Voltage sensor across resistor  $R_1$ . Tap **Run** (  ) and record the voltage value in your data table.
6. Connect the leads of the Voltage sensor across resistor  $R_2$ . Tap **Run** (  ) and record the voltage value in your data table.

**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 both resistors	$V$ (V)	2	
Current	$I$ (A)	2	
Voltage across $R_1$	$V_1$ (V)	3	
Voltage across $R_2$	$V_2$ (V)	4	



## Data Analysis

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

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 20

# Resistors in Parallel

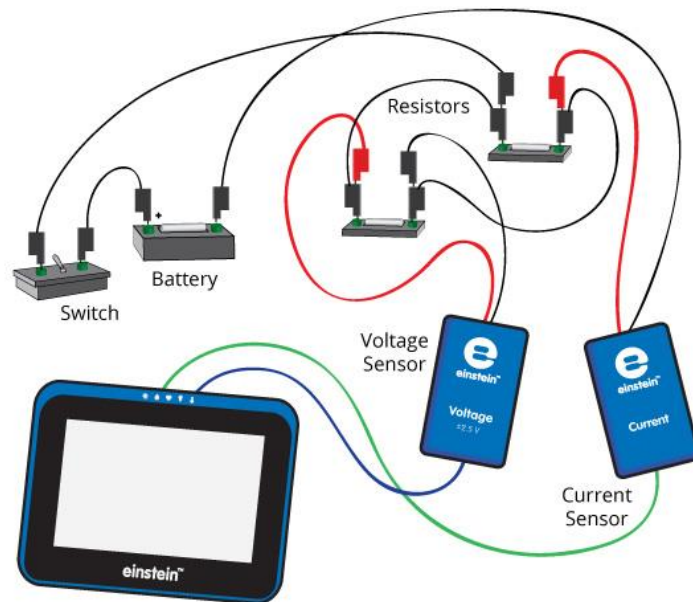


Figure 1



## 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.

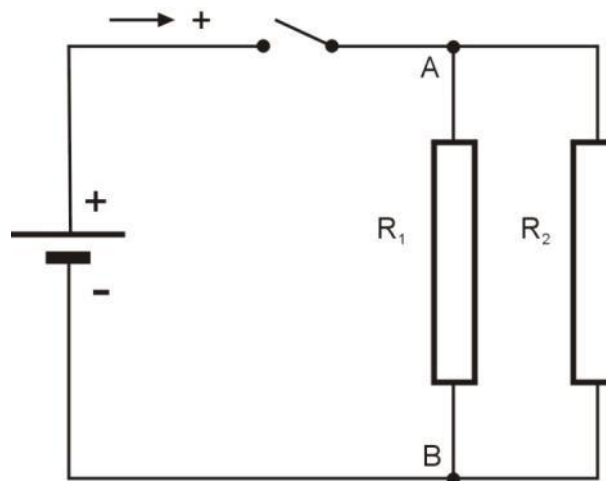


Figure 2

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™Tablet+ with MiLAB or Android/iOS Tablet with MiLAB and einstein™LabMate
- Voltage sensor ( $\pm 2.5$  V)
- Current sensor ( $\pm 250$  mA)
- Resistor ( $10 \Omega$ ), Resistor ( $20 \Omega$ )
- 1.5 V battery with battery holder
- Connecting wires
- Switch (On/Off)

## 123

## Equipment Setup Procedure

1. Launch MiLAB ().
2. Connect the Voltage sensor to a port on the einstein™Tablet+ or einstein™LabMate.
3. Connect the Current sensor to a port on the einstein™Tablet+ or 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:

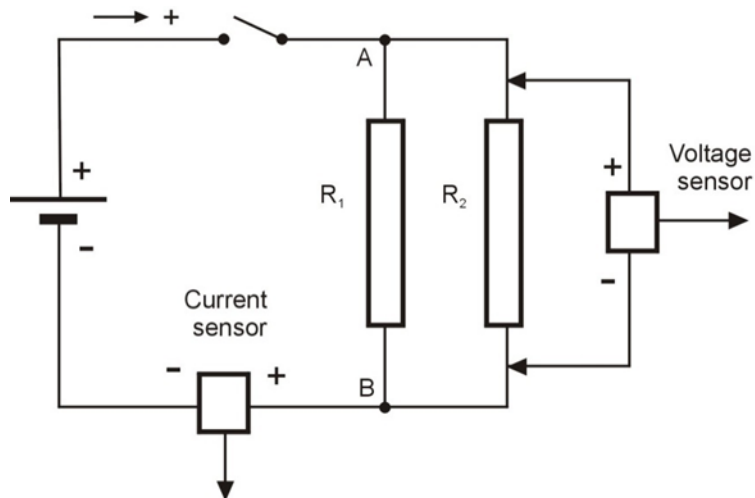


Figure 3

**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. Make sure that only the Voltage and Current sensors are selected.

## Experimental Setup

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

<b>Voltage Sensor (<math>\pm 2.5</math> V)</b>	Voltage (V)
Set As Zero	ON
<b>Current Sensor (<math>\pm 250</math> mA)</b>	Current (mA)
Set As Zero	ON
Rate:	10/sec
Duration:	5 Sec

## Procedure

1. Tap **Meter** () on the lower toolbar.
2. Choose the **Digital** () display option for the Current and Voltage sensors.
3. Tap **Run** () on the main toolbar each time you wish to record a data sample.
4. Turn the switch to the On position, tap **Run** () and record the voltage and current values in your data table.
5. 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).

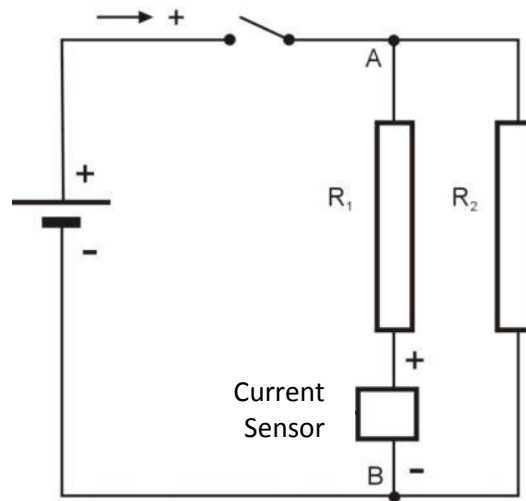


Figure 4

6. Tap **Run** (▶) and record the current value in your data table.
7. Rearrange the circuit to measure the current that flows through resistor  $R_2$ .
8. Tap **Run** (▶) and record the current value in your data table.

