Andrews University
PHYSICS ENTERPRISES

Constant Velocity 5-Tube Set

Experiment Guide

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Designed by

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PHYSICS ENTERPRISES

Introduction

Description

The Constant Velocity 5-Tube Set consists of five transparent plastic tubes filled with liquid. These are simple devices that students can use to generate position vs. time data to explore constant motion and improve their graphing skills. Four of the tubes contain colored oils of three different viscosities. A bubble of air in each tube rises at a constant velocity that is determined by the viscosity of the liquid, the angle at which the tube is inclined, and the temperature. The fifth tube contains a colorless oil and two balls — one plastic and one steel. A magnet is also included to hold and release the balls.

Purpose

The Constant Velocity 5-Tube Set provides students with practice setting up experiments and graphing data. Students discover that the slope of a position vs. time graph is the speed of the moving object, and verify graphically that the bubbles and balls travel at constant speeds.

This manual contains a prelab exercise followed by 3 experiments. These are NOT independent experiments, but rather variations with increasing levels of complexity. Choose the experiment that is most appropriate for your students.

- Experiment 1 is the simplest of the three and focuses on identifying and interpreting the slope of the graph. This experiment may be performed without the prelab exercise.

- Experiment 2 identifies and interprets both the slope and y-intercept for a variety of speeds, directions, and initial positions. This experiment should be performed after the prelab exercise.

- Experiment 3 is an advanced version of experiment 2, with an additional prediction phase, followed by data collection to test the predictions. This experiment should be performed after the prelab exercise.

Other Experiments

- Students may be challenged to predict and test the effect of angle on the velocity of the bubble/ball. The results may be somewhat surprising.

- Students may test the effect of temperature on the velocity of the bubble/ball. Different speeds can be safely determined between the temperatures of 10°C and 40°C using an ice bath and hot tap water. Do NOT use heating/cooling methods that exceed this temperature range.

Demonstrations

- Bernoulli's principle can be visualized by watching the movement of tiny bubbles in the transparent tube. Use the magnet and steel ball to break up the large bubble into tiny bubbles. Hold the tube at an angle and watch the bubbles as the ball moves by. You should see the bubbles speed up due to the reduced area around the ball.

- Centrifugal force can be demonstrated by observing the location of the bubble when the tube is spun. Hold a colored tube horizontally in the middle and gently rotate your wrist back and forth. The oil moves to the ends of the tube, displacing the bubble and causing it to move to the middle.

Care and Use

Although plastic, the tubes may crack or break as a result of rough treatment. Some simple precautions will help ensure the tubes provide years of use:

- Caution students not to place tubes where they may fall, such as by rolling off a table.

- Do NOT expose the tubes to heat, chemicals, or other extreme conditions.

- Store the tubes out of direct sunlight.

- Do NOT store the tubes in a chemical storeroom.

- Clean the tubes, if necessary, with mild, nonabrasive dish soap.

- The tubes contain hydraulic oils with small amounts of additives. If a tube should crack or break, absorb the spilled fluid with rags, and clean up with soapy water.

- The fluids might stain some materials. Stains may often be removed by ordinary procedures such as laundry stain removers.

Safety

Please teach and expect safe behavior in your classroom and lab. Safety considerations call for supervision of students at all times: safety eyewear, no horseplay, immediate reporting to the instructor of accidents or breakage, among others.

This product is intended for use by students age 13 years and older, under competent adult supervision.

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Prelab

Graphing in the Lab

Purpose

The purpose of this activity is to help students develop graphing skills that will be needed to complete the activities with the Constant Velocity Tubes.

Background

Graphs are an effective way of presenting numerical data in a laboratory report, but that is not their only use. Graphs can also be used to determine the mathematical relationship between two variables. In the following graphing exercise, you will work with two types of variables: an independent variable and a dependent variable. An independent variable is the part of the experiment that you change in a measured, controlled way. The dependent variable is the part of the experiment that changes as a result of the changes in the independent variable.

In a previously conducted experiment, a measured volume of liquid mercury (independent variable) was added to a glass beaker, and the mass of the beaker and mercury (dependent variable) was measured with a platform balance.

Procedure

1. In an experiment, there are generally several variables that might affect the dependent variable. If we allow only one of these to vary and hold the others constant, it is far easier to interpret the results. In this experiment, the volume of mercury is allowed to vary, but everything else stays constant. For example, the type of liquid might affect the mass, so we must use the same liquid throughout the experiment. Can you think of any other variables that should be held constant?

   ____

   ____

   ____

2. The experiment began by filling a beaker with 250 mL of liquid mercury. The mass of the beaker and mercury was then measured to be 3600 g. Next, the beaker was emptied and filled again with a volume of 50 mL, resulting in a mass of 1000 g. Notice that these first two sets of data represent extreme possibilities. Why do you suppose such values were chosen?

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3. It is useful to sketch a graph of the data as it is collected and examine the pattern that forms. This can help you decide what to do next. You will begin by plotting the first 2 data points. The pattern will become clearer as you obtain and plot additional points.

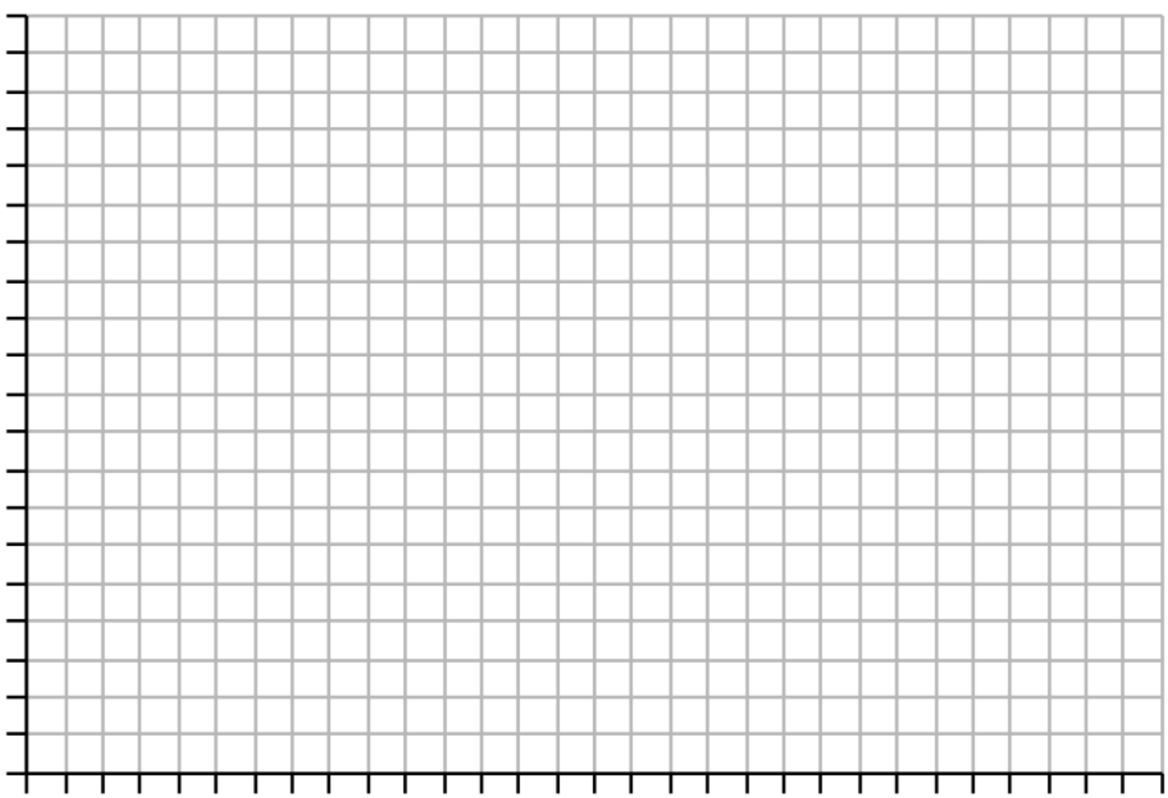
    a. Label the horizontal axis with the name of the independent variable (sometimes called the “control” variable). Follow the name with the measurement units enclosed in parentheses ( ). In a similar manner, label the vertical axis, with the dependent variable.

    b. Number the axes. Start numbering with zero at the origin (lower left corner).

    When numbering the axes, number the lines, not the spaces. Choose a regular numbering system (e.g. by fives, tens, fifties, etc). Adopt a spacing system that numbers every second, every fifth, or possibly every tenth line. These choices make it easier to locate and plot data from metric system measurements, as compared to numbering every third or fourth line. The numbering chosen will depend on the largest numbers that need to be plotted.

    c. Plot the two data points. Make small, precise points. Then, because small points are hard to find, make them more obvious by surrounding each point with a small circle, triangle, or similar shape. These are called point protectors.

    If you feel uncertain about your work thus far, seek help before proceeding.



4. On the same graph, plot this additional data:
   Volume = 100 mL, Mass = 1600 g
   Volume = 150 mL, Mass = 2500 g

5. Looking at your graph, what volume would you suggest next? ______________________________

6. Now plot this data pair: Volume = 200 mL, Mass = 1300 g

   Plotting data on a graph helps reveal mistakes. If the graph is made as the experiment is being done, the mistake can be corrected. Later, it may be difficult or impossible to reconstruct the experiment and correct the error.

7. Which of the data points on your graph represents a mistake? _______________________________

   It is not wise to immediately discard data that “looks wrong”. Many important new discoveries in science “looked wrong” at first. In this case, however, a simple mistake was made: the “1” and the “3” in the last mass reading were switched. The data pair should have been: V = 200 mL, m = 3100 g.

8. Correct the mistake noted.

9. By now a pattern should be clear. To make the pattern more visible, draw a best-fit line (the line that most closely follows the pattern revealed by the data points). Since the pattern seems to be straight, it is appropriate to use a straight edge to draw the line. (A transparent plastic straight edge is particularly useful for this purpose.) Extend the line all the way to the vertical axis.

   You may find that the points don’t fit perfectly on the line. This is because all measurements include uncertainty. This can be caused by imperfections in the measuring tools, our inability to read these tools perfectly, and that other variables have varied, despite our attempts to keep them constant. The odds are that some points are too high, and some are too low. Even though the individual points are not exactly where they should be, we can discover the true relationship between mass and volume by examining the pattern they form. In this experiment, we make the reasonable assumption that the data should follow a straight line, and that the points miss the line due to errors.

   Computer programs, such as spreadsheets and built-in programs on some calculators, can also draw a best-fit line. The process is called *curve-fitting*. If we decide in advance that a straight line is the appropriate pattern, the process is called *linear regression*.

