1A Measurement

Are you able to use scientific tools to make accurate measurements?

In everyday life we use tools to make our work easier. For example, it is difficult to pound a nail in without a hammer, to wrap a gift without tape, or to open clear plastic packages without scissors. In science, it is important to be able to correctly choose and use laboratory equipment to make measurements. During the "Measurement Olympics" you and a partner will practice choosing the correct tool to make measurements accurately. The group with the best averages overall wins the "Measurement Olympics!"

Materials (per group)

- Paper cup
- Pebbles
- Water
- Masking tape
- Graduated Cylinder
- Electronic balance
- Meter Stick
- CPO Timer

1 Stop and Think

a. Are you familiar with the tools necessary to make measurements of length, mass, and volume? Look at the list of materials above and write down a tool used for measuring each property.

Property	Tool Used
Length	
Mass	
Volume	

b. Do you understand what metric units coincide with length, mass, and volume? Discuss this with your partner and write an appropriate unit that corresponds to each property.

Property	Unit Used
Length	
Mass	
Volume	

c. Read about the events listed below in part 2 and predict the outcome of each event for yourself before you actually perform the task.

Event	Prediction
Straw Javelin	
Paper Cup	
Pebble grab	
Side Step	
Hoppity Hop	

2 Doing the Activity

A. Perform the "Olympic" task, collect, and record data.

1. **Straw Javelin:** During this event, you will be throwing a straw as far as you can, like it is a javelin. Your front foot may not cross the start line, and you must throw the straw like a javelin with only one hand. Measure the distance of your throw in meters and centimeters.
2. **Paper Cup Challenge:** How much water can you move from a tank to a beaker in 10 seconds using just one paper cup? Use a graduated cylinder to measure the volume of water you successfully transferred. Be careful so you don't spill any water!
3. **Pebble Grab:** Who can grab the greatest mass of pebbles? Use ONLY ONE HAND to grab as many pebbles as you can out of a container. Transfer them to an **electronic** balance to measure the mass. Be sure the balance is measuring **in the correct units** before you begin!
4. **Side Step:** How far is your leg span? From a starting point step as far as you can to the side. Your partner will measure the length of your step in meters and centimeters.
5. **Hoppity Hop:** Who can hop 10 meters the fastest on one foot? Mark 10 meters on the floor with the masking tape. To use the timer, plug the power cord into an outlet, and then into the side of the electronic timer. Turn the timer on by sliding the small, black button on the side of the timer. To start the clock, push the "A" button; push it again to stop the clock. Push the "reset" button to reset the clock. Time how long it takes your partner to hop 10 meters on one foot!

B. Olympic Results

1. Record your results below. Any result with missing or incorrect units will be automatically disqualified from the Measurement Olympics!
2. After you have recorded your results there will be a class discussion to see who the winners are in each event. Decide within your group who has the best score for each event. Use that score for the class data set. Record the data in the data table your

teacher has drawn on the board. Determine the best overall score for the group winner. Record the individual winner's results for each event in the data table below.

Olympic Event	My Results	Winner's Results
Straw Javelin		
Paper Cup Challenge		
Pebble Grab		
Side Step		
Hoppity Hop		

3 Thinking about what you observed

a. Calculate the difference between the winner's results and your results for each event. (Don't forget units!)

Olympic Event	Difference
Straw Javelin	
Paper Cup Challenge	
Pebble Grab	
Side Step	
Hoppity Hop	

b. In which event were you closest to the winner?

c. In which event were you the farthest away from the winner?

d. How close were you to your predictions?

e. Which measurement were you most familiar with before The Olympics? Why?

f. Which measurement did you find easiest to make during The Olympics? Why was it so easy for you?

g. Which measurement did you find to be the most difficult during the Olympics? Why?

4 Exploring on your own

a. Scientists work hard to be precise in their measurements when experimenting. In real life, most of us are accurate enough, but hardly precise, every time we perform a task that involves a measurement. Do you know the difference? Look it up and draw several examples that represent the difference between accuracy and precision.

b. Create a "quiz" that your classmates could "take" regarding the different tools used in a science lab and their appropriate units. Include an answer key.

c. Find a real science article from a magazine, newspaper, or internet website where scientists are measuring something. Explain in a one-paragraph summary what they are measuring, what tools they are using or could use to make the measurements, and the units associated with the measurements.