**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.**

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 21

# Resistors in Mixed Connection

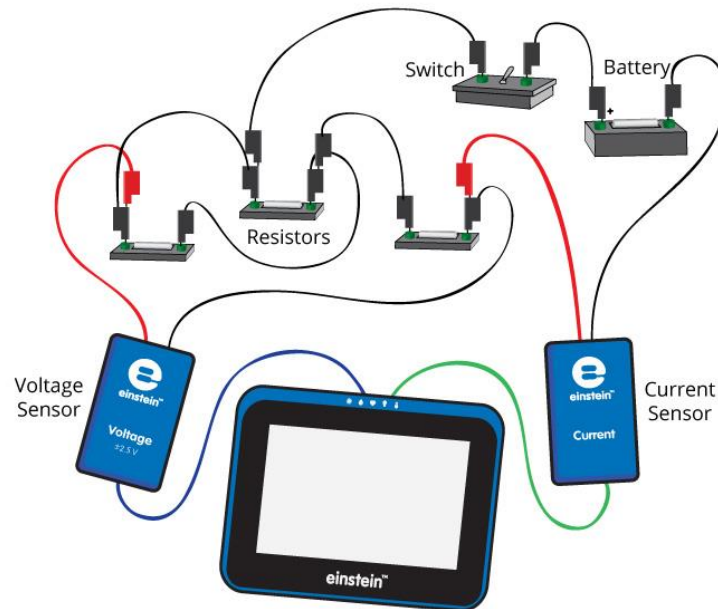


Figure 1



## 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.

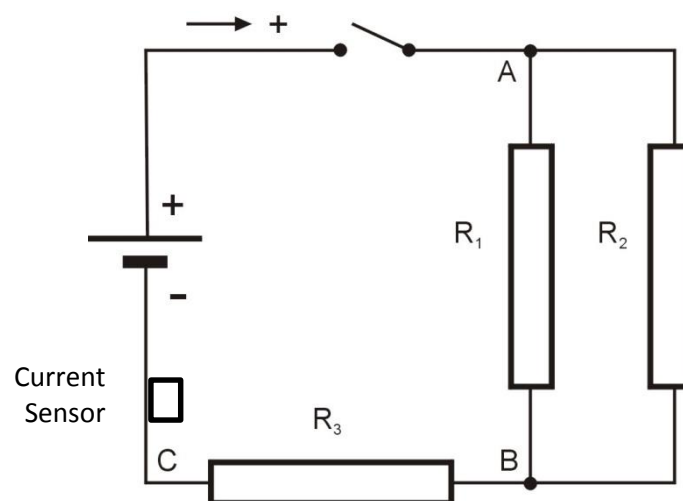


Figure 2

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™Tablet with MiLAB or Android /iOS Tablet with MiLAB and einstein™LabMate
- Voltage sensor ( $\pm 2.5$  V)
- Current sensor ( $\pm 250$  mA)
- Resistor ( $20 \Omega$ )
- Resistor ( $30 \Omega$ )
- Resistor ( $8 \Omega$ )
- Battery (1.5 V) and battery holder
- Connecting wires
- Switch (On/Off)



## Equipment Setup Procedure (Part 1)

1. Launch MiLAB (.
2. Connect the Voltage sensor to one of the ports on the einstein™Tablet+ or einstein™LabMate.
3. Connect the Current sensor to one of the ports on the einstein™Tablet+ or 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) 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. Make sure that only the Voltage sensor and Current sensor are selected.












## Experimental Setup

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

<b>Voltage Sensor (<math>\pm 2.5</math> V)</b>	Voltage (V)
Set As Zero	ON
<b>Current Sensor (<math>\pm 250</math> mA)</b>	Current (mA)
Set As Zero	ON
Rate:	10/sec
Duration:	5 Sec



## Procedure

1. Tap **Meter** () on the lower toolbar.
2. Choose the **Digital** () display option for the Current and Voltage sensors.
3. Tap **Run** () on the main toolbar each time you wish to record a data sample.
4. Turn the switch to the On position, tap **Run** () and record the voltage and current values in your data table.
5. Record the voltage drop across each resistor.
6. Connect the Voltage sensor between points A and B (see Figure 2) and tap **Run** () to record the voltage drop across  $R_1$  and  $R_2$ .
7. Connect the Voltage sensor between points B and C (see Figure 2) and tap **Run** () to record the voltage drop across  $R_3$  in your data table.
8. Rearrange the circuit to measure the current that flows through resistor  $R_1$  (see Figure 2).
9. Tap **Run** () and record the current value in your data table.
10. Rearrange the circuit to measure the current that flows through resistor  $R_2$ .
11. Tap **Run** () and record the current value in your data table.
12. When you have collected all the data you need, tap **Stop** () on the main tool bar.

**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	$V_{AC}(V)$	2	
Voltage drop across $R_1$ and $R_2$	$V_{AB}(V)$	6	
Voltage drop across $R_3$	$V_{BC}(V)$	7	
Current through $R_3$	$I_3(A)$	1	
Current through $R_1$	$I_1(A)$	8	
Current through $R_2$	$I_2(A)$	10	



## Data Analysis

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

- 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 resistors 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 22

# Connections of Batteries

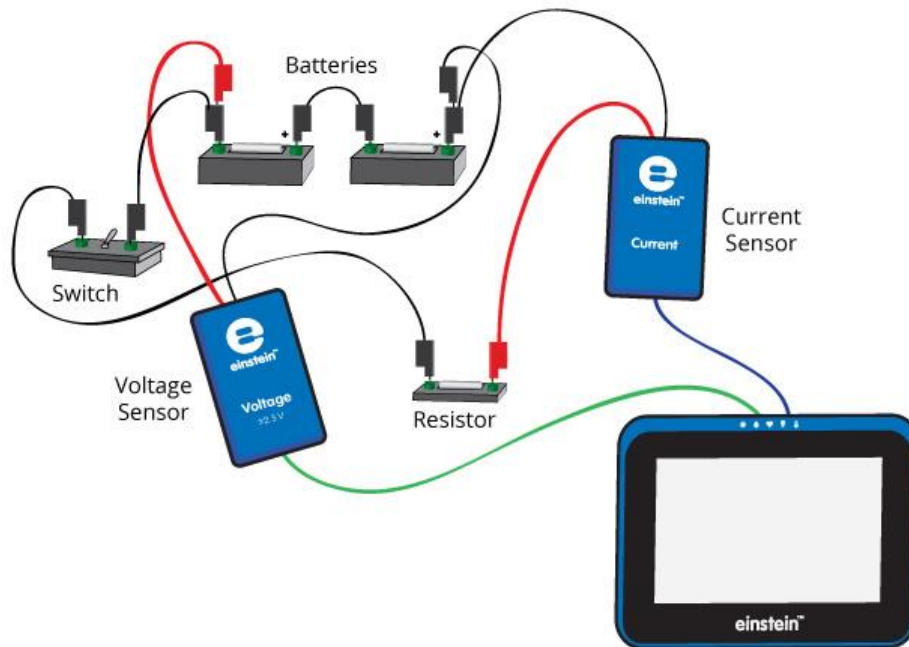


Figure 1



## 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 you will examine these relationships.




## Equipment

- einstein™Tablet+ with MiLAB or Android/iOS Tablet with MiLAB and einstein™LabMate
- Two 1.5 V batteries
- Two 1.5 V battery holders
- Resistor ( $2\ \Omega$ , 5 W)
- Voltage sensor 0 – 5 V
- Current sensor  $\pm 2.5\ \text{A}$
- Connecting wires
- Switch (On/Off)

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## Equipment Setup Procedure

1. Launch MiLAB ()
2. Connect the Voltage sensor to a port on the einstein™Tablet+ or einstein™LabMate.
3. Connect the Current sensor to a port on the einstein™Tablet+ or 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) leads of the sensor and the negative (black) leads.
5. Make sure that only the Voltage and Current sensors are selected.



## Experimental Setup

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

<b>Voltage Sensor (<math>\pm 2.5\ \text{V}</math>)</b>	Voltage (V)
Set As Zero	ON
<b>Current Sensor (<math>\pm 2.5\ \text{A}</math>)</b>	Current (A)
Set As Zero	ON
Rate:	10/sec
Duration:	5 Sec



## Procedure

### Batteries in series:

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

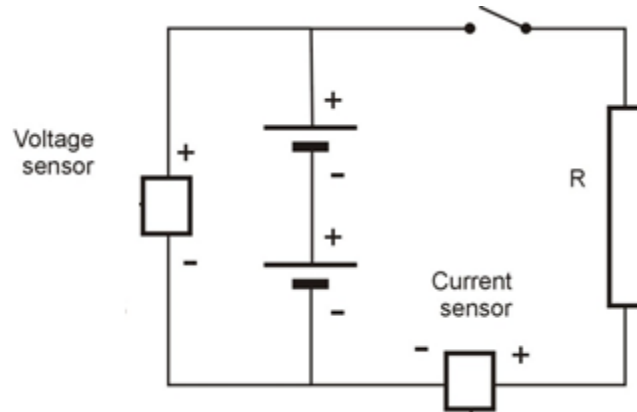







Figure 2

**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. Tap **Meter** (  ) on the lower toolbar.
4. Choose the **Digital** (  ) display option for the Current and Voltage sensors.
5. Tap **Run** (  ) on the main toolbar each time you wish to record a data sample.
6. Tap **Run** (  ) to make the first reading. Record the values in your data table.
7. Turn the switch to the On position, tap **Run** (  ) and record the voltage and current values in your data table.
8. Return the switch to the Off position.