   In algebra, the type of graph seen in this experiment is described by the equation: $y = \mathrm{m}x + \mathrm{b}$

   where: y is the quantity on the vertical axis,
   x is the quantity on the horizontal axis,
   m is the slope, and
   b is the y-intercept (also called the vertical intercept)

   By replacing these abstract symbols with the physical quantities from the experiment, the mathematical equation can be transformed into a physics equation.

10. In the space below, write the equation that results when you replace the symbols *y* and *x* in the equation for a straight line, $y = mx + b$, with the physical quantities, *mass* and *volume*:

____

11. In the space below, substitute a y-intercept value of 350 g for b in the equation (notice that the dimensional units, grams, are part of the value).

____

12. It is unlikely that your line shows a y-intercept of exactly 350 g. What is the y-intercept on your graph?

____

13. Calculate the slope, m, as follows:

The slope, m, is found from the formula, slope = rise / run. The first step in finding slope is to mark two points directly on your best-fit line. Label these points so they won't be confused with data points. The farther apart you place them, the more accurate your result will be. Choosing points that are on one of the grid lines will also improve your accuracy.

a. Select two points on the best-fit line, and read their coordinates from your graph:
First Point (x_1, y_1): x_1 = ____________ y_1 = ____________
Second Point (x_2, y_2): x_2 = ____________ y_2 = ____________
Remember to include the measurement units after the number.

b. Calculate the rise and run from these coordinates: (remember to include measurement units)
Rise (y_2 - y_1) = ____________
Run (x_2 - x_1) = ____________

c. Calculate the slope: (remember to include measurement units)
Slope = Rise/Run = ____________
Your answer should be approximately 13.4 g/mL. You should not expect to get exactly this answer.

14. Substitute this value for the slope, m, in the formula:

____

15. The equation above allows us to calculate the mass that would result if some other volume of mercury were used. Using algebra to solve for volume, we can obtain an equation that tells us what volume of mercury is needed to yield a desired mass.

Solve the equation for volume. Ask for help if you need it.

The original equation would be much more useful if it applied to other substances besides mercury and to other containers besides the beaker used in this experiment. By reasoning through the equation and the experimental procedure, we can often adapt our equation to fit the general case.

16. Look at your graph and see if you can express in words the meaning of the y-intercept. (Not the mathematical meaning, but rather some aspect of the experiment that this value represents.)
    Hint: What is the volume, at the y-intercept?

    ____

17. Does the value of the slope remind you of anything? How about the units? Keep in mind that the numerical value we obtained by experiment will not be exact. Hint: use a reference to look up the physical properties of mercury. The following unit conversion may be useful (1 mL = 1 cm^3).

    ____

Finally, the mass reading from the balance might be better called *gross mass*, which is the mass of both the container and its contents. The preceding ideas can be used to rewrite the equation into a more generally useful form:

Gross Mass = Density of Contents * Volume of Contents + Mass of Container

Experiment 1

Speed of the Bubble

Purpose

The purpose of this experiment is to study the motion of a bubble rising in a tube of oil and show how graphs connect ideas from math and science.

Safety

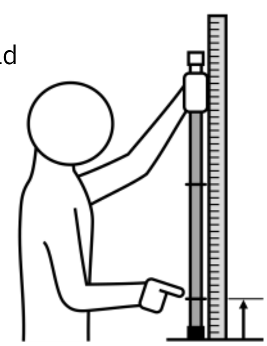
Follow proper lab behavior rules, such as wearing safety glasses. Ask your teacher if you do not know these rules, or do not understand them.

These tubes are breakable. Treat them with care. Tell your teacher immediately if a tube cracks, breaks, or leaks. Then take the proper clean-up steps.

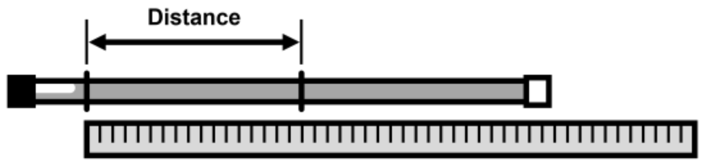
Equipment

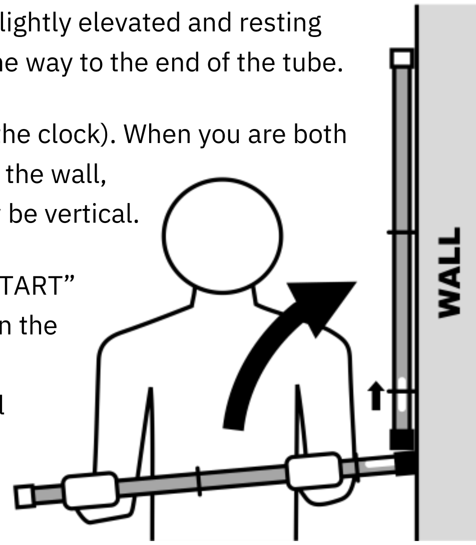
- 3 tubes filled with colored oils (red, green, blue)
- Meter stick (preferred) or metric measuring tape
- Stopwatch (preferred) or clock

Procedure



1. Obtain one of the 3 colored tubes. Each tube should have 2 rubber rings on it.
2. Hold the tube vertically on a table with the white cap up. Position the bottom ring 6 cm above the bottom of the tube as shown. This will be the starting position of the bubble. Do NOT move this ring again for the rest of the experiment.
3. Work with a partner to record the motion of the bubble as follows:
    a. Move the top ring to a stop position of your choosing. For the first measurement, place it about 8-10 cm above the bottom ring.
    b. Measure the distance between the two rings and record this value in the appropriate table on page 11.



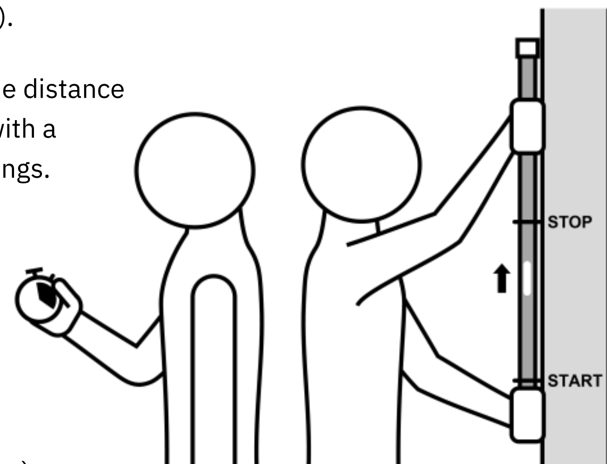


c. Hold the tube nearly horizontal with the black-capped end slightly elevated and resting against the wall as shown. Wait for the bubble to travel all the way to the end of the tube.

d. Your partner should be operating a stopwatch (or watching the clock). When you are both ready, quickly rotate the tube into a vertical position against the wall, pivoting around the black-capped end. The tube should now be vertical.

e. When the <u>bottom of the bubble</u> reaches the first ring, say “START” and your partner will start the stopwatch (or note the time on the clock). Your partner should <u>NOT</u> be watching the bubble but rather listening for you to say “START” and “STOP”. This will minimize error from user delay.

f. Watch the bubble rise, and as soon as the <u>bottom of the bubble</u> reaches the second ring, say “STOP”. Your partner will stop the stopwatch (or note the time on the clock).



g. Record the time in the table on page 11 next to the distance you already recorded. If you measured the time with a clock, record the difference of the two clock readings.

h. Carefully plot the data point (time and distance) on the graph on page 11. Identify the point by drawing a small circle, square, or triangle around it. For consistency, use a circle for the red tube, a square for green, and a triangle for blue.

4. Repeat the previous steps with a stop position (top ring) such that the bubble has almost reached the top of the tube. (Do <u>NOT</u> move the bottom ring.)

5. Choose 3-5 additional stop positions spaced evenly between the first two positions. Record the time and distance data in the table, and plot the points as you go.

6. Use a straightedge to draw a “best-fit line” through the points to represent the pattern of your data. Extend the line to meet the vertical axis. Label the line “red tube”, “green tube”, or “blue tube”. Ideally, the points should fall exactly on the line, however, in practice, this rarely happens. All measurements contain uncertainty which prevent them from perfectly matching predictions.

   For this experiment, we also expect the line to pass through the origin (0,0). Can you explain why?

   ____

   ____

   ____

7. Repeat the previous steps with each of the remaining tubes and plot the data on the same graph.

Experiment Data

Table 1 - Red Tube

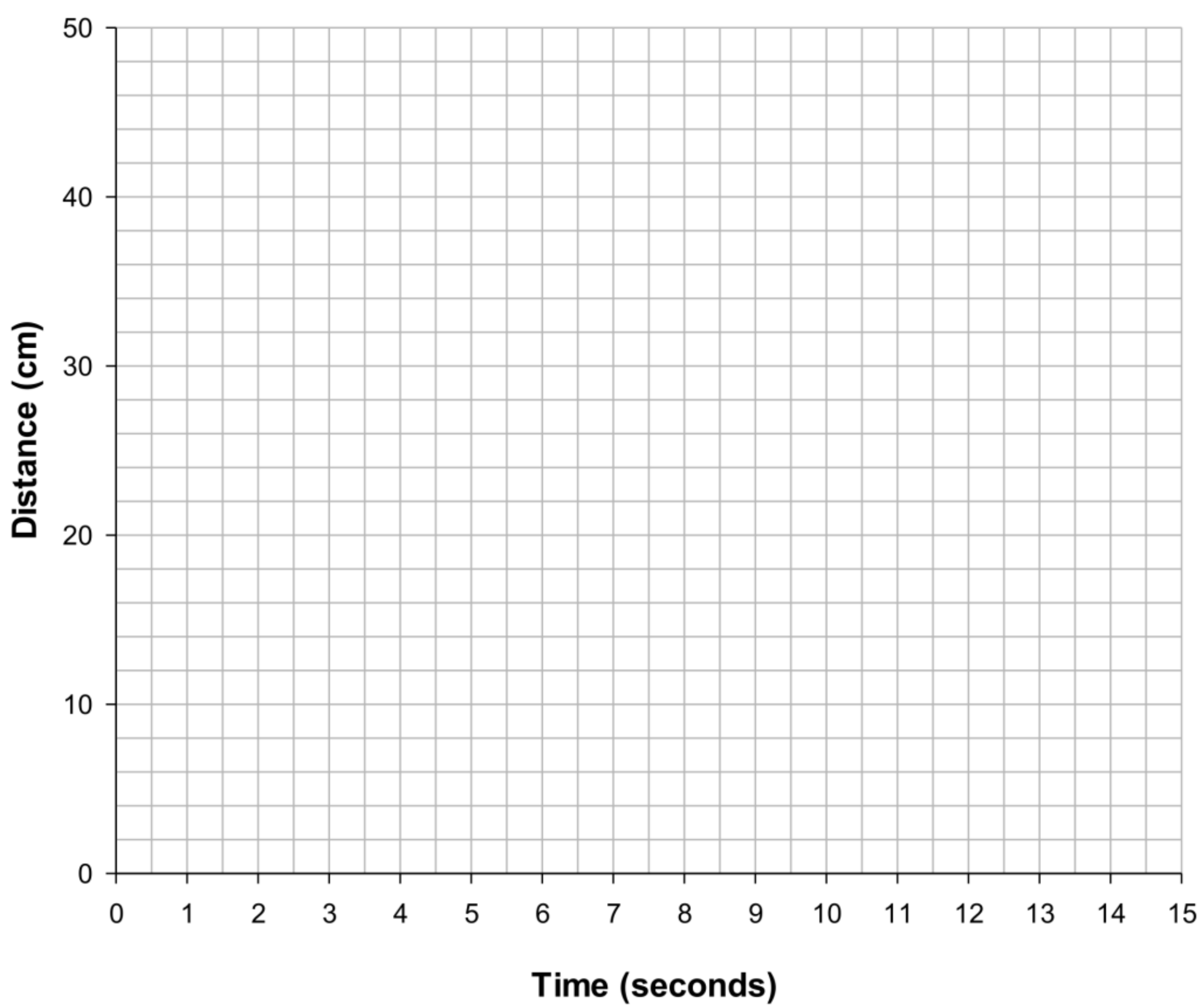
Time (s)	Distance (cm)