1B Conversion Chains

How can you use unit canceling to solve conversion problems?

$$115\ \mathbf{km} \times \frac{1\ \mathbf{mi}}{\mathbf{1.6\ km}} = \mathbf{72\ mi}$$

Suppose you are traveling in Canada or Mexico, and you see a sign that says the next city is 115 km away. How many miles is that? You could use the dimensional analysis process to figure it out. Dimensional Analysis is a method of using conversion factors and unit canceling to solve unit conversion problems. In this activity, you will use conversion chains to start and solve conversions.

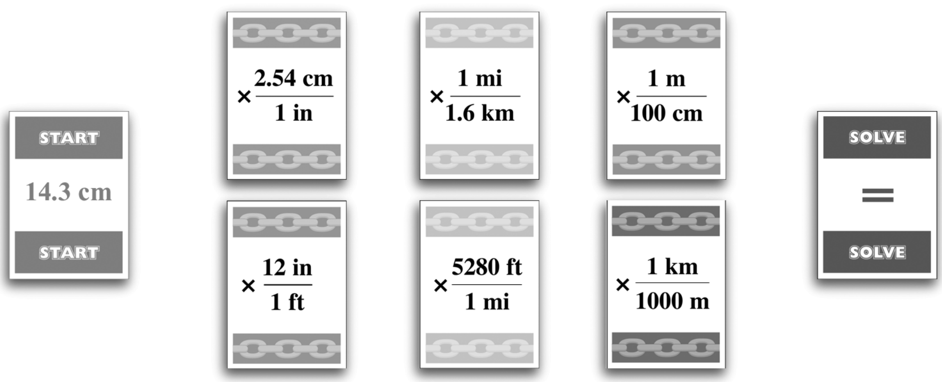
Materials

- Conversion Chain Card deck
- Conversion chain table for recording chains and solutions
- Calculator

1 Conversion Chain Cards

The deck of cards contains:

- 12 START cards, 12 SOLVE cards, 36 conversion factor cards



1. Look at the cards to identify what a START, SOLVE, and conversion factor card looks like.
2. Shuffle the cards thoroughly!

2 Creating conversion chains

The object of the game is to have the most points after solving 6 conversion chains.

1. Deal 4 cards to each player (works best with 3–5 players).
2. Choose a player to go first. This player must play a START card or one card that will correctly continue a conversion chains. That means that the card must have a denominator unit that matches a START card unit, to cancel the starting unit and continue the chain. Anytime a START card is played, the player scores 5 points.
3. If the player has more than one card that could be played on multiple START cards, the player must choose only *one* card to play on each turn.
4. After playing a card, the player *must* draw a card.
5. If the player does not have a suitable card, the player must draw one card from the deck. If the card will play, he can play it. If the card won't play, he must pass his turn.

6. The next player plays a conversion factor card, plays a START card, or draws a card, and play continues.
7. A team can have as many as 3 conversion chains going at once.
8. After a minimum of 3 conversion factor cards have been played on any particular START card, any player is allowed to play a SOLVE card on her turn, and the player ***immediately scores 5 points for each conversion chain card in the chain***.

3 Solving a chain and scoring points

1. Anytime a SOLVE card is played on any conversion chain, all players must record the chain on the answer sheet and calculate the answer with the correct number of significant digits and unit.
2. Players compare answers and determine who has the correct answer. Consult your teacher if there are disagreements.
3. *Any* player with the correct answer, even the one that played the SOLVE card, scores 25 points.
4. Keep playing until your team has created and solved 6 conversion chains.
5. At the end of the game, after 6 conversion chains have been scored, players must subtract 5 points per card for unplayed cards remaining in the hand.
6. Total up points, subtract unused cards, and determine winner.