### Batteries in parallel:

1. Rearrange the circuit as shown in Figure 3.

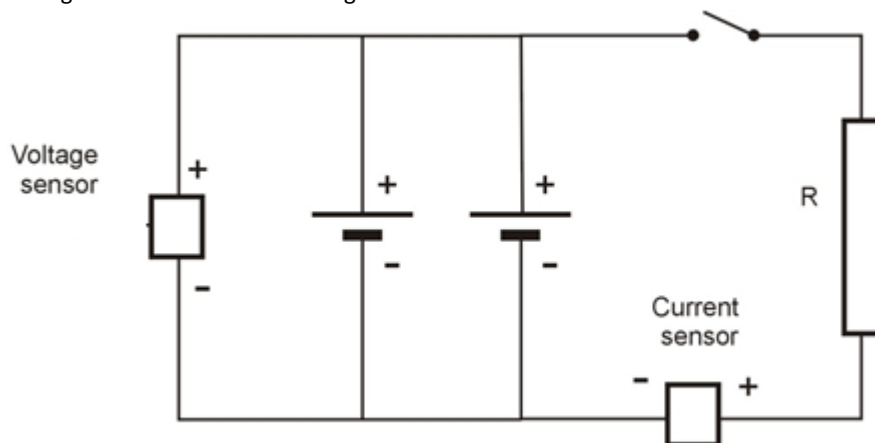




Figure 3

2. Make sure the switch is in the Off position.
3. Tap **Run** () to take the third reading. Record the values in your data table
4. Turn the switch to the On position.
5. Tap **Run** () to take the fourth reading. Record the values in your data table.
6. Return the switch to the Off position.

## 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.**

1. Explain why, when the switch is in the Off position, the voltage readings are actually 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 23

# Charge Measurements in a Parallel Plate Capacitor

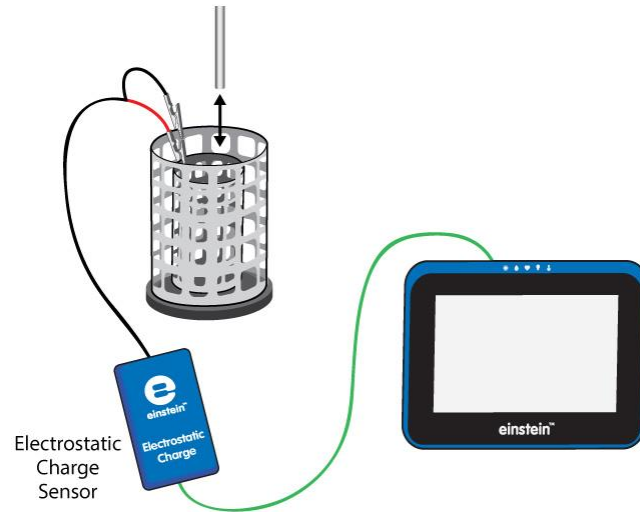


Figure 1



## Introduction

A capacitor is an electric 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 plate 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™Tablet+ with MiLAB or Android/iOS Tablet with MiLAB and einstein™LabMate
- Electrostatic Charge sensor
- Test leads with BNC connector
- Faraday ice pail
- Metal plate with handles (2)
- Right angle clamp (2)
- Stand (2)
- Black banana lead
- Red banana lead
- High voltage power supply
- Charge sampler

### 123

## Equipment Setup Procedure

1. Launch MiLAB .
2. Connect the Electrostatic Charge sensor to one of the ports on the einstein™Tablet+ or einstein™LabMate.
3. Connect the test leads to the Electrostatic Charge sensor.
4. Assemble the equipment as shown in Figures 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.
5. Use the red banana lead to connect one plate to the +3 kV socket in the high voltage power supply (see Figure 2).
6. Use the black banana lead to connect the second plate to the -3 kV socket in the high voltage power supply (see Figure 2).
7. Position the two plates parallel to each other so that the distance between them is 3 cm (see Figure 2).
8. Make sure that only the Electrostatic Charge sensor is selected.

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




## Experimental Setup

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

Electrostatic Charge Sensor	Charge, 25 nC (nC)
Set As Zero	ON
Rate:	10/sec
Duration:	2 Min



## 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. Tap **Run** (  ) on the main toolbar 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).

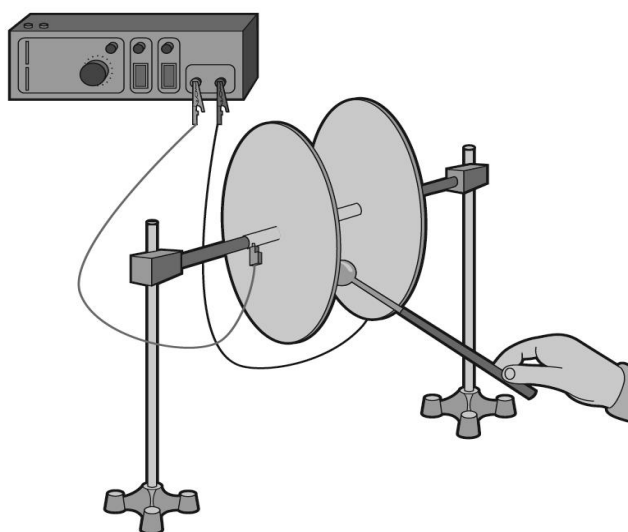


Figure 2

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 4 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		
5		



## Data Analysis

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

1. Compare the charge on the positive plate to the charge on the negative plate.
2. Create a graph relating the charge measured to the 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 plates.



## 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 24

# Charging and Discharging a Capacitor

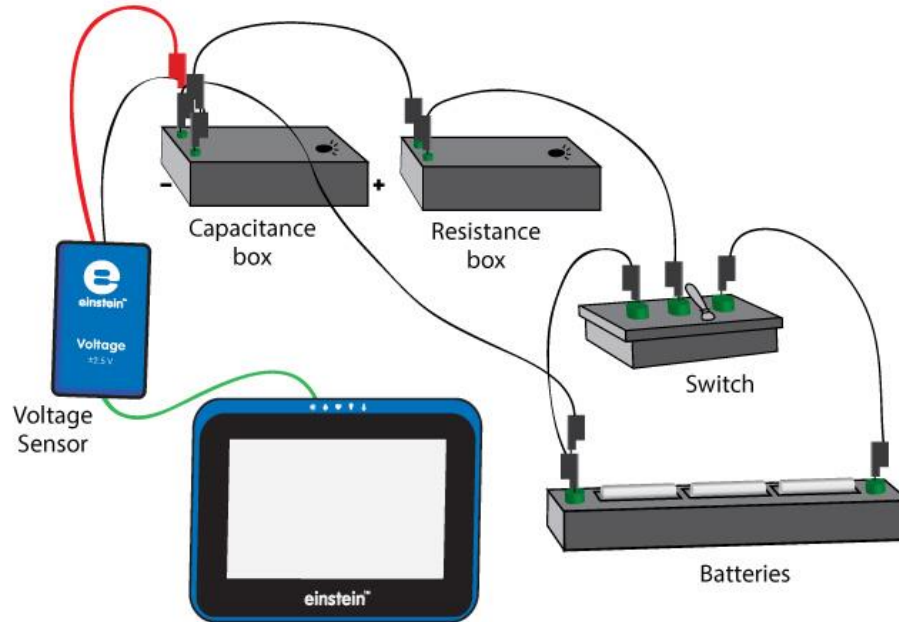


Figure 1



## 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:

$\varepsilon$  = 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™Tablet+ with MiLAB or Android/iOS Tablet with MiLAB and einstein™LabMate
- Voltage sensor
- Box of capacitors
- Box of resistors
- 1.5 V battery with battery holder (3)
- Switch with one pole and two positions (1P2T)