Table 2 - Green Tube

Time (s)	Distance (cm)

Table 3 - Blue Tube

Time (s)	Distance (cm)



Analysis

1. How far did the bubble in the red tube travel in 3.5 seconds? ___________________________________
(*Find the point on the best-fit line that is directly above the 3.5 second mark on the bottom of the graph. Then trace horizontally to the left side to find the corresponding distance.*)

2. How far did the bubble in the green tube travel in 3.5 seconds? ___________________________________

3. How far did the bubble in the blue tube travel in 3.5 seconds? ___________________________________

4. In which tube was the bubble the fastest? ____

5. Which tube has the steepest best-fit line? ____

6. Is there a connection between your answers to questions 4 and 5?

____

7. In the field of mathematics, we often use the word "slope" to describe how steep something is. Slope is defined as *Rise* divided by *Run*, where rise is the vertical measurement between two points, and run is the horizontal measurement.

Follow the steps to find the slope of the best-fit line for each tube:

a. Mark two points on the line, and label them "A" and "B." The points should be on the line and far apart from each other. Try to choose points that will make it easy to read the distance and time measurements. Record the values in the table below.

	Point A		**Point B**	
Tube	**Time (s)**	**Distance (cm)**	**Time (s)**	**Distance (cm)**
Red				
Green				
Blue				

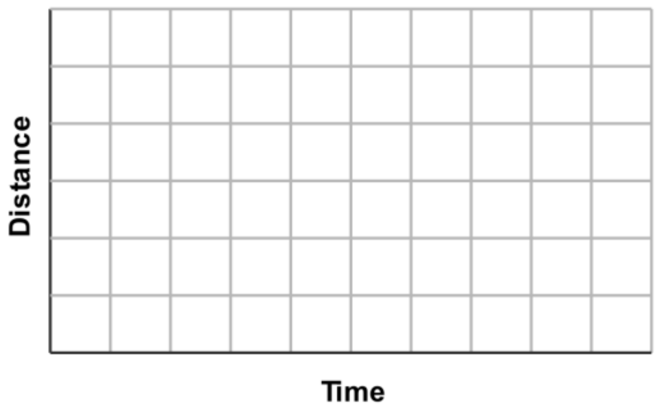
b. Rise is the vertical difference between A and B. Run is the horizontal difference. Calculate the rise and run for each tube in the table below. Include measurement units.

c. Calculate the slope (rise/run) for each tube in the table below. Include measurement units.

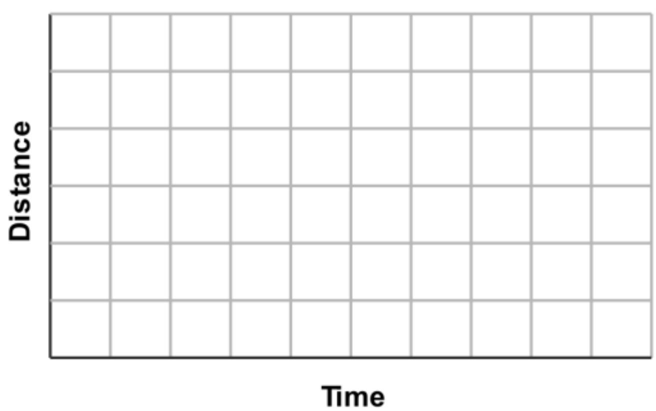
Tube	**Rise = Distance B - Distance A**	**Run = Time B - Time A**	**Slope = Rise / Run**
Red			
Green			
Blue			

8. In the previous calculations, you divided rise by run. The rise was a distance, and the run was a time.
   "Distance divided by time" is the formula for calculating ______________________.
   Therefore, the slope of a distance vs. time graph is the ______________________ of the moving object.

9. Imagine an object that traveled at a steady speed, then stopped and remained motionless for a while.
   Sketch the shape of graph that would result.



10. Imagine an object that goes faster and faster as it travels.
    Sketch of the shape of graph that would result.



11. What feature of the graph from this experiment shows that the bubbles traveled at constant speeds?

    ____

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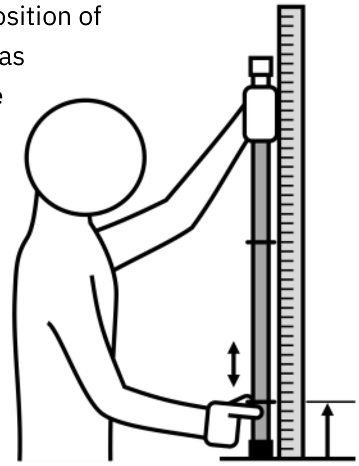
Experiment 2 Setup

Equipment Setup (Teacher)

Before the experiment, the teacher must set the position of one O-ring on each colored tube. This will be used as the starting point for the bubble and will determine the y-intercept of the students' data.



Hold the tube vertically on a table with the white cap up. Position the bottom ring exactly 6 cm (red and purple tubes) or 12 cm (blue tube) up from the bottom as shown. It doesn't matter where the top ring is, as it will be moved around during the experiment. Remind students not to move the bottom ring.

Since the rings on the red and purple tubes are at the same position, students should discover that these tubes produce the same y-intercept. Likewise, the blue tube has a higher start position, and therefore a greater y-intercept.

Experiment 2 Part 1

Constant Velocity and the Linear Graph

Purpose

The purpose of this experiment is to study the motion of a bubble rising through a tube of oil and to develop a quantitative description of that motion.

Introduction

At the most basic level, motion is described by position as a function of time. In this experiment, time and position are measured, while other variables that might affect the motion, such as tube angle and temperature, are held constant.

First, a reference frame must be chosen in which to measure the position. The initial position of a moving object is often chosen to be zero, however, for this experiment, we will define the end of the tube to be zero. This will make the measurements easier and will reveal additional insights during the analysis. We will also define position to be positive above the bottom of the tube, since the bubble will always be above this point. Positions will be measured by holding a meter stick or measuring tape next to the tube.

When the data points from one tube are graphed, a clear pattern can be seen. Plotting the other tubes on the same graph produces similar patterns, but with distinctive differences relating to the motion of the bubbles. These patterns should be familiar to algebra students, and an equation for each can be written.

Safety

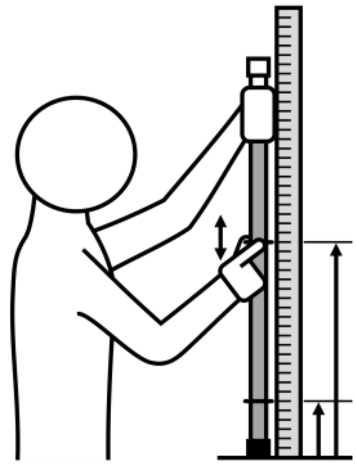
Follow proper lab behavior rules, such as wearing safety glasses. Ask you teacher if you do not know these rules, or do not understand them.

These tubes are breakable. Treat them with care. Tell you teacher immediately if a tube cracks, breaks, or leaks. Then take the proper clean-up steps.

Equipment

- 3 tubes filled with colored oils (red, blue, purple)
- Meter stick (preferred) or metric measuring tape
- Stopwatch (preferred) or clock

Procedure

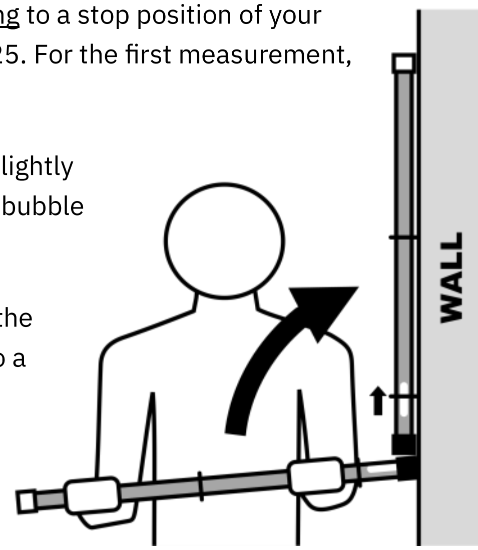


1. Obtain one of the 3 colored tubes. Notice that each tube has 2 rubber rings on it. Your teacher has positioned one of these rings near the end of the tube. Do NOT move this ring. Ask your teacher if you are not sure which ring to move during the experiment.

2. Hold the tube vertically on a table with the white cap up. Measure from the table up to the bottom ring and record its position in Table 1 on page 25. Do NOT move this ring during the experiment.