4 Reminders and Strategy

1. Whenever you play a START card, you score 5 points! If you draw a START card after 6 chains have already been started, you must keep that card in your hand, and it will cost you 5 points in the end.
2. Remember: you always draw a card at the end of *every* turn.
3. When a conversion chain has been solved, place the start, chain, and solve cards to the side in a pile. You might want to look at a solved chain later in the game. Also, this will help your team keep track of how many conversion chains have been solved (the goal is to solve 6).
4. You can play a SOLVE card only after there are at least 3 conversion factor cards in any chain. For beginners, a SOLVE card should be played after 3 chain cards are in a chain. For advanced players, a SOLVE card can be held back and played after the chain is much longer. The SOLVE card player benefits, since she gets 5 points for each chain card in the chain!
5. Record each conversion chain your team creates in Table 1. There are blanks for recording 6 conversion factors per chain. If a chain has less than 6, just leave remaining boxes blank. If you need more than 6, continue on the back of the page.
6. The first row of Table 1 shows an example chain.

Table 1: Conversion Chains

START card							Answer with correct sig figs and unit	Points scored
46.3 m	x $\frac{1\ km}{1000\ km}$	x $\frac{1\ mi}{1.6\ km}$	x $\frac{5280\ ft}{1\ mi}$	× ——	× ——	× ——	153 ft	
	× ——	× ——	× ——	× ——	× ——	× ——		
	× ——	× ——	× ——	× ——	× ——	× ——		
	× ——	× ——	× ——	× ——	× ——	× ——		
	× ——	× ——	× ——	× ——	× ——	× ——		
	× ——	× ——	× ——	× ——	× ——	× ——		
	× ——	× ——	× ——	× ——	× ——	× ——		
							TOTAL	

5 Thinking about the game

a. The conversion chains you create for this game could be quite long, and the actual conversions could be solved with fewer conversion factors. What is the least number of conversion factors you would need to make these conversions, given the cards you have in the deck?

- converting ft to cm
- converting mi to m

b. Because of the limitations of the cards in the deck, to convert from km to cm, you would have to go through English units. What is a much easier way to convert from km to cm? Explain.

c. Explain the math reasoning behind why you are able to “cancel” like units that appear in the numerator and denominator of conversion factors in a conversion chain.

2A Mass, Volume, and Indirect Measurement

How can you find the mass of a single rice grain?

In this investigation you will find the average mass of a single grain of rice. One grain of rice is too small to register a mass value on your electronic scale. There are many situations like this where scientists need to measure something that is too small or too large to measure directly. In these situations, scientists use methods of indirect measurement. To do this, you calculate the measurement you can't make from other measurements that you can make.

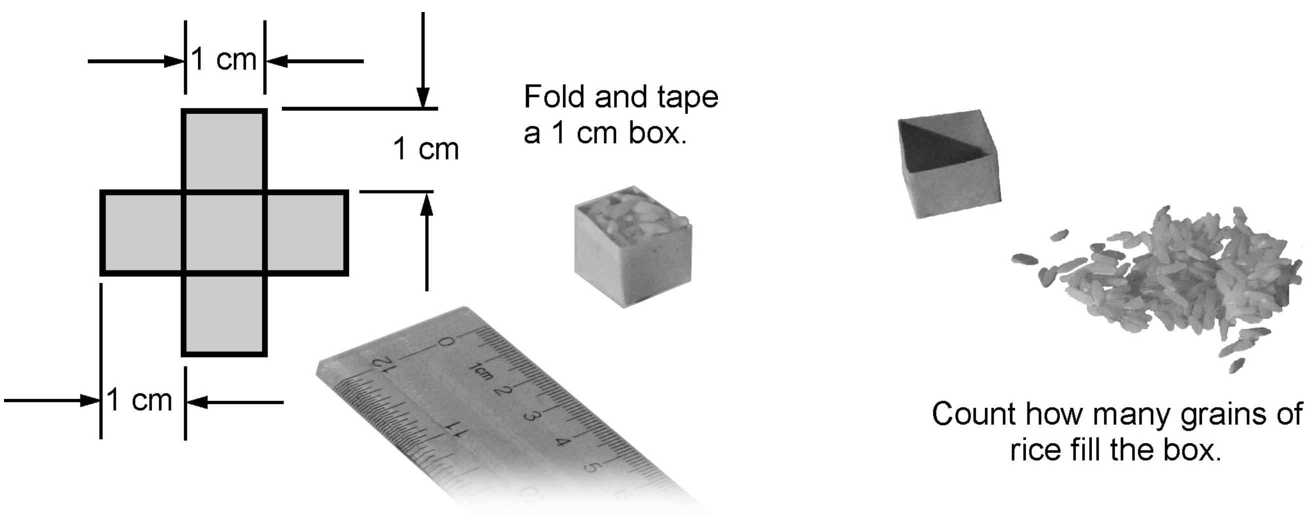
Materials (per group)