## 123

## Equipment Setup Procedure

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

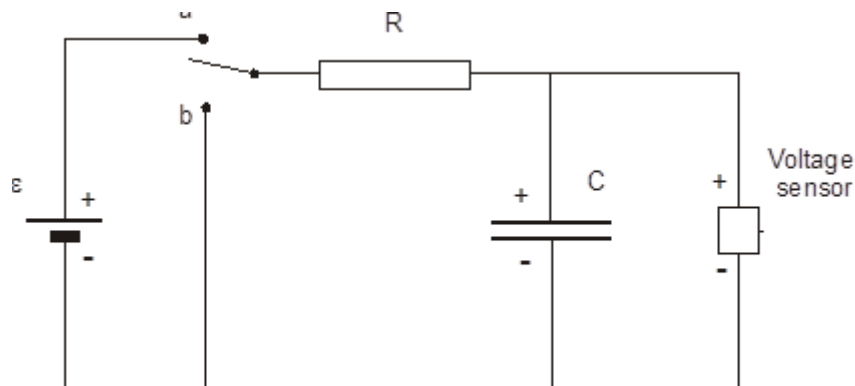


Figure 2

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. Make sure that only the Voltage sensor is selected.




## Experimental Setup

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

Voltage Sensor ( $\pm 25$ V)	Voltage (V)
Set As Zero	ON
Rate:	10/sec
Duration:	2 Min



## 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. Tap **Run** (  ) on the main toolbar to begin recording data. A graph displaying the voltage will automatically appear on the screen.
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.

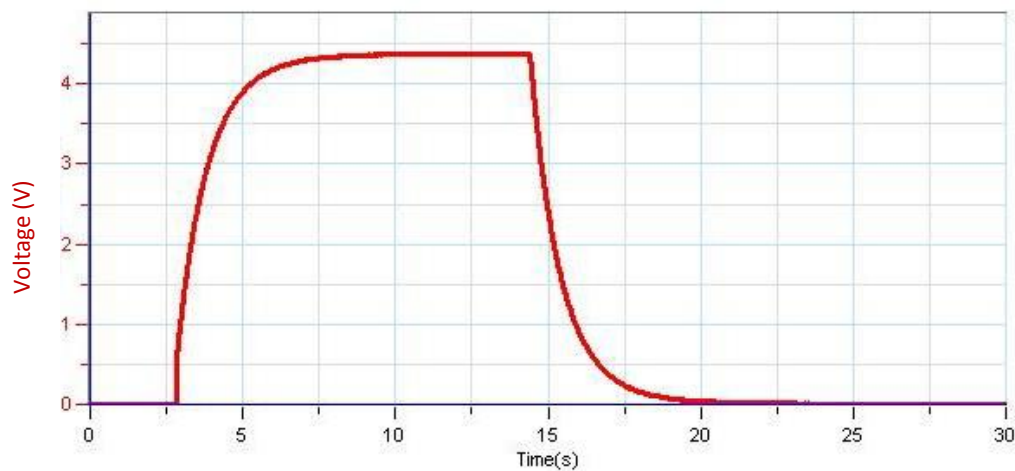


Figure 3

5. Tap **Save** (  ) to save data.



## Data Analysis

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

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

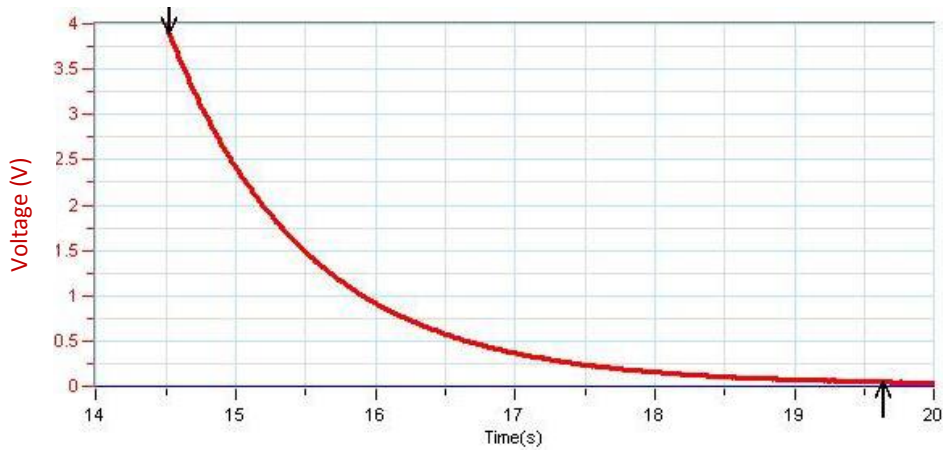


Figure 4

- a. Tap the **Function** button ( $f_x$ ).
  - b. Tap the Setup button ( $\otimes$ ) next to the **Ln** function from the **Mathematical Functions** menu.
  - c. In the **G1** drop down menu select the Voltage data.
  - d. This will give a graph of  $\ln V$  vs. time (Figure 5).
3. Next, fit a line to your processed data:
    - a. Tap the **Function** button ( $f_x$ ).
    - b. Tap the **Linear** function from the **Curve Fit** menu.
    - c. The linear fit equation will be displayed below the x-axis.



Figure 5

- d. 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. Tap the **Function** button ( $f_x$ ).
- ii. Tap the Setup button ( $\otimes$ ) next to the **Derivative** function from the **Mathematical Functions** menu.
- iii. In the **G1** drop down menu select the Voltage data.
- 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. Tap the **Function** button ( $f_x$ ).
  - ii. Tap the Setup button ( $\otimes$ ) next to the **Integral** function from the **Mathematical Functions** menu.
  - iii. In the **G1** drop down menu select the current.

## Chapter 25

# Magnetic Field of a Bar Magnet

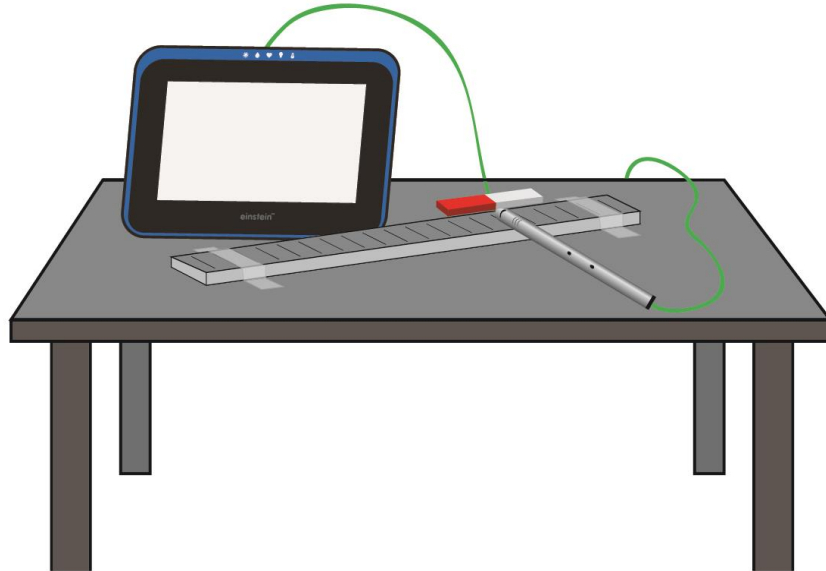


Figure 1



### 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™Tablet+ with MiLAB or Android /iOS Tablet with MiLAB and einstein™LabMate
- Magnetic Field sensor
- Bar magnet
- Ruler (nonmetallic)
- Clear tape

## 123 Equipment Setup Procedure






1. Launch MiLAB (.
2. Connect the Magnetic Field sensor to one of the ports on the einstein™Tablet+ or einstein™LabMate.
3. Set the sensor switch to the low sensitivity range.
4. Tape the ruler to the Tabletop using clear tape.
5. Place the bar magnet parallel to the ruler so that the ruler extends at least 4 cm past the magnet on either side (see Figure 1). This will enable you to map the magnetic field 4 cm distance from the magnet.
6. Use the pull down menu in the Sensor Control Panel to select the Magnetic Field sensor.
7. Make sure that only the Magnetic Field sensor is selected.