3. Work with a partner to record the motion of the bubble as follows:

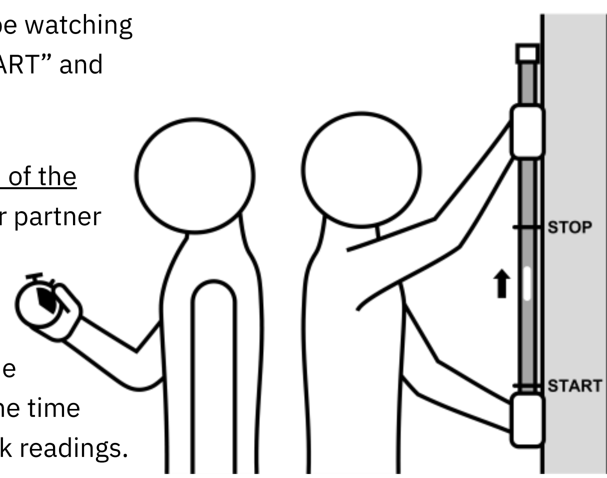
    a. Still holding the tube with the white cap up, move the top ring to a stop position of your choosing and record its position in Table 2, 3, or 4 on page 25. For the first measurement, place it about 8-10 cm above the bottom ring.



    b. Hold the tube nearly horizontal with the black-capped end slightly elevated and resting against the wall as shown. Wait for the bubble to travel all the way to the end of the tube.

    c. Your partner should be operating a stopwatch (or watching the clock). When you are both ready, quickly rotate the tube into a vertical position against the wall, pivoting around the black-capped end. The tube should now be perfectly vertical.

    d. When the bottom of the bubble reaches the first ring, say "START" and your partner will start the stopwatch (or note the time on the clock). Your partner should NOT be watching the bubble but rather listening for you to say "START" and "STOP". This will minimize error from user delay.



    e. Watch the bubble rise, and as soon as the bottom of the bubble reaches the second ring, say "STOP". Your partner will stop the stopwatch (or note the time on the clock).

    f. Record the time in the table on page 25 next to the position you already recorded. If you measured the time with a clock, record the difference of the two clock readings.

    g. Plot the data point (time and position) on the graph on page 26.

If time permits, accuracy can be improved by repeating a measurement more than once and plotting the average time for that position.

4. Repeat the previous steps with a stop position (top ring) such that the bubble has almost reached the top of the tube. (Do NOT move the bottom ring.)

5. Repeat the previous steps with 3-5 additional stop positions spaced evenly between the first two positions. Record the data in the table, and plot the points as you go. You should see a pattern begin to form. Look out for obvious mistakes, but do not rush to throw out any of your data.

6. Draw a best-fit line through the points to represent the pattern of your data. Extend the line to meet the vertical axis. A straight line drawn with a ruler should follow the pattern well. If it does not, ask your instructor for advice. Label the best-fit line "red tube", "blue tube", or "purple tube" accordingly.

7. Repeat the previous steps with each of the remaining colored tubes and plot the data on the same graph. You may want to use a different symbol or color to represent the data points for each tube.

Analysis

1. Record the y-intercept for each of the best-fit lines. Remember to include measurement units.

   Red Tube y-intercept: ________________

   Blue Tube y-intercept: ________________

   Purple Tube y-intercept: ________________

2. Calculate the slope of the best-fit line for each of the three tubes. Fill in the tables to show the results of your intermediate steps. Remember to include measurement units.

Red Tube

First Point	
x_1 =	y_1 =
Second Point	
x_2 =	y_2 =
Run = x_2 - x_1	**Rise = y_2 - y_1**
Slope = Rise/Run	

Blue Tube

First Point	
x_1 =	y_1 =
Second Point	
x_2 =	y_2 =
Run = x_2 - x_1	**Rise = y_2 - y_1**
Slope = Rise/Run	

Purple Tube

First Point	
x_1 =	y_1 =
Second Point	
x_2 =	y_2 =
Run = x_2 - x_1	**Rise = y_2 - y_1**
Slope = Rise/Run	

3. What is the physical meaning of the y-intercept for this experiment? (not the mathematical meaning)

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____

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4. Compare the best-fit lines from the red and purple tubes. Try to explain the reasons for any similarities or differences between the lines.

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5. Compare the best-fit line from the blue tube to the other two lines. Try to explain the reasons for any similarities or differences between the lines.

____

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STOP: Your instructor may ask you to stop here for further discussion. If not, continue with step 6.

6. Compare the start position on each tube (bottom ring) to verify your explanation from question 5.

7. Did your best-fit line for the blue tube correctly show its y-intercept to be at a point higher than the y-intercepts for the other two tubes?

____

8. Compare each y-intercept to the bottom ring position for that tube (Table 1). Are the y-intercepts very close to these starting positions? Why or why not?

____

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9. What arguments can you offer, based on this experiment, that the speed of the bubble is the same as the slope of the position vs. time graph?

____

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10. In algebra, the type of graph seen in this experiment is described by the equation: $y = \mathrm{m}x + \mathrm{b}$

Where: *y* is the quantity on the vertical axis,
x is the quantity on the horizontal axis,
m is the slope, and
b is the y-intercept (also called the vertical intercept)

Write equations for each of the tubes by substituting the slope and y-intercept values you found into the basic equation above. Replace the symbols, *y* and *x*, with new symbols to represent *position* and *time*.

Red Tube Equation: ___________________________________

Blue Tube Equation: ___________________________________

Purple Tube Equation: ___________________________________

11. The mathematical equation can be transformed into a general equation of motion by replacing the symbols and numbers with the physical quantities they represent. Write an equation of motion using the words *position*, *time*, *velocity*, and *initial position*.

____

Experiment 2 Part 2

Constant Negative Velocity

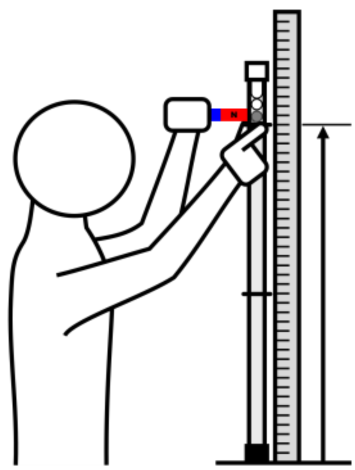
Purpose

The purpose of this part of the experiment is to study the motion of two small balls as they fall through a tube of oil and to relate that motion to the graph of the rising bubbles.

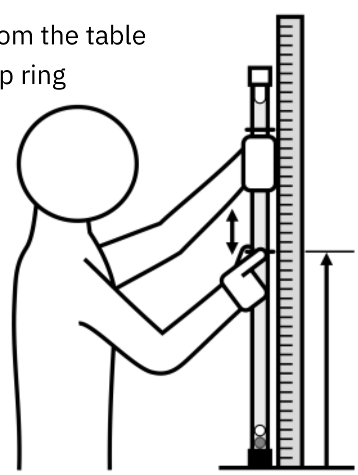
Equipment

- 1 transparent tube with steel and plastic balls
- 1 tube filled with purple colored oil
- Meter stick (preferred) or metric measuring tape
- Stopwatch (preferred) or clock
- Magnet

Procedure



1. Obtain a magnet and a transparent tube containing two balls (one steel and one plastic). Wipe any particles off the magnet to avoid scratching the tube.
2. Hold the tube vertically with the white cap up. (The plastic ball should be above the steel.) Use the magnet to move both balls to the top, but still submerged in oil.
3. Move the top ring up to the magnet as shown. Do <u>NOT</u> move this ring for the remainder of the experiment.
4. Support the tube on a table, measure up from the table as shown, and record the position of the top ring in Table 1 on page 25.



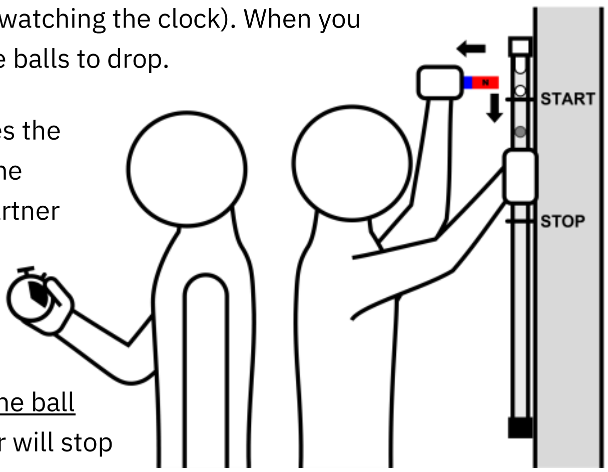
5. Work with a partner to record the motion of each ball as follows:
    a. Move the <u>bottom ring</u> to a stop position of your choosing, and record its position in Table 5 or 6 on page 25. For the first measurement, place it about 6-8 cm <u>below the top ring</u>.

b. Hold the tube vertically against a wall. This is <u>important</u> for achieving accurate results. The velocity will change if it is angled even a few degrees.

c. Use the magnet to hold both balls at their starting position above the top ring. Wait for the bubble to rise to the top of the tube before proceeding.

d. Your partner should be operating a stopwatch (or watching the clock). When you are both ready, pull the magnet away, allowing the balls to drop.

e. When the <u>bottom of the ball</u> you are timing reaches the top ring, say "START" and your partner will start the stopwatch (or note the time on the clock). Your partner should <u>NOT</u> be watching the ball but rather listening for you to say "START" and "STOP". This will minimize error from user delay.



f. Watch the ball fall, and as soon as the <u>bottom of the ball</u> reaches the bottom ring, say "STOP". Your partner will stop the stopwatch (or note the time on the clock).

g. Record the time in the table on page 25 next to the position you already recorded. If you measured the time with a clock, record the difference of the two clock readings.

h. Plot the data point (time and position) on the graph on page 26.

If time permits, accuracy can be improved by repeating a measurement more than once and plotting the average time for that position.

Tip: To save time, record the other ball with this stop position before moving the bottom ring. Plot the data on the same graph using a different symbol or color.

6. Repeat the previous steps with a stop position (bottom ring) such that the ball has almost reached the bottom of the tube.

7. Repeat the previous steps with 3-5 additional stop positions spaced evenly between the first two positions. Record the data in the table, and plot the points as you go. You should see a pattern begin to form. Look out for obvious mistakes, but do not rush to throw out any of your data.

8. Draw a best-fit line through the points to represent the pattern of your data. Extend the line to meet the vertical axis. A straight line drawn with a ruler should follow the pattern well. If it does not, ask your instructor for advice. Label the best-fit line "steel ball" or "plastic ball" accordingly.

9. Repeat the previous steps with the other ball (if you haven't already) and plot the data on the same graph. You may want to use a different symbol or color to represent the data points for each ball.

Analysis

1. Compare the best-fit lines from the steel and plastic balls. Try to explain the reasons for any similarities or differences between the lines.

   ____

   ____

   ____

2. Record the y-intercept for each of the best-fit lines. Remember to include measurement units.

   Steel Ball y-intercept: ________________

   Plastic Ball y-intercept: ________________

   The y-intercepts should be close to the starting positions of each ball (as seen with the bubbles). Compare the y-intercepts with the starting positions in Table 1 to see if this is the case.

3. Calculate the slope of the best-fit line for each ball. Fill in the tables to show the results of your intermediate steps. Remember to include measurement units.