- About 1/4 cup of rice
- Cellophane tape
- Electronic scale
- Scissors
- Index card

1 Getting started

To find the average mass of a single grain of rice, you will measure the mass of a 1-cm box filled with rice. You will then estimate how many grains there are in the cube. By dividing the mass of the cube by the number of grains in the cube, you will get a good indirect measurement of the average mass of a single grain of rice.

The first thing we need to do is find out how many grains of rice there are in a cubic centimeter.



1. Cut out and fold up the small cube (made out of an index card) as shown in the diagram. Use tape to hold the cube together. This cube has a volume of 1 cubic centimeter (1 cm^3 or 1 cc).
2. Fill the cube level with rice.
3. Carefully empty the rice in the cube onto the table. Count how many grains fit into the cube and record the value in Table 1.

4. Calculate the number of grains of rice per cubic centimeter and record this value in Table 1. Use this formula: *number of grains / volume of cube = grains per cubic centimeter*

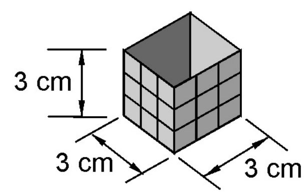
Table 1: Data on number of rice grains per cubic centimeter

Volume of cube (cm^3)	1
Number of grains of rice	
Calculated grains per cubic centimeter	

2 Accuracy, precision, and resolution

No instrument in science makes perfect measurements. A single cubic centimeter of rice is a very small mass and difficult to measure precisely with an ordinary balance. For example, suppose you want a measurement that is precise to one percent. A typical electronic balance has a resolution of 0.1 grams. That means the smallest mass you can measure with this balance is 100 times as large as its resolution. 100×0.1 g = 10 g therefore, 10 grams is the smallest mass you can measure to a precision of one percent. Since the mass of one cubic centimeter of rice is less than 10 grams, we will use a much larger amount of rice.

3 Making a precise measurement



Make and fill a 3 cm box with rice.

1. Cut out and fold up the 3 centimeter cube as shown in the diagram. Use tape to hold the cube together.
2. Calculate the cube's volume and record in Table 2.
3. Place the cube on the balance and reset the balance to zero. The balance display should now read 0.0 grams.
4. Remove the cardboard cube and fill it level with rice. Place the filled cube back on the balance and record the mass.
5. Calculate the number of grains of rice in the cube based on the value of grains per cubic centimeter you calculated in Table 1.
6. Use the mass of rice in the large cube and the calculated number of rice grains to find the average mass of one grain of rice.

Table 2: Data on the mass of a grain of rice

Volume of cube (cm^3)		Number of grains of rice in 3 cm cube	
Mass of rice in cube (g)		Calculated mass of 1 grain of rice (g)	

4 Stop and think

a. Why did the balance show a small negative mass when you removed the empty cardboard cube at the beginning of step 4?

b. Why does this experiment measure the *average* mass instead of the *actual* mass of a grain of rice?

c. Why is the average mass a more useful quantity than the actual mass of any single grain of rice?

d. Compare your average mass of one grain of rice with other groups' results. How do your results compare? Discuss.

2B Density

How is an object's density related to its volume, mass, and tendency to sink or float?

You may be familiar with the trick question "Which is heavier: a pound of feathers or a pound of bricks?" The answer, of course, is that they have the same weight. However, the pound of feathers has a much greater volume because feathers have a much lower density than bricks. The brick material is squeezed together tightly, while the feathers contain a large amount of empty space. In this investigation you will study the relationship between mass, volume, and density. You will also determine how an object's density affects whether it sinks or floats in water.