## Experimental Setup

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

<b>Magnetic Field Sensor</b>	<b>Magnetic <math>\pm 10</math> mT (mT)</b>
Rate:	50/sec
Duration:	5 Sec

## 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. Tap **Run** () each time you wish to record a data sample and record the value in your notebook.
3. Save your data after each measurement by tapping **Save** () on the main toolbar.
4. Tap **Run** () on the main toolbar 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 tap **Run** () 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 by tapping **Run** () until you have reached a point 4 cm beyond the other end of the bar magnet.



## Data Analysis

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

Consider the data in your notebook and answer the following questions:

1. What was the strongest positive magnetic field around the bar magnet?
2. Where on the bar magnet did you measure the strongest positive magnetic field?
3. What was the strongest negative magnetic field around the bar magnet?
4. Where on the bar magnet did you measure the strongest 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 26

# The Magnetic Field near a Current-Carrying Wire

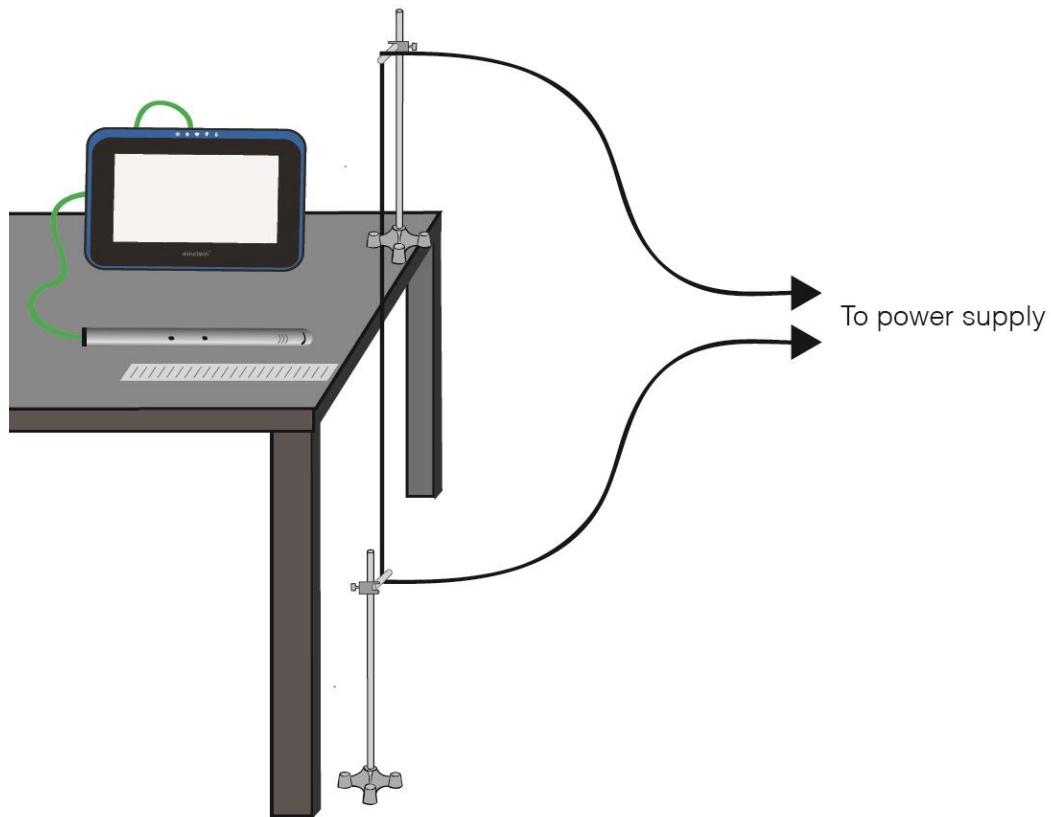


Figure 1



## 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:

$$B = \frac{\mu_0}{2\pi} \cdot \frac{I}{r} \quad (1)$$

Where:

$\mu_0$  = 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™Tablet+ with MiLAB or Android/iOS Tablet with MiLAB and einstein™LabMate
- Magnetic Field sensor
- Long conductive wire (about 2 m long)
- 10A DC power supply
- Stand (2)
- Right angle clamp (2)
- Short plastic rod (2)
- Ruler (nonmetallic)
- Clear tape

123

## Equipment Setup Procedure

1. Launch MiLAB ().
2. Connect the Magnetic Field sensor to one of the ports on the einstein™Tablet+ or 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 beneath 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 Sensor Control Panel to select the Magnetic Field sensor.
5. Make sure that only the Magnetic Field sensor is selected.



## Experimental Setup




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

<b>Magnetic Field Sensor</b>	<b>Magnetic <math>\pm 0.2</math> mT (mT)</b>
Rate:	10/sec
Duration:	5 Sec



## 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. Tap **Meter** ( ) on the lower toolbar. Use the **Digital** ( ) display option.
3. Tap **Run** ( ) on the main toolbar each time you wish to record a data sample.
4. Record the background magnetic field strength at this point by tapping **Run** ( ). Record the value in your data table.
5. Turn on the power supply and adjust it to 10 A.

6. Tap **Run** (  ) to record the magnetic field strength at this point. Record the value in the data table.
7. Now position the edge of the magnetic probe on the 2 cm mark of the ruler, keeping the probe perpendicular to the table edge. Tap **Run** (  ) again and record the value in the data table.
8. Move the sensor along the ruler in 1 cm steps, each time taking a reading by tapping **Run** (  ).

## 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)
5			
4			
3			
2			
1			
5			
6			
7			
8			
9			
10			



## Data Analysis

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

1. Select the data set in the **Archive** (  ) that you want to export.
2. Tap the **Export Data** icon (  ) in the Data Toolbar and export the data as a .csv file.
3. Open the .csv file in a spreadsheet program
4. Fill the data table according to the titles in the column headers. Pay attention to units.
5. Plot a graph of the magnetic field without background (y-axis) vs. the distance from wire (x-axis).
6. Discuss the graph.
7. Plot a graph of the magnetic field without background (y-axis) vs. the reciprocal of the distance from the wire (x-axis).
8. Fit a straight line that passes through the data points. What are the units of the slope?
9. Use the slope of the straight line fit to calculate  $\mu_0$  - (the permeability of free space or magnetic constant). Record the result.
10. 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 27

# The Magnetic Field of the Earth

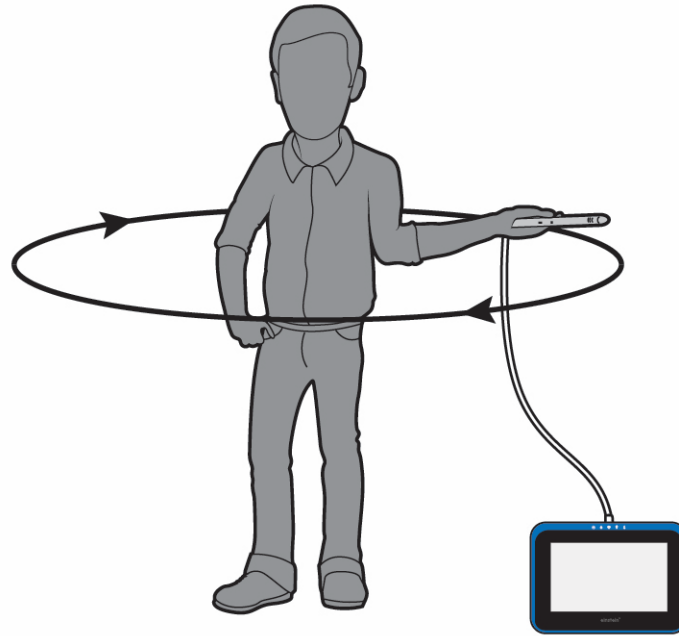


Figure 1



### 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™Tablet+ with MiLAB or Android/iOS Tablet with MiLAB and einstein™LabMate
- Magnetic Field sensor
- Compass
- Protractor
- Plumb (or level)

## 123 Equipment Setup Procedure


1. Launch MiLAB (  ).
2. Connect the Magnetic Field sensor to one of the ports on the einstein™Tablet+ or 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**.