Steel Ball

First Point	
x_1 =	y_1 =
Second Point	
x_2 =	y_2 =
Run = x_2 - x_1	**Rise = y_2 - y_1**
Slope = Rise/Run	

Plastic Ball

First Point	
x_1 =	y_1 =
Second Point	
x_2 =	y_2 =
Run = x_2 - x_1	**Rise = y_2 - y_1**
Slope = Rise/Run	

4. If you calculated the two slopes correctly, they should be <u>negative</u> numbers. What does this tell you about the motion of the balls?

   ____

   ____

   ____

5. Again, the type of graph seen in this experiment is described by the equation: $y = \text{m}x + \text{b}$

   Where: *y* is the quantity on the vertical axis,
   x is the quantity on the horizontal axis,
   m is the slope, and
   b is the y-intercept (also called the vertical intercept)

   Write an equation for each ball by substituting the slope and y-intercept values you found into the basic equation above. Replace the symbols, *y* and *x*, with new symbols to represent *position* and *time*.

   Steel Ball Equation: ______________________________________

   Plastic Ball Equation: ______________________________________

6. If you were to place the purple tube next to the transparent tube and release the balls so that the bottom of the plastic ball passes its start ring at the same time as the bottom of the bubble passes its start ring, when and where would the bubble and plastic ball pass one another? Remember to include measurement units.

   Hint: You should be able to answer this question by looking at your graph (or you may use algebra to solve the two equations for the time and position where they cross).

   Time: ____________ Position: ____________

7. How did you determine your answers to question 6?

   ____

   ____

   ____

8. Test your answers experimentally. How close were your experimental values to the time and position you predicted? (You will likely need a third person to test this.)

   ____

   ____

   ____

Experiment Data

Table 1 - Starting Position

Tube	Position (cm)
Red Tube	
Blue Tube	
Purple Tube	
Steel & Plastic Balls	

Note: In this experiment, position is varied and the resulting time is measured. This improves the accuracy, but it also means that position is the independent variable and time is the dependent variable. Normally, the independent variable is plotted on the x-axis and the dependent variable on the y-axis. For this graph, they have been switched, because the data will be easier to interpret if position is in the y-axis and time is on the x-axis.

Table 2 - Red Tube

Time (s)	Position (cm)

Table 3 - Blue Tube

Time (s)	Position (cm)

Table 4 - Purple Tube

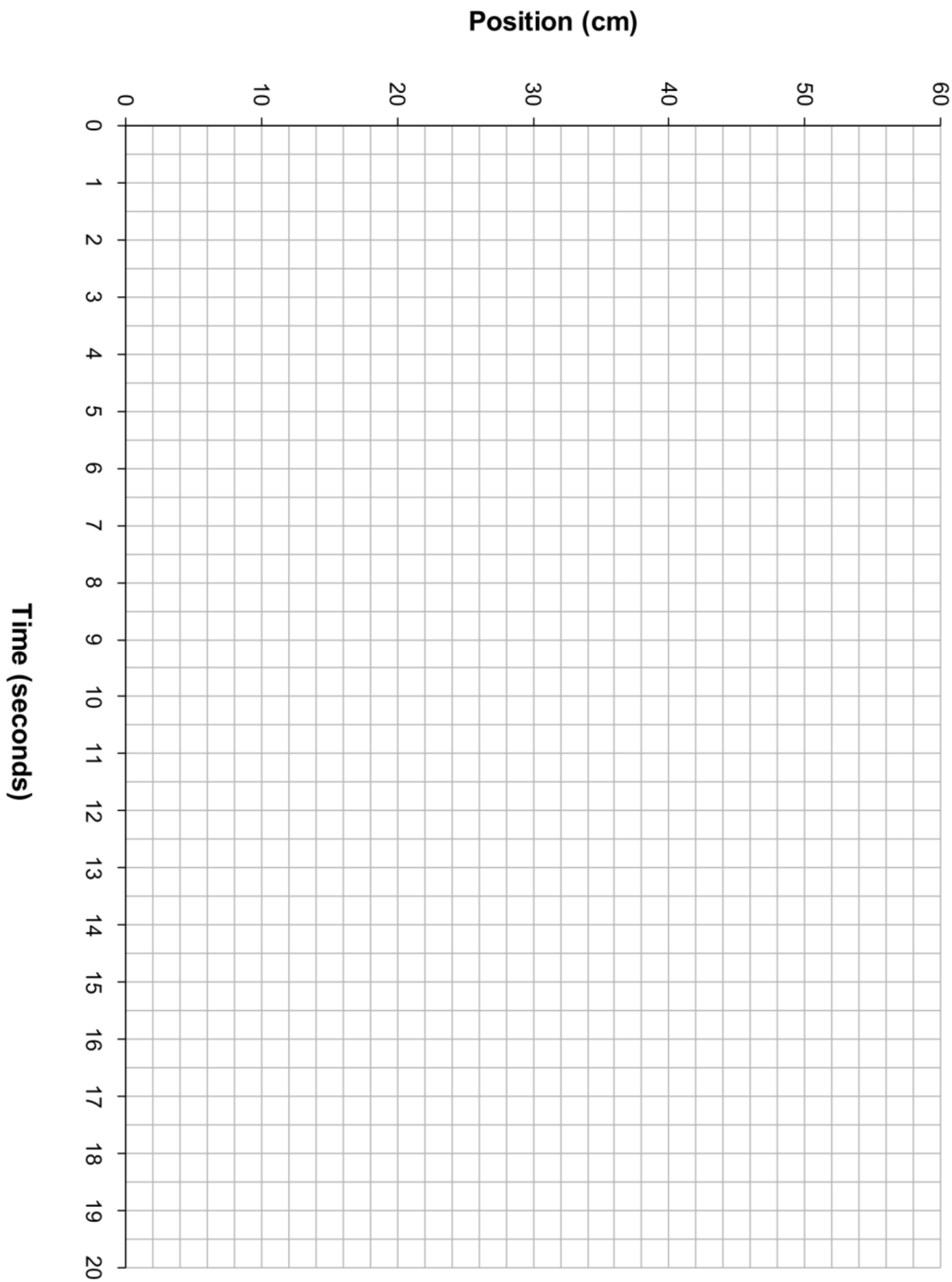
Time (s)	Position (cm)

Table 5 - Steel Ball

Time (s)	Position (cm)

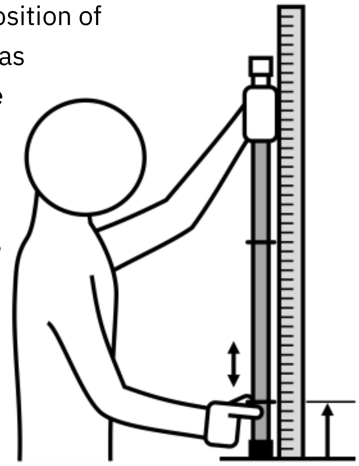
Table 6 - Plastic Ball

Time (s)	Position (cm)


Position (cm)
0
10
20
30
40
50
60
Time (seconds)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

Experiment 3 Setup

Equipment Setup (Teacher)



Before the experiment, the teacher must set the position of one O-ring on each colored tube. This will be used as the starting point for the bubble and will determine the y-intercept of the students' data.

Hold the tube vertically on a table with the white cap up. Position the bottom ring exactly 6 cm (blue and green tubes) or 12 cm (red and purple tubes) up from the bottom as shown. It doesn't matter where the top ring is, as it will be moved around during the experiment. Remind students not to move the bottom ring.

Since the rings on the blue and green tubes are at the same position, students should discover that these tubes produce the same y-intercept. Likewise, the red and purple tubes should also have the same y-intercept. Furthermore, because the red and purple tubes have a higher start position than the blue and green tubes, their y-intercepts should be greater.

To preserve the element of discovery in Part 2, students should return (or set aside) the blue tube after Part 1. They will need the red and green tubes for comparison at the beginning of Part 2, but the blue tube will not be used again until the end of Part 2.

Experiment 3 Part 1

Constant Velocity and the Linear Graph

Purpose

The purpose of this experiment is to study the motion of a bubble rising through a tube of oil and to develop a quantitative description of that motion.

Introduction

At the most basic level, motion is described by position as a function of time. In this experiment, time and position are measured, while other variables that might affect the motion, such as tube angle and temperature, are held constant.

First, a reference frame must be chosen in which to measure the position. The initial position of a moving object is often chosen to be zero, however, for this experiment, we will define the end of the tube to be zero. This will make the measurements easier and will reveal additional insights during the analysis. We will also define position to be positive above the bottom of the tube, since the bubble will always be above this point. Positions will be measured by holding a meter stick or measuring tape next to the tube.

When the data points from one tube are graphed, a clear pattern can be seen. Plotting the other tubes on the same graph produces similar patterns, but with distinctive differences relating to the motion of the bubbles. These patterns should be familiar to algebra students, and an equation for each can be written.

Safety

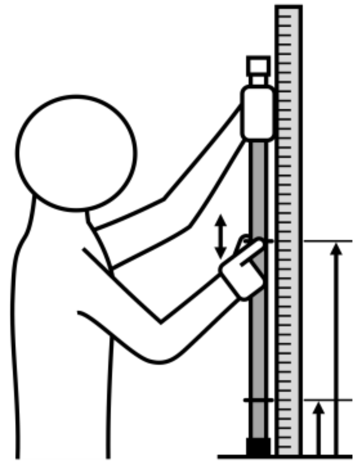
Follow proper lab behavior rules, such as wearing safety glasses. Ask you teacher if you do not know these rules, or do not understand them.

These tubes are breakable. Treat them with care. Tell you teacher immediately if a tube cracks, breaks, or leaks. Then take the proper clean-up steps.

Equipment

- 3 tubes filled with colored oils (red, green, blue)
- Meter stick (preferred) or metric measuring tape
- Stopwatch (preferred) or clock

Procedure

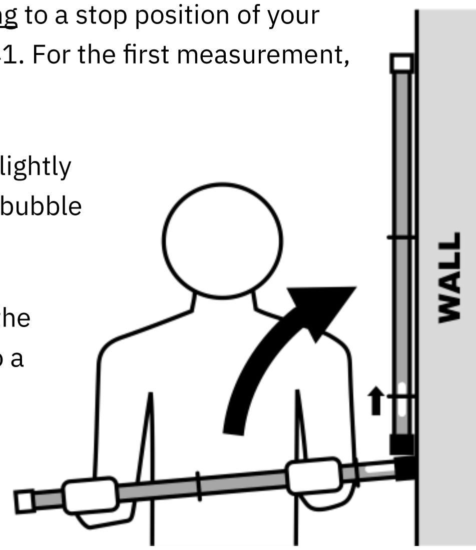


1. Obtain one of the 3 colored tubes. Notice that each tube has 2 rubber rings on it. Your teacher has positioned one of these rings near the end of the tube. Do NOT move this ring. Ask your teacher if you are not sure which ring to move during the experiment.