Materials

- Balance
- Displacement tank
- Disposable cup
- 250-milliliter beaker
- Set of six identical objects
- 100-milliliter graduated cylinder
- Graph paper
- Density cubes
- Metric ruler
- Water
- Paper towels

1 Measuring mass and volume

1. Each lab group has a unique set of six objects. Find the mass and volume of one of your objects. Add a second object and find the total mass and volume of both objects. Then find the total mass and volume of three, four, and five objects. Record your data in Table 1. Note: Although your objects look identical, there may be small differences. Do not obtain your data by multiplying the mass or volume of one object by the number of objects you have. Use the displacement method for measuring density.

Table 1: Mass and volume data

	one object	two objects	three objects	four objects	five objects
mass in grams (g)					
volume in milliliters (mL)					

2. Plot your data on graph paper. Label the x-axis “volume” and the y-axis “mass.” Be sure use the entire space on your graph paper for making your graph.

Title: ______________________________

y label: ______________________________

x label: ______________________________

2 Analyzing your results

a. Is there any pattern to the data points on your graph? For example, the points might form a smooth curve, a straight line, a random scattering, or a cluster in a certain region. Describe any pattern you see.

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b. Line up your ruler along the points on your graph so it is as close as possible to all of the dots. The line may not touch all of the dots, but should have an equal number of dots on each side of it. This line is called the “line of best fit.” Draw the line.

c. Find the slope of the line of best fit. To do this, choose any two points on the line. These will be represented as (X_1, Y_1) and (X_2, Y_2). Use the formula below to calculate the slope of the line:

$$\frac{(Y_2 - Y_1)}{(X_2 - X_1)} = \text{slope}$$

The slope tells how many grams of matter are contained in each milliliter of material. Some substances, like lead, have quite a few grams of matter packed into each milliliter. Other substances, like styrofoam, have less than a single gram of matter packed into each milliliter.

d. Compare your slope with the result obtained by other groups. Are your slopes similar or different?

e. The relationship between a substance's mass and volume is called its density. What is the density of the material you tested?

3 Using your knowledge

a. Your graph shows data for five objects. Use your graph to predict the mass of *six* objects.

b. Next, use the balance to find the total mass of all six objects.

c. How does your value from your graph compare to the mass obtained using the balance?

d. Use the mass that you found in step 3 b. Find that number on the y-axis of your graph. Now find the point on the line with that y-value. What is the x-value of the point?

e. Now, find the volume of six objects experimentally.

f. How does the x-value from the graph compare with the measured volume?

4 Comparing class data

Collect data from each group in the class to fill in Table 2.

Table 2: Class data for density of objects

	Group1	Group 2	Group 3	Group 4	Group 5	Group 6
volume of one object (mL)						
type of material						
density (g/mL)						

Using the data above, answer the following questions:

a. Does density depend on the size of the material? Give evidence to support your answer.

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b. Does density depend on the type of material? Give evidence to support your answer.

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c. Using what you have observed in this lab, do you suppose that density depends on the shape of the material? Why or why not?

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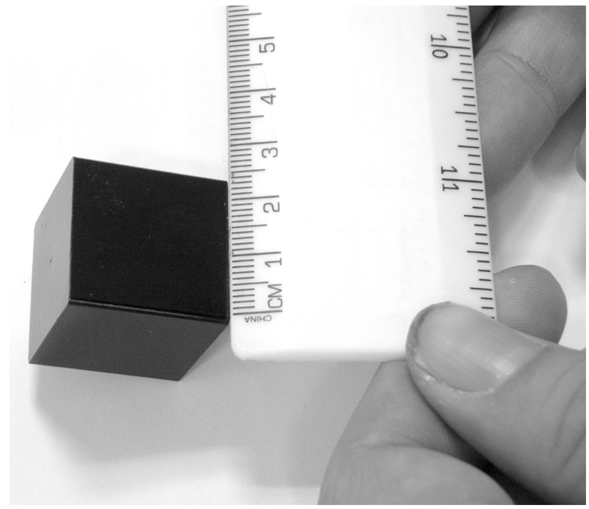
5 Using a different method to find volume

You used the displacement method to find the volume of your objects in the first part of the investigation. The displacement method works because an object's volume is equal to the volume of water it displaces, or pushes aside. This method is useful for objects with complicated shapes.

If an object has a simple shape, such as a cube, its volume can be found by measuring its dimensions. The volume of a cube is found using the formula:

Volume = length × width × height



When length, width, and height are measured in centimeters, volume is in cubic centimeters or cm^3. A 1 cm × 1 cm × 1 cm cube displaces one milliliter of water, so 1 cm^3 = 1 milliliter.