## Experimental Setup

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

Magnetic Field Sensor	Magnetic $\pm 0.2$ mT (mT)
Rate:	10/sec
Duration:	50 Sec

## 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.

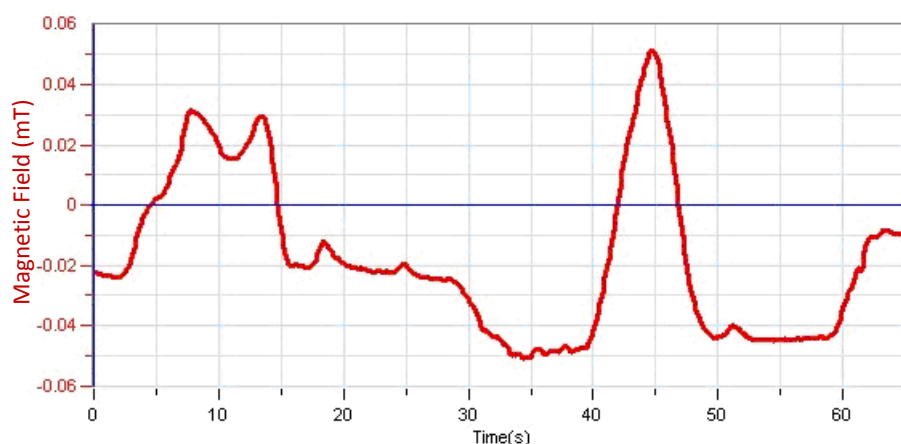


Figure 2



## Data Analysis

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

1. Zoom in on the data acquired during the vertical circling.
2. Use two cursors 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 below 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.
5. Use two cursors 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 below 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 28

# Induction Current and Electromotive Force

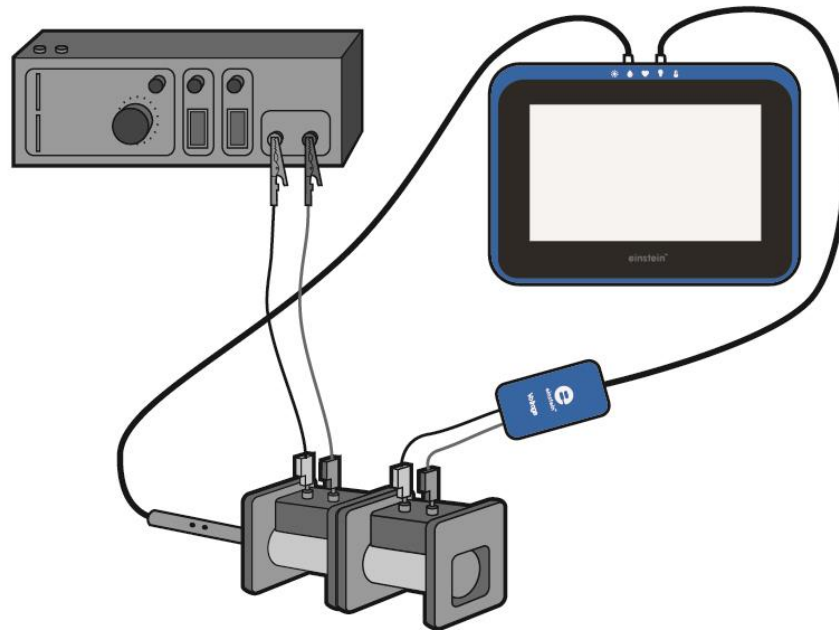


Figure 1



## Introduction

Electromagnetic induction is the production of an electrical potential difference (or 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 is 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:

$\varepsilon$  = The electromotive force (EMF) produced along a closed path

$\Phi$  = The magnetic flux through any surface bounded by that path

In this experiment we will investigate this relationship




## Equipment

- einstein™Tablet+ with MiLAB or Android/iOS Tablet with MiLAB and einstein™LabMate



- Voltage sensor ( $\pm 2.5$  V)
- Magnetic Field sensor
- Two coils with the same physical dimensions. One with about 500 turns (the low turn coil) and the other with about 10,000 turns (the high turn coil)
- Signal generator with power output
- Connecting wires

## 123 Equipment Setup Procedure

1. Launch MiLAB ()
2. Connect the Magnetic Field 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 equipment as shown in Figure 1.
  - a. Place the coils on the table facing each other.
  - 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.
5. Set the sensor switch to the high sensitivity range.
6. Use the pull down menu in the Sensor Control Panel to select the Magnetic Field sensor.
7. Make sure that only the Magnetic Field and Voltage sensors are selected.






## Experimental Setup

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

<b>Magnetic Field Sensor</b>	Magnetic $\pm 0.2$ mT (mT)
<b>Voltage Sensor (<math>\pm 2.5</math> V)</b>	Voltage (V)
Set As Zero	ON
Rate:	100/sec
Duration:	10 Sec






## Procedure

1. Turn on the signal generator.
2. Adjust the signal generator to a frequency of 1 Hz and triangular waveform.
3. Tap **Run** (  ) to begin recording data.
4. Wait for 20 seconds then tap **Stop** (  ).
5. Save your data by tapping **Save** (  ).
6. Change the signal generator's frequency to 2 Hz and repeat steps 3 to 5.
7. Return to a 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**.

1. Select **Archive** (  ) and then select and display the first graph you produced.
2. Discuss the graph in view of Faraday's Induction Law (Equation (1)).
3. Select **Archive** (  ) and then select and display the second graph you produced.
4. Discuss the graph in view of Faraday's Induction Law. What was the effect of doubling the frequency?
5. Select **Archive** (  ) and then select and display the third graph you 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 29

# The Transformer

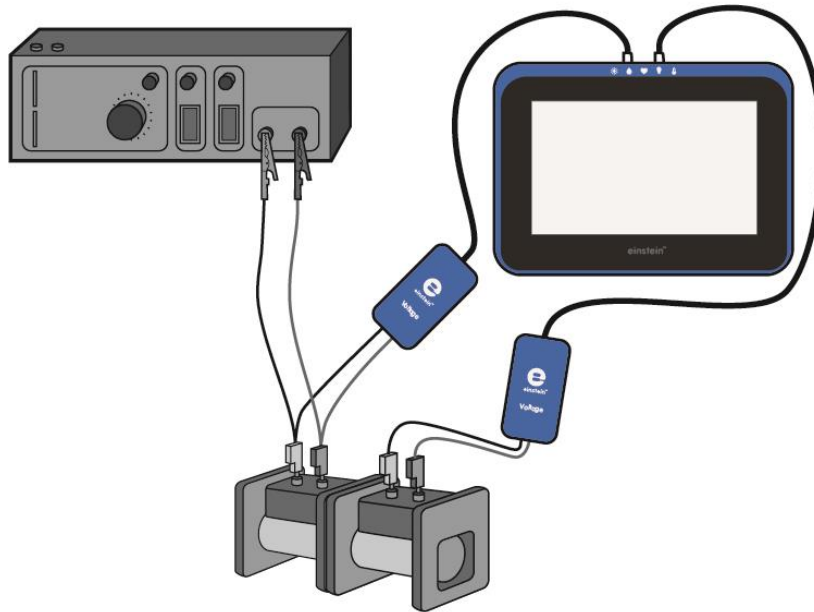


Figure 1



## 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:

$$B = \frac{\mu_o NI}{\ell} \quad (1)$$

Where:

$\mu_o$  = The permeability of free space (the magnetic constant)

$N$  = The number of turns of the wound coil

$I$  = The current through the solenoid

$\ell$  = 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.