2. Hold the tube vertically on a table with the white cap up. Measure from the table up to the bottom ring and record its position in Table 1 on page 41. Do NOT move this ring during the experiment.

3. Work with a partner to record the motion of the bubble as follows:

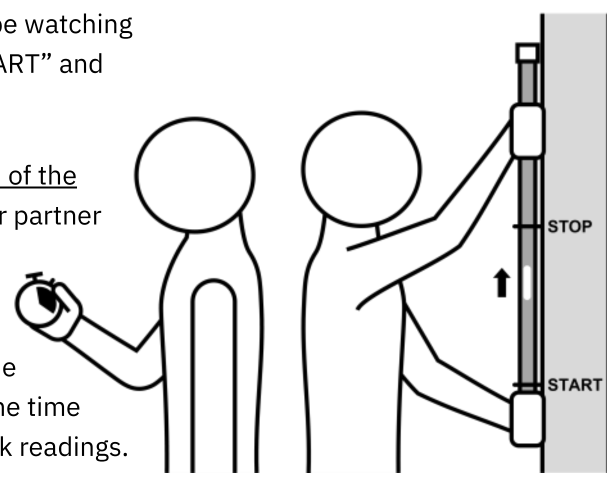
   a. Still holding the tube with the white cap up, move the top ring to a stop position of your choosing and record its position in Table 2, 3, or 4 on page 41. For the first measurement, place it about 8-10 cm above the bottom ring.



   b. Hold the tube nearly horizontal with the black-capped end slightly elevated and resting against the wall as shown. Wait for the bubble to travel all the way to the end of the tube.

   c. Your partner should be operating a stopwatch (or watching the clock). When you are both ready, quickly rotate the tube into a vertical position against the wall, pivoting around the black-capped end. The tube should now be perfectly vertical.

   d. When the bottom of the bubble reaches the first ring, say “START” and your partner will start the stopwatch (or note the time on the clock). Your partner should NOT be watching the bubble but rather listening for you to say “START” and “STOP”. This will minimize error from user delay.



   e. Watch the bubble rise, and as soon as the bottom of the bubble reaches the second ring, say “STOP”. Your partner will stop the stopwatch (or note the time on the clock).

   f. Record the time in the table on page 41 next to the position you already recorded. If you measured the time with a clock, record the difference of the two clock readings.

   g. Plot the data point (time and position) on the graph on page 42.

If time permits, accuracy can be improved by repeating a measurement more than once and plotting the average time for that position.

4. Repeat the previous steps with a stop position (top ring) such that the bubble has almost reached the top of the tube. (Do NOT move the bottom ring.)

5. Repeat the previous steps with 3-5 additional stop positions spaced evenly between the first two positions. Record the data in the table, and plot the points as you go. You should see a pattern begin to form. Look out for obvious mistakes, but do not rush to throw out any of your data.

6. Draw a best-fit line through the points to represent the pattern of your data. Extend the line to meet the vertical axis. A straight line drawn with a ruler should follow the pattern well. If it does not, ask your instructor for advice. Label the best-fit line “red tube”, “green tube”, or “blue tube” accordingly.

7. Repeat the previous steps with each of the remaining colored tubes (red, green, blue) and plot the data on the same graph. You may want to use a different symbol or color to represent the data points for each tube.

Analysis

1. Record the y-intercept for each of the best-fit lines. Remember to include measurement units.

   Red Tube y-intercept: ________________

   Green Tube y-intercept: ________________

   Blue Tube y-intercept: ________________

2. Calculate the slope of the best-fit line for each of the three tubes. Fill in the tables to show the results of your intermediate steps. Remember to include measurement units.

Red Tube

First Point	
x_1 =	y_1 =
Second Point	
x_2 =	y_2 =
Run = $x_2 - x_1$	**Rise = $y_2 - y_1$**
Slope = Rise/Run	

Green Tube

First Point	
x_1 =	y_1 =
Second Point	
x_2 =	y_2 =
Run = $x_2 - x_1$	**Rise = $y_2 - y_1$**
Slope = Rise/Run	

Blue Tube

First Point	
x_1 =	y_1 =
Second Point	
x_2 =	y_2 =
Run = $x_2 - x_1$	**Rise = $y_2 - y_1$**
Slope = Rise/Run	

3. What is the physical meaning of the y-intercept for this experiment? (not the mathematical meaning)

____

____

____

4. Compare the best-fit lines from the blue and green tubes. Try to explain the reasons for any similarities or differences between the lines.

____

____

____

5. Compare the best-fit line from the red tube to the other two lines. Try to explain the reasons for any similarities or differences between the lines.

____

____

____

STOP: Your instructor may ask you to stop here for further discussion. If not, continue with step 6.

6. Compare the start position on each tube (bottom ring) to verify your explanation from question 5.

7. Did your best-fit line for the red tube correctly show its y-intercept to be at a point higher than the y-intercepts for the other two tubes?

 ____

8. Compare each y-intercept to the bottom ring position for that tube (Table 1). Are the y-intercepts very close to these starting positions? Why or why not?

 ____

 ____

 ____

9. What arguments can you offer, based on this experiment, that the speed of the bubble is the same as the slope of the position vs. time graph?

 ____

 ____

 ____

10. In algebra, the type of graph seen in this experiment is described by the equation: $y = mx + b$

 Where: y is the quantity on the vertical axis,
 x is the quantity on the horizontal axis,
 m is the slope, and
 b is the y-intercept (also called the vertical intercept)

 Write equations for each of the tubes by substituting the slope and y-intercept values you found into the basic equation above. Replace the symbols, y and x, with new symbols to represent *position* and *time*.

 Red Tube Equation: ________________________________

 Green Tube Equation: ________________________________

 Blue Tube Equation: ________________________________

11. The mathematical equation can be transformed into a general equation of motion by replacing the symbols and numbers with the physical quantities they represent. Write an equation of motion using the words *position*, *time*, *velocity*, and *initial position*.

 ____

Experiment 3 Part 2

Predicting the Shape of a Graph

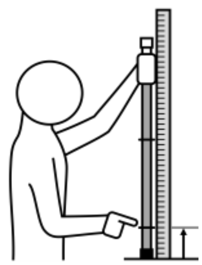
Purpose

The purpose of this part of the experiment is to make predictions about the motion of the bubble based on what you learned in Part 1.

Equipment

- 1 tube filled with purple colored oil (other tubes needed for comparison)
- Meter stick (preferred) or metric measuring tape
- Stopwatch (preferred) or clock

Observations and Predictions



1. Hold the purple tube vertically on a table with the white cap up. Measure from the table up to the bottom ring and record its position in Table 1 on page 41. Do NOT move this ring during the experiment.

2. Compare the starting position on the purple tube (bottom ring) to the starting positions of the other tubes (Table 1). Based on what you learned from Part 1, what value do you expect for the y-intercept of the purple tube data? Remember to include measurement units.

   Predicted Purple Tube y-intercept: ________________

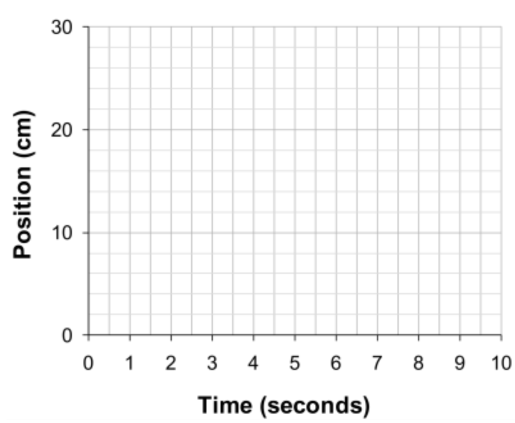
3. Hold the red, green, and purple tubes side-by-side and watch their bubbles rise. Rank their speeds from slowest to fastest.

   _________________ < _________________ < _________________

4. Based on your observations in question 3, what value do you expect for the slope of the purple tube data? Remember to include measurement units.

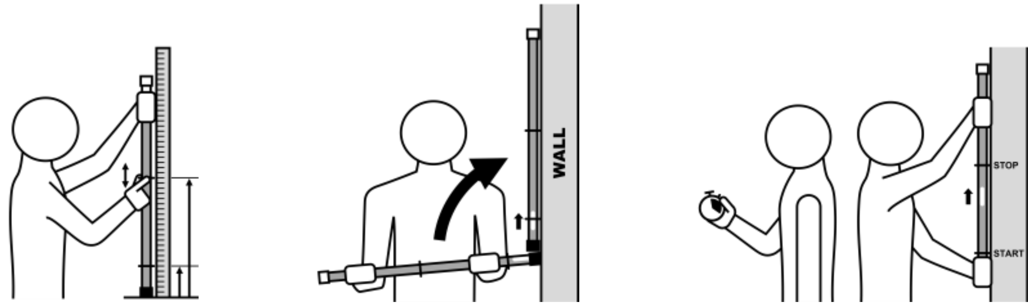
   Predicted Purple Tube Slope: ________________

5. Sketch the shape of the graph you expect for the purple tube. Use your predicted values for the y-intercept and slope to sketch the graph.



Procedure

1. Work with a partner to record the motion of the bubble using the same procedure as in Part 1.



2. Record the time and position data in Table 5 on page 41.
3. Plot the data points as you go on the graph on page 42.
4. Draw a best-fit line through the points to represent the pattern of your data. Extend the line to meet the vertical axis. A straight line drawn with a ruler should follow the pattern well. If it does not, ask your instructor for advice. Label the best-fit line “purple tube”.

Analysis

1. Record the y-intercept of the best-fit line. Remember to include measurement units.

   Purple Tube y-intercept: _________________

2. Calculate the slope of the best-fit line. Fill in the table to show the results of your intermediate steps. Remember to include measurement units.
3. Compare the best-fit line from the purple tube to your predictions on the previous page:

Purple Tube

First Point	
x_1 =	y_1 =
Second Point	
x_2 =	y_2 =
Run = $x_2 - x_1$	**Rise = $y_2 - y_1$**
Slope = Rise/Run	

   a. How well did the overall shape of your predicted graph match the experimental graph on page 42?

   ____

   b. How close was your predicted y-intercept to the y-intercept of the best-fit line?

   ____

   c. How close was your predicted slope to the slope of the best-fit line?