1. Use the method demonstrated in the diagram on the right to measure the length, width, and height of the steel cube in centimeters.
2. Record your measurements in Table 3.
3. Calculate the volume of the steel cube. Record your volume calculations in cubic centimeters in Table 3.
4. Repeat steps 1–5 for the other 4 cubes.

Table 3: Cube volume table

Material of solid cube	Length (cm)	Width (cm)	Height (cm)	Volume from calculation (cm^3)
Steel				
Oak				
Aluminum				
Copper				
PVC				

6 Calculating the density

Each cube's volume is almost exactly the same, but their masses are different because they are all made of different materials. Use Table 4 to calculate the density of each cube.

1. Use a balance to determine the mass of the steel cube, and record it in Table 4.

2. Divide the mass by the volume of the steel cube to calculate its density:
   Density (g/cm^3) = mass (g) / volume (cm^3). Record the density value in Table 4.
3. Repeat steps 1 and 2 and calculate the density of each cube.

Table 4: Cube density data

Material of solid cube	Mass (g)	Volume (cm^3)	Density (g/cm^3)	Prediction (sink or float)	Result (sink or float)
Steel					
Oak					
Aluminum					
Copper					
PVC					

7 Stop and think

a. How do the volumes compare to each other? Why do you think they might be different?

b. Pick up and hold each cube. Predict whether it will sink or float in water. Record your predictions in Table 4. What did you base your predictions on?

c. What is the density of water in g/cm^3?

d. Compare the density of water to the density you calculated for each cube. Take another look at your sink/float predictions. Make any changes you need to based on density.

e. What rule did you use to make your prediction? Write the rule down in one sentence.

8 Testing the hypothesis

Your predictions from part 7d, and the rule from part 7e, represent a hypothesis. Test the hypothesis by dropping each cube in a beaker of water. Record your results in Table 4.

9 Thinking about what you learned

a. Describe two different ways you can find the density of a regularly-shaped object like a cube.

b. Explain why two different objects can have equal volumes but different masses.

c. Which method of prediction was better, testing the weight of the cube in your hand, or comparing the density of the cube to the density of water? Why?

3A Measuring Time

How is time measured accurately?

A measurement is a quantity with a unit that tells what the quantity means. For example, 3 seconds is a measurement of time that includes a quantity (3) and a unit (seconds). This investigation will explore time measurement.

Materials

- Data Collector and 2 photogates.

1 Using the timer as a stopwatch

A stopwatch measures a **time interval**. The Data Collector stopwatch shows time in seconds up to 60 seconds. The display shows **min:sec** for times longer than one minute.

1. Go to the Data Collector's timer function, and select stopwatch mode.
2. Practice starting and stopping the stopwatch.
3. Reset the stopwatch to zero.

2 Observing reaction time

The time it takes a signal from your brain to move a muscle is called **reaction time**.

1. This experiment takes two people. One person (the watcher) watches the stopwatch and the other person (operator) pushes the buttons without looking at the display. The watcher selects a time between 5 and 10 seconds and keeps the time secret.
2. The operator starts (and stops) the stopwatch *without looking at the display*. The watcher looks at the display and says STOP at the secret time. For example, if the secret time is 6 secondsthe watcher should say STOP when the display reaches 6.00 seconds.
3. Repeat the experiment several times, record your results in Table 1, and calculate reaction time by taking and average of the difference in times for all 5 trials.

Table 1: Reaction Time

Trial	Secret time (sec.)	Measured time (sec.)	Difference (sec.)	Avg. Difference Reaction time (sec.)
1				
2				
3				
4				
5				

3 Mixed units for time

In physical science, you are usually going to measure time in seconds. However, time is often given in mixed units, which may include hours, minutes, and seconds. Consider the following three time intervals.

1. 16,000 seconds
2. 250 minutes
3. 4 hours, 23 minutes and 15 seconds (4:23:15)

a. Which one is in mixed units?

b. Can you tell which time is longest or shortest?

c. 1 minute = 60 seconds; how many seconds is 250 minutes?

d. 1 hour = 60 minutes; how many minutes are in 4 hours?