$\varepsilon$  = The electromotive force (EMF) induced in the coil.

$\Phi$  = 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  $\varepsilon_1$  and  $N_1$  are the electromotive force and number of turns of the primary coil, through which the current is passed.  $\varepsilon_2$  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™Tablet + with MiLAB or Android/iOS Tablet with MiLAB and einstein™LabMate
- Voltage sensor ( $\pm 25$  V)
- Voltage sensor ( $\pm 2.5$  V)
- Signal generator
- Power supply
- Coil (400 turns)
- Coil (1600 turns)
- Armature
- U core with armature
- Banana cords (2)

## 123

## Equipment Setup Procedure

1. Launch MiLAB ().
2. Connect the  $\pm 2.5$  Voltage sensor to one of the ports on the einstein™Tablet+ or einstein™LabMate then connect the banana plugs to the 400 turns coil (primary coil)..
3. Connect the  $\pm 25$  Voltage sensor to one of the ports on the einstein™Tablet+ or einstein™LabMate then connect the banana plugs 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. Make sure that only the two Voltage sensors are selected.






## Experimental Setup

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

<b>Voltage Sensor (<math>\pm 2.5</math> V)</b>	Voltage (V)
Set As Zero	ON
<b>Voltage Sensor (<math>\pm 25</math> V)</b>	Voltage (V)
Set As Zero	ON
Rate:	100/sec
Duration:	20 Sec



## Procedure

1. Turn on the signal generator and set it to:  
Output voltage:  $\sim 2$  V  
Frequency: 5 Hz  
Waveform: Sinusoidal
2. Tap **Run** (  ) on the main toolbar to begin recording data.
3. After a couple of seconds tap **Stop** (  ).
4. Save your data by tapping **Save** (  ).
5. Use the cursors to measure the voltage drops across the primary and secondary coils. Record the values in your notebook.
6. Insert the armature into both the coils and repeat steps 2 to 5.
7. Mount the coils on the U core and close it with the armature and repeat the experiment..
8. Repeat steps 2 to 5.
9. Set the signal generator's frequency to 50 Hz and increase the data logger's recording rate to 1000 samples per second.
10. Repeat steps 2 to 5.



## Data Analysis

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

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

## Chapter 30

# Capacitor in Alternating Current

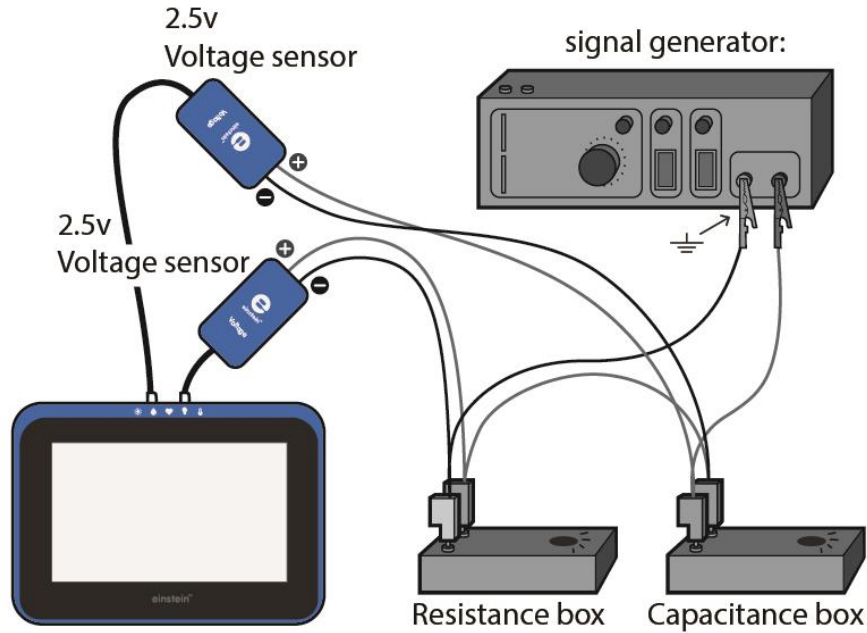


Figure 1



## 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  $\phi$  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 several independent parts. You may perform only some of them.




## Equipment

- einstein™Tablet+ with MiLAB or Android/iOS Tablet with MiLAB and einstein™LabMate
- Voltage sensors  $\pm 2.5$  V (or  $\pm 25$  V) (2)
- Box of capacitors
- Box of resistors
- Signal generator

## 123

## Equipment Setup Procedure

1. Launch MiLAB ()
2. Connect the Voltage sensors to the ports on the einstein™Tablet+ or einstein™LabMate.
3. Assemble the electric circuit as shown by Figures 1 and 2.
4. Make sure that only the two Voltage sensors are selected.

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

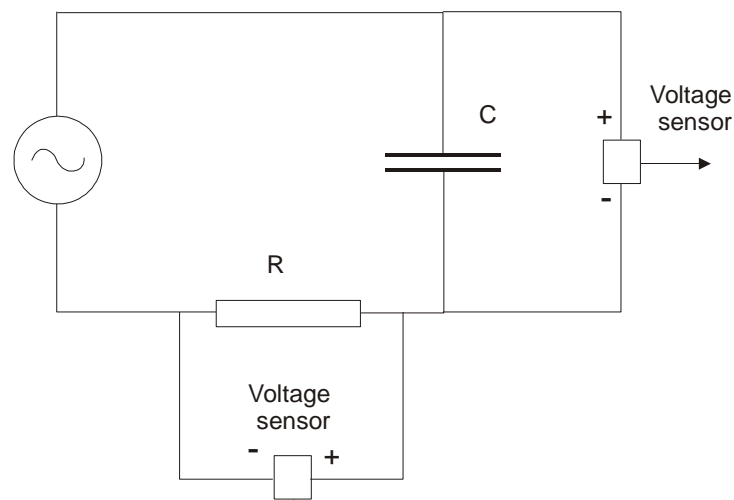


Figure 2



## Experimental Setup

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

Voltage Sensor $\pm 2.5$ V (or $\pm 25$ V)	Voltage (V)
Set As Zero	ON
Voltage Sensor $\pm 2.5$ V (or $\pm 25$ V)	Voltage (V)
Set As Zero	ON
Rate:	1000 samples per second
Duration:	2 Sec



## 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. Tap **Run** ( ) on the main toolbar to begin recording data.
4. Save your data by tapping **Save** ( ) on the main toolbar.

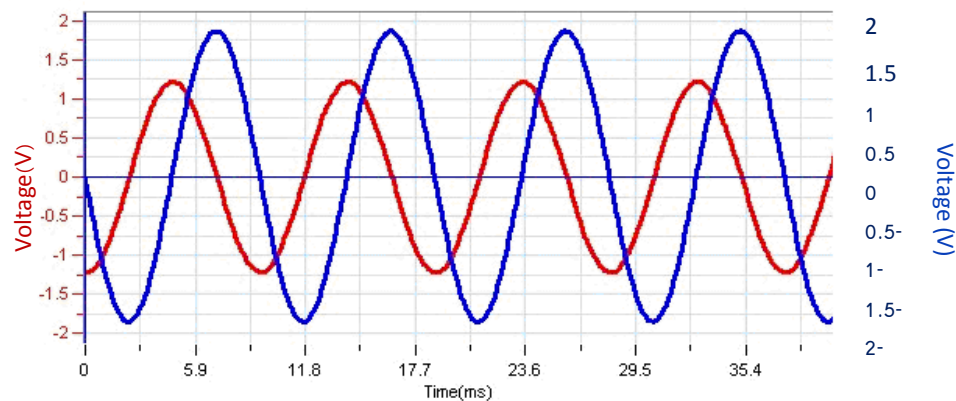


Figure 3



## Data Analysis

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

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

1. Zoom in to display one or two periods of the voltage.
2. Use the cursors to measure the Period  $\tau$  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 dissipated by the capacitor:

- Use the graph of the Voltage vs. Time for the resistor to produce a graph of the Current vs. Time:
  - Tap the **Function** button ( $f_x$ ).
  - Tap the Setup button ( $\otimes$ ) next to the **Linear** function from the **Mathematical 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:
  - Tap the **Function** button ( $f_x$ ).
  - Tap the Setup button ( $\otimes$ ) next to the **Multiply** function from the **Mathematical 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.