   ____

4. Did your purple tube best-fit line correctly have the same y-intercept as the red tube?

____

5. Why should the red and purple tubes have the same y-intercept?

____

6. Did your purple tube best-fit line correctly have the same slope as the blue tube?

____

7. What does your answer to question 6 tell you about the speeds of the blue and purple tubes?

____

8. Hold the blue and purple tubes side-by-side and compare the speeds of the bubbles. Does this confirm your answer to question 7?

____

9. Again, the type of graph seen in this experiment is described by the equation: $y = \mathrm{m}x + \mathrm{b}$

   Where: y is the quantity on the vertical axis,
   x is the quantity on the horizontal axis,
   m is the slope, and
   b is the y-intercept (also called the vertical intercept)

   Write an equation for the purple tube by substituting the slope and y-intercept values you found (from the best-fit line, not the predictions) into the basic equation above. Replace the symbols, *y* and *x*, with new symbols to represent *position* and *time*.

   Purple Tube Equation: ________________________________

Experiment 3 Part 3

Constant Negative Velocity

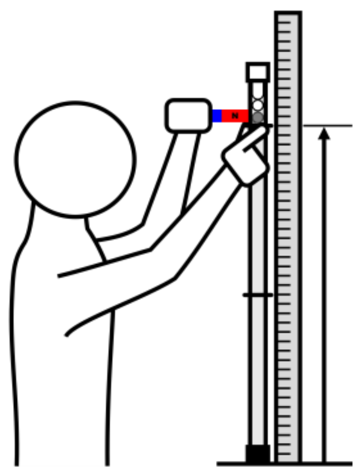
Purpose

The purpose of this part of the experiment is to study the motion of two small balls as they fall through a tube of oil and to relate that motion to the graph of the rising bubbles.

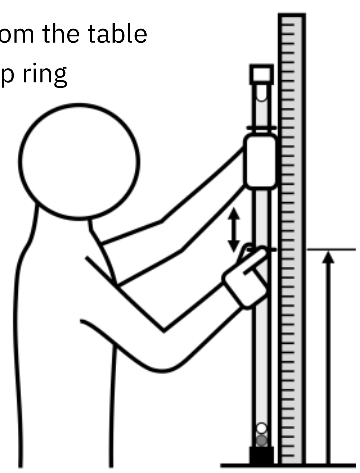
Equipment

- 1 transparent tube with steel and plastic balls
- 1 tube filled with purple colored oil
- Meter stick (preferred) or metric measuring tape
- Stopwatch (preferred) or clock
- Magnet

Procedure



1. Obtain a magnet and a transparent tube containing two balls (one steel and one plastic). Wipe any particles off the magnet to avoid scratching the tube.
2. Hold the tube vertically with the white cap up. (The plastic ball should be above the steel.) Use the magnet to move both balls to the top, but still submerged in oil.
3. Move the top ring up to the magnet as shown. Do NOT move this ring for the remainder of the experiment.
4. Support the tube on a table, measure up from the table as shown, and record the position of the top ring in Table 1 on page 41.

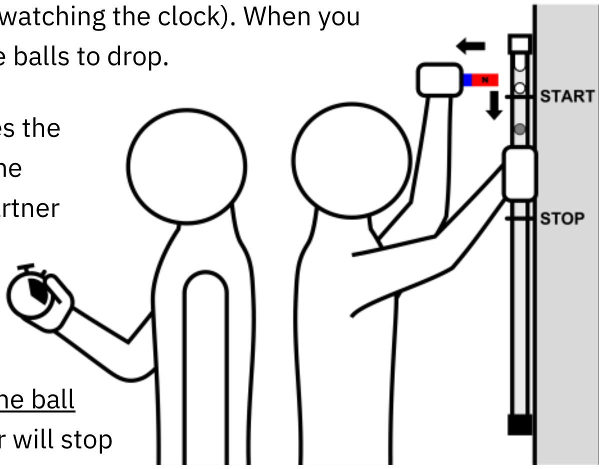


5. Work with a partner to record the motion of each ball as follows:
   a. Move the bottom ring to a stop position of your choosing, and record its position in Table 6 or 7 on page 41. For the first measurement, place it about 6-8 cm below the top ring.

b. Hold the tube vertically against a wall. This is <u>important</u> for achieving accurate results. The velocity will change if it is angled even a few degrees.

c. Use the magnet to hold both balls at their starting position above the top ring. Wait for the bubble to rise to the top of the tube before proceeding.

d. Your partner should be operating a stopwatch (or watching the clock). When you are both ready, pull the magnet away, allowing the balls to drop.



e. When the <u>bottom of the ball</u> you are timing reaches the top ring, say "START" and your partner will start the stopwatch (or note the time on the clock). Your partner should <u>NOT</u> be watching the ball but rather listening for you to say "START" and "STOP". This will minimize error from user delay.

f. Watch the ball fall, and as soon as the <u>bottom of the ball</u> reaches the bottom ring, say "STOP". Your partner will stop the stopwatch (or note the time on the clock).

g. Record the time in the table on page 41 next to the position you already recorded. If you measured the time with a clock, record the difference of the two clock readings.

h. Plot the data point (time and position) on the graph on page 42.

If time permits, accuracy can be improved by repeating a measurement more than once and plotting the average time for that position.

Tip: To save time, record the other ball with this stop position before moving the bottom ring. Plot the data on the same graph using a different symbol or color.

6. Repeat the previous steps with a stop position (bottom ring) such that the ball has almost reached the bottom of the tube.

7. Repeat the previous steps with 3-5 additional stop positions spaced evenly between the first two positions. Record the data in the table, and plot the points as you go. You should see a pattern begin to form. Look out for obvious mistakes, but do not rush to throw out any of your data.

8. Draw a best-fit line through the points to represent the pattern of your data. Extend the line to meet the vertical axis. A straight line drawn with a ruler should follow the pattern well. If it does not, ask your instructor for advice. Label the best-fit line "steel ball" or "plastic ball" accordingly.

9. Repeat the previous steps with the other ball (if you haven't already) and plot the data on the same graph. You may want to use a different symbol or color to represent the data points for each ball.

Analysis

1. Compare the best-fit lines from the steel and plastic balls. Try to explain the reasons for any similarities or differences between the lines.

 ____

 ____

 ____

2. Record the y-intercept for each of the best-fit lines. Remember to include measurement units.

 Steel Ball y-intercept: ________________

 Plastic Ball y-intercept: ________________

 The y-intercepts should be close to the starting positions of each ball (as seen with the bubbles). Compare the y-intercepts with the starting positions in Table 1 to see if this is the case.

3. Calculate the slope of the best-fit line for each ball. Fill in the tables to show the results of your intermediate steps. Remember to include measurement units.

Steel Ball

First Point	
x_1 =	y_1 =
Second Point	
x_2 =	y_2 =
Run = x_2 - x_1	**Rise = y_2 - y_1**
Slope = Rise/Run	

Plastic Ball

First Point	
x_1 =	y_1 =
Second Point	
x_2 =	y_2 =
Run = x_2 - x_1	**Rise = y_2 - y_1**
Slope = Rise/Run	

4. If you calculated the two slopes correctly, they should be <u>negative</u> numbers. What does this tell you about the motion of the balls?

 ____

 ____

 ____

5. Again, the type of graph seen in this experiment is described by the equation: $y = mx + b$

   Where: y is the quantity on the vertical axis,
   x is the quantity on the horizontal axis,
   m is the slope, and
   b is the y-intercept (also called the vertical intercept)

   Write an equation for each ball by substituting the slope and y-intercept values you found into the basic equation above. Replace the symbols, *y* and *x*, with new symbols to represent *position* and *time*.

   Steel Ball Equation: ______________________________

   Plastic Ball Equation: ______________________________

6. If you were to place the purple tube next to the transparent tube and release the balls so that the bottom of the plastic ball passes its start ring at the same time as the bottom of the bubble passes its start ring, when and where would the bubble and plastic ball pass one another? Remember to include measurement units.

   Hint: You should be able to answer this question by looking at your graph (or you may use algebra to solve the two equations for the time and position where they cross).

   Time: ___________ Position: ___________

7. How did you determine your answers to question 6?

   ____

   ____

   ____

8. Test your answers experimentally. How close were your experimental values to the time and position you predicted? (You will likely need a third person to test this.)

   ____

   ____

   ____

Experiment Data

Table 1 - Starting Position

Tube	Position (cm)
Red Tube	
Green Tube	
Blue Tube	
Purple Tube	
Steel & Plastic Balls	

Note: In this experiment, position is varied and the resulting time is measured. This improves the accuracy, but it also means that position is the independent variable and time is the dependent variable. Normally, the independent variable is plotted on the x-axis and the dependent variable on the y-axis. For this graph, they have been switched, because the data will be easier to interpret if position is in the y-axis and time is on the x-axis.

Table 2 - Red Tube

Time (s)	Position (cm)

Table 3 - Green Tube

Time (s)	Position (cm)

Table 4 - Blue Tube

Time (s)	Position (cm)