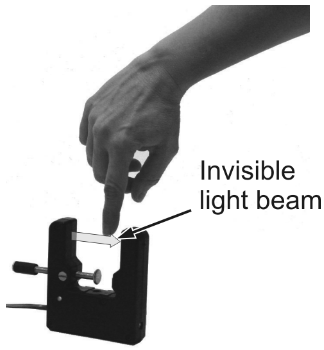
e. Use part (d) to figure out how many seconds are in 4:23:15.

f. Arrange the three measurements from smallest to largest.

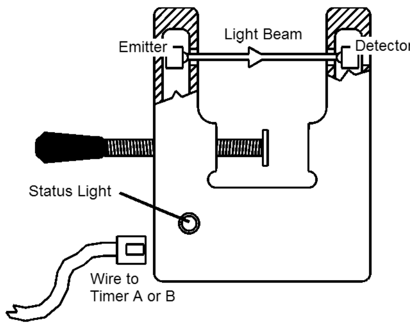
4 Using the photogates

A photogate allows us to use an infrared light beam to start and stop the Data Collector. When the timer function is in interval mode, it uses photogates to control the clock.

1. Connect a single photogate to the "**A**" input with a cord.
2. Select **interval mode** in the timer function of the Data Collector.
3. Try blocking the infrared beam with your finger and observe what happens on the timer display.



Try your own experiments until you can answer the following questions. Be very specific in your answer. Someone who has never used the Data Collector before should be able to read your answer and know what to do with the infrared beam to make the clock start and stop.



a. How do you start the clock?

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b. How do you stop the clock?

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c. What time interval has the clock measured?

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5 Using two photogates

1. Connect a second photogate to the Data Collector.
2. Make sure the light on each photogate is green and press the reset button. Pressing reset clears the clocks and also tells the timer to look at its inputs to see which photogates are connected.
3. Do your own experiments and fill in the rest of Table 2.

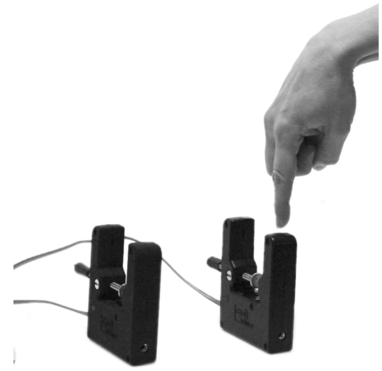


Table 2: Timer and photogate rules

t_A	
How do you start the t_A clock?	
How do you stop the t_A clock?	

t_B	
How do you start the t_B clock?	
How do you stop the t_B clock?	

t_{AB}	
How do you start the t_{AB} clock?	
How do you stop the t_{AB} clock?	