## 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:

$$\text{slope} = \frac{1}{2\pi C} \quad (4)$$

## The phase as a function of frequency:

- 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.
- Select **Run** () to begin recording data.
- Save your data by tapping **Save** () on the main toolbar.
- Zoom in to display only one period of the voltage of the resistor.
- Measure the phase difference between the signal generator's voltage and the current (the current is

represented by the voltage of the resistor):

- Use the cursors to measure the period  $\tau$ .
  - Use the cursor to measure  $t_1$ , the time at which one period of the resistor's voltage begins.
  - 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  $\phi$ :

$$\phi = 2\pi \frac{t_1 - t_2}{\tau} \quad (5)$$

- Calculate  $\tan(\phi)$ . Remember that  $\phi$  is given in radians.
- 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.
- 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:

$$\text{slope} = \frac{1}{2\pi RC} \quad (6)$$



## Further Suggestions

- 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  $\pi/2$ .
- You may wish to explore  $X_C$  and  $\phi$  as a function of the capacity: repeat the experiments described above with different values of capacitance.

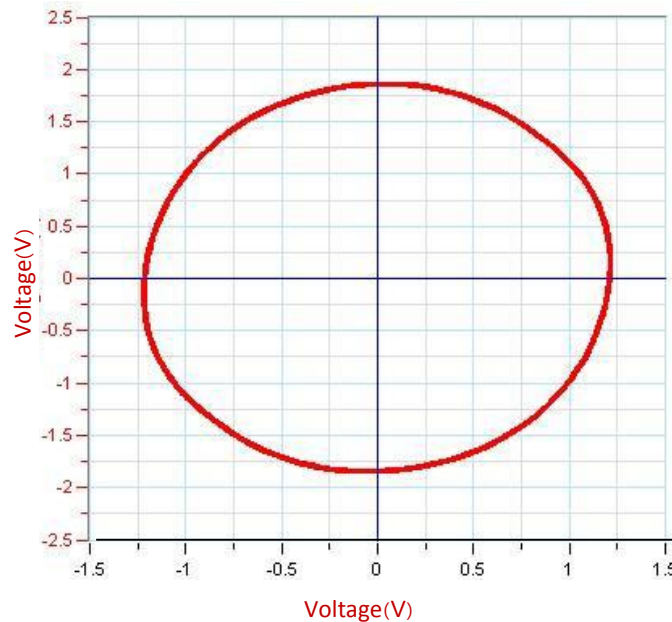


Figure 4

## Chapter 31

# Measuring the Speed of Sound

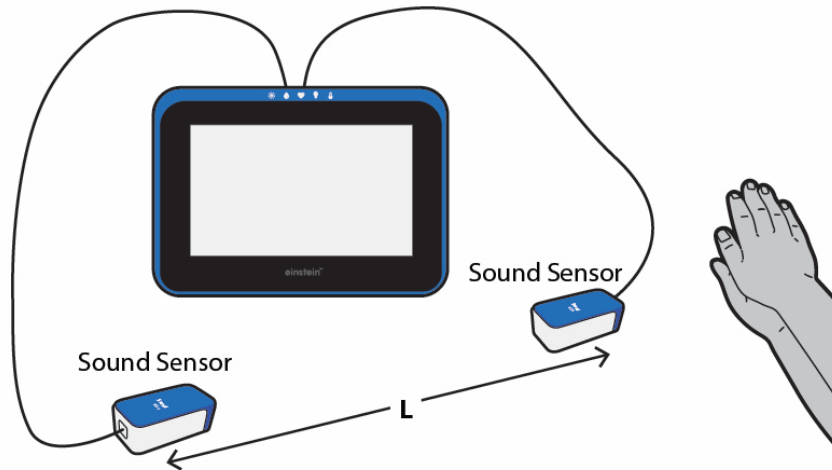


Figure 1



## 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™Tablet+ with MiLAB or Android/iOS Tablet with MiLAB and einstein™LabMate
- 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)



## Equipment Setup Procedure

1. Launch MiLAB (.
2. Connect the Microphone sensors to two of the ports on the einstein™Tablet+ or einstein™LabMate.
3. Place the two microphones at least 2m apart, both facing the sound source (see Figure 1).
4. Make sure that only the Microphone sensors are selected.



## Experimental Setup


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

Microphone Sensor	Microphone
Rate:	1000 samples per second
Duration:	2 Sec





## 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 tapping **Save** (  ).

### 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.**

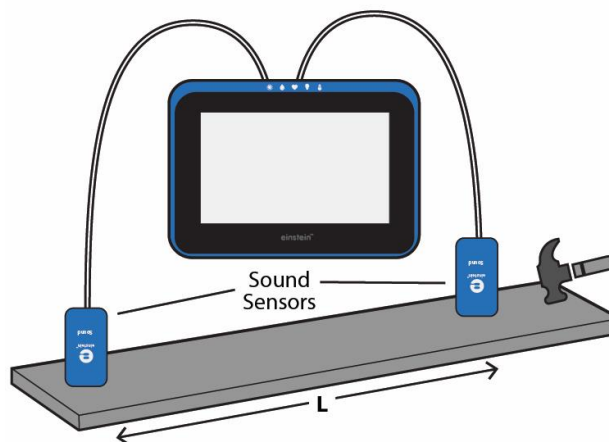


Figure 2

- After setting up the next experiment, repeat steps 21 to 44 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).

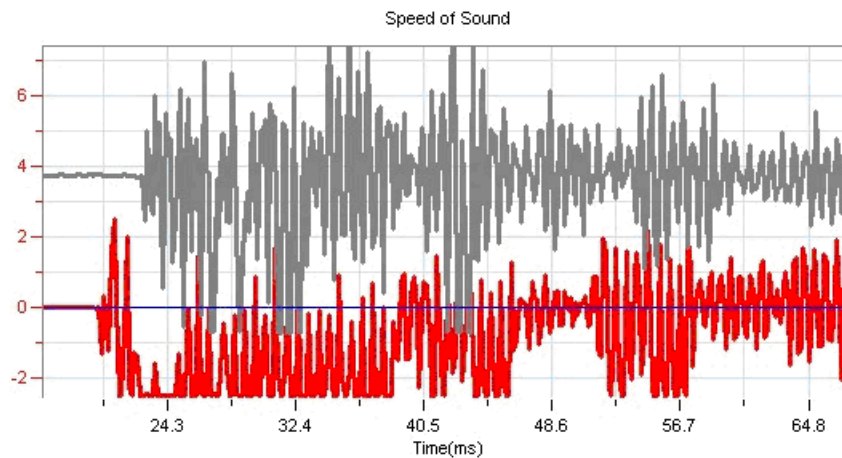


Figure 3



## Data Analysis

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

- Zoom in on the part of the graph when the sound reached the microphones.
- 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.
- Calculate the speed of sound:

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

Where:

- $v$  = The speed of sound
- $\ell$  = The length of the medium
- $t$  = The time

- Repeat the same procedure for each material.
- 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).



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