3B Experiments and Variables

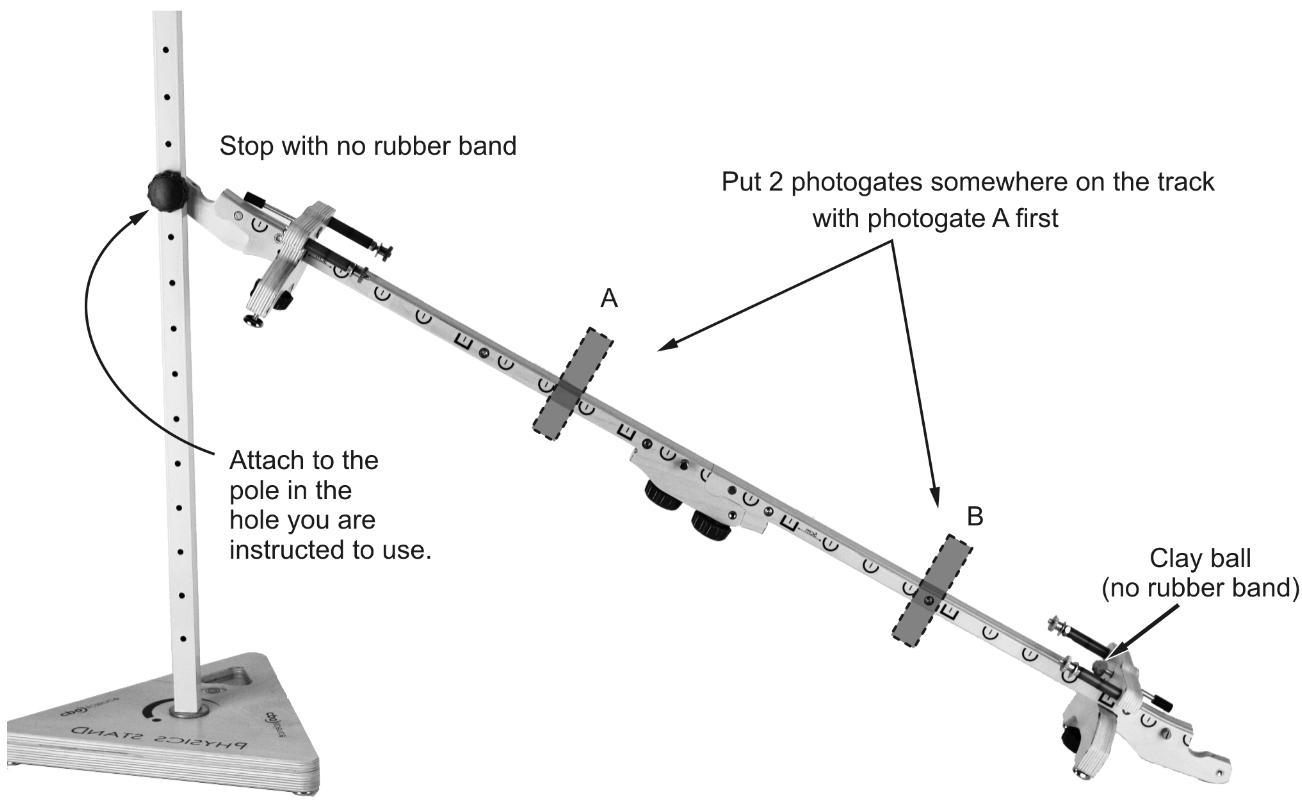
How do you design a valid experiment?

Experiments help us collect evidence so we can unlock nature's puzzles. If an experiment is well-planned, the results can provide an answer to a scientific question like "What would happen if I did this?" If the experiment is not well-planned, you will still get results, but you may not know what they mean. In this investigation, you will experiment with a car on a ramp. Only by paying careful attention to the variables can you make sense of the results.

Materials

- Energy car and track
- Data Collector and photogates

1 Setting up the experiment



1. Set up the track with a long straight section. Your teacher will tell you which hole in the stand to attach the track. Each group will have a different angle.
2. Put a clay ball on the stop at the bottom.
3. Place two photogates on the track with photogate A higher than photogate B.
4. Roll the car down and record the time it takes the car to pass between the photogates (t_{AB}).

2 Stop and think

a. Which track should have the fastest car? Which track should have the shortest time between photogates?

b. Write a one sentence hypothesis that relates the time between photogates to the angle of the track.

c. Use Table 1 to record the results from each group in your class. Record the times in the column labeled “First Trial”. Leave the column labeled “Second Trial” blank. How do the results compare with your hypothesis? Can you give a reason why they did or did not behave as you expected?

Table 1: Photogate times from A to B

	First Trial	Second Trial
Attached at (holes from bottom)	Time from A to B (s)	Time from A to B (s)

3 Variables

a. List at least six variables in your system which affect the time between photogates.

b. Which variable is the experimental variable in your class? How do you know?

c. What should be done with the other variables (other than the experimental variable)? Why should this be done?

d. Name two variables that should not be included in your system. These variables should not have much (or any) influence on the time from photogate A to B.

4 A controlled experiment

1. With your teacher and the rest of your class, decide on how to control the variables other than the experimental variable.
2. Practice rolling the car until you can get three consecutive times within 0.0010 seconds of each other.
3. Repeat the experiment in step one. Record the new data in the column titled "Second Trial."

5 Applying what you have learned

a. Does the second trial of the experiment produce results that agree with your hypothesis?

b. Why does the second trial produce better agreement with your hypothesis than the first trial did?

c. If something does not work, discuss what you should do to try and find the problem. List at least three steps that relate to variables, experiments, and controls.