Table 5 - Purple Tube

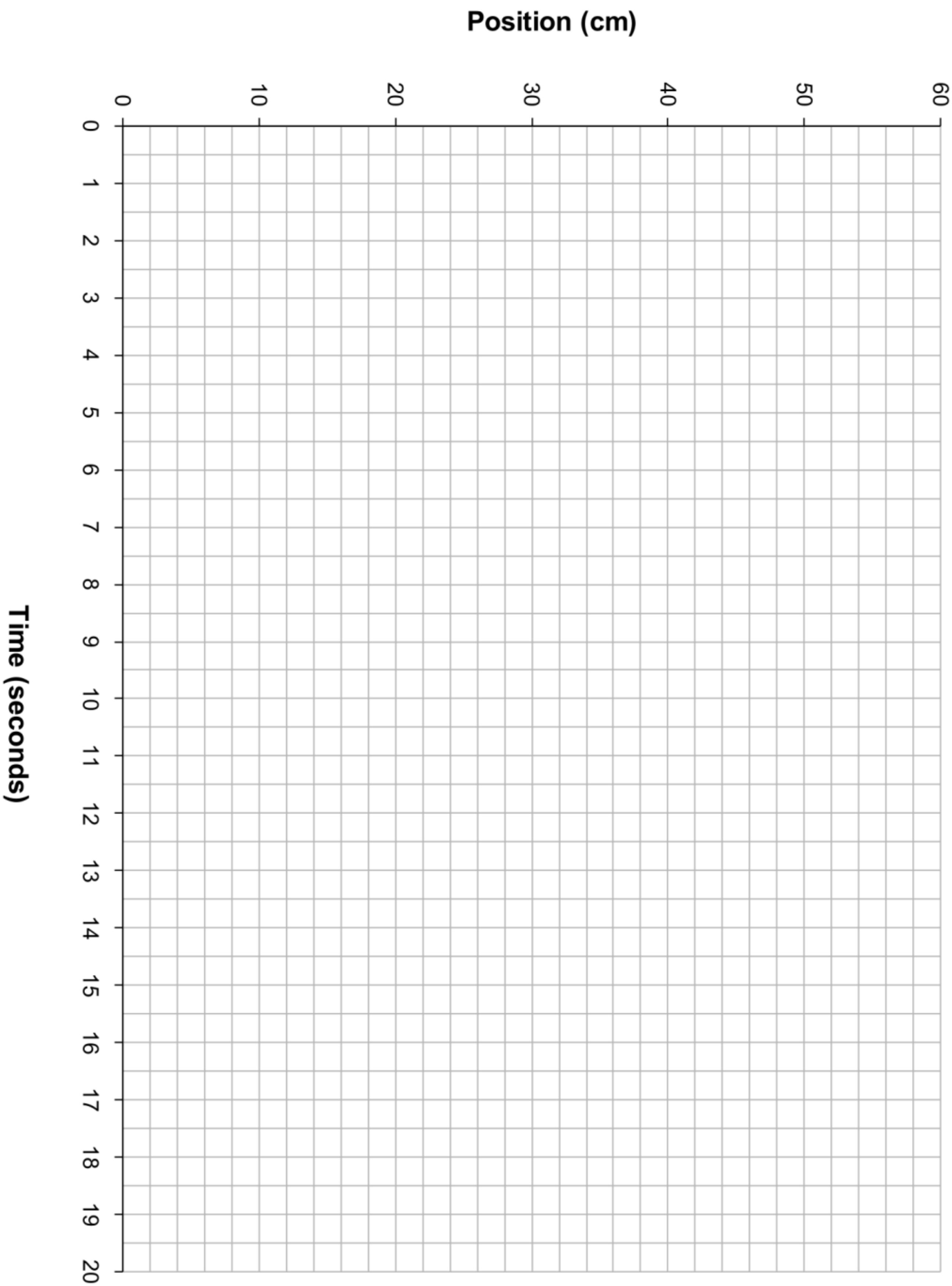
Time (s)	Position (cm)

Table 6 - Steel Ball

Time (s)	Position (cm)

Table 7 - Plastic Ball

Time (s)	Position (cm)


Position (cm)
0 10 20 30 40 50 60
Time (seconds)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

Answer Key

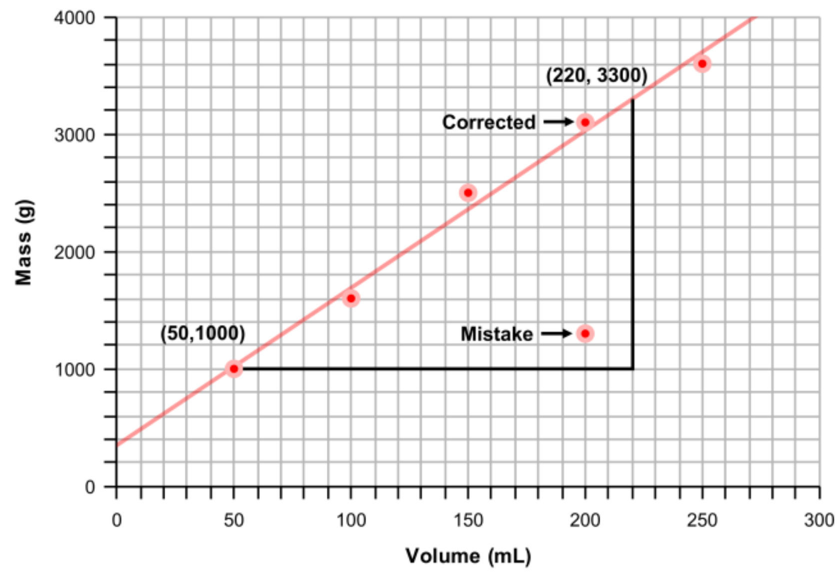
Typical Results & Answers

Prelab

1. Other potential variables that should be held constant include the container (could be a different mass), the balance used (might not be properly calibrated, or calibration methods could be crude), two different methods of measuring the liquid (e.g. beaker vs. graduated cylinder), or ambient temperature.

2. Plotting the extremes allows one to begin the graphing process with the assurance that all data will fit on the graph and to more accurately guess the slope of the true line that represents the relationship between the variables (assuming it is a linear relationship).

3. Sample Graph:



4. See graph above

5. Answers will vary

6. See graph above

7. The data point (200 mL, 1300 g)

8. See graph above

9. See graph above

10. mass = m * volume + b

11. mass = m * volume + 350 g

12. Answers will vary around 350 g

13. Answers will vary somewhat:

    a. First Point (x_1, y_1): x_1 = 50 mL y_1 = 1000g
       Second Point (x_2, y_2): x_2 = 220 mL y_2 = 3300g

    b. Rise (y_2 - y_1) = 2300 g
       Run (x_2 - x_1) = 170 mL

    c. Slope = Rise/Run = 13.5 g/mL

14. mass (g) = 13.5 g/mL * volume (mL) + 350 g

15. volume (mL) = [mass (g) - 350 g] / 13.5 g/mL

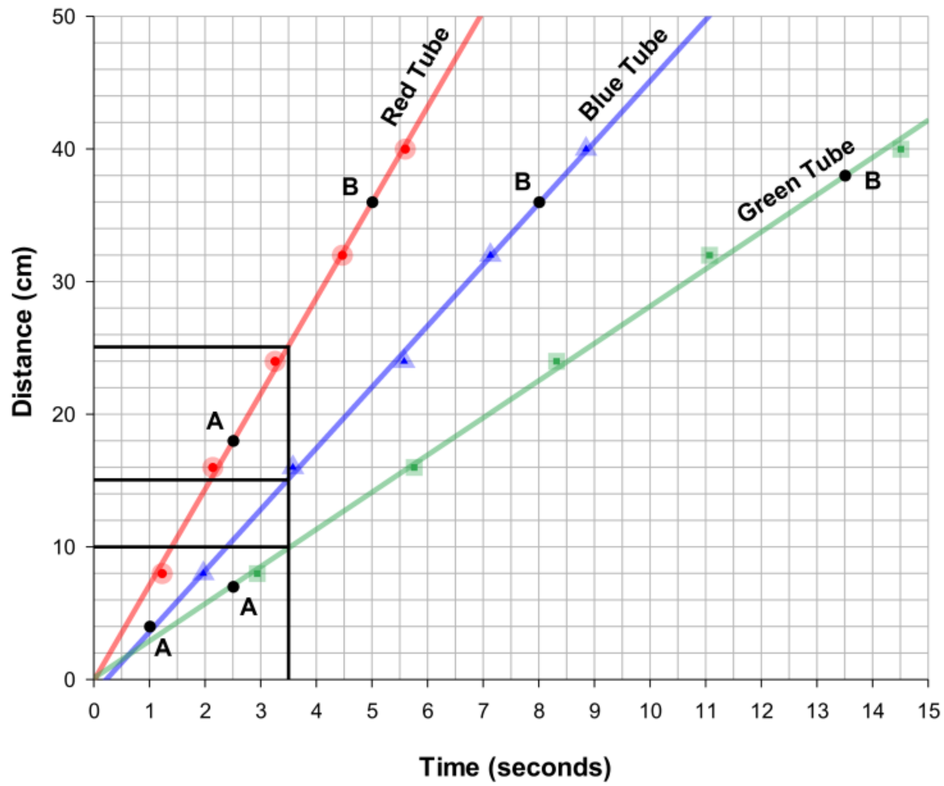
16. The y-intercept equals the mass of the beaker.

17. The slope represents the density of the liquid mercury. The accepted value for the density of mercury is 13.5 g/mL at room temperature, or 13.6 g/mL at 0°C. Students should expect to get something close to these values.

Experiment 1

Procedure

Sample Graph:



6. The best-fit line passes through the origin, because the timer started (time = 0) when the bubble was at the bottom ring (distance = 0).

Analysis (typical results based on sample graph)

1. The bubble in the red tube traveled 25 cm in 3.5 seconds.
2. The bubble in the green tube traveled 15 cm in 3.5 seconds.
3. The bubble in the blue tube traveled 10 cm in 3.5 seconds.
4. The bubble in the red tube was the fastest.
5. The red tube had the steepest best-fit line.
6. Students should see a connection between “steepness” and speed.

7. Slope calculation for each tube:

   a. Mark and record two points on each line (see sample graph and table below).

	Point A		Point B	
Tube	**Time (s)**	**Distance (cm)**	**Time (s)**	**Distance (cm)**
Red	2.5	18	5	36
Green	2.5	7	13.5	38
Blue	1	4	8	36

   b. Calculate rise and run (see table below).

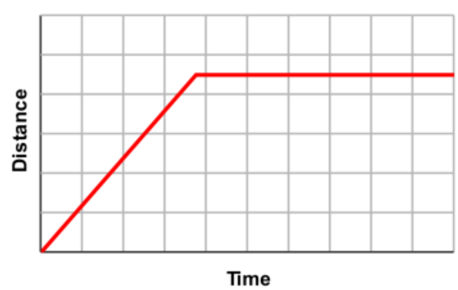
   c. Calculate slope (see table below).

Tube	Rise = Distance B - Distance A	Run = Time B - Time A	Slope = Rise / Run
Red	36 cm - 18 cm = 18 cm	5 s - 2.5 s = 2.5 s	18 cm / 2.5 s = 7.2 cm/s
Green	38 cm - 7 cm = 31 cm	13.5 s - 2.5 s = 11 s	31 cm / 11 s = 2.8 cm/s
Blue	36 cm - 4 cm = 32 cm	8 s - 1 s = 7 s	32 cm / 7 s = 4.6 cm/s

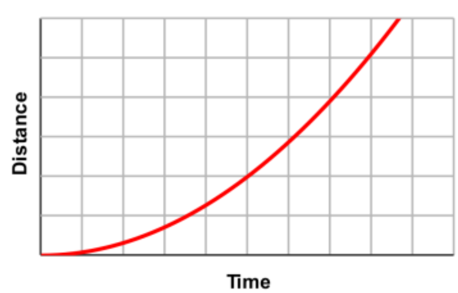
8. “Distance divided by time” is the formula for calculating <u>speed</u>.
   Therefore, the slope of a distance vs. time graph is the <u>speed</u> of the moving object.

   This is the key idea from this experiment. It is worthwhile to point out that the measurement units of the slope calculation turn out to be appropriate units for speed.

9. Sample Sketch:



10. Sample Sketch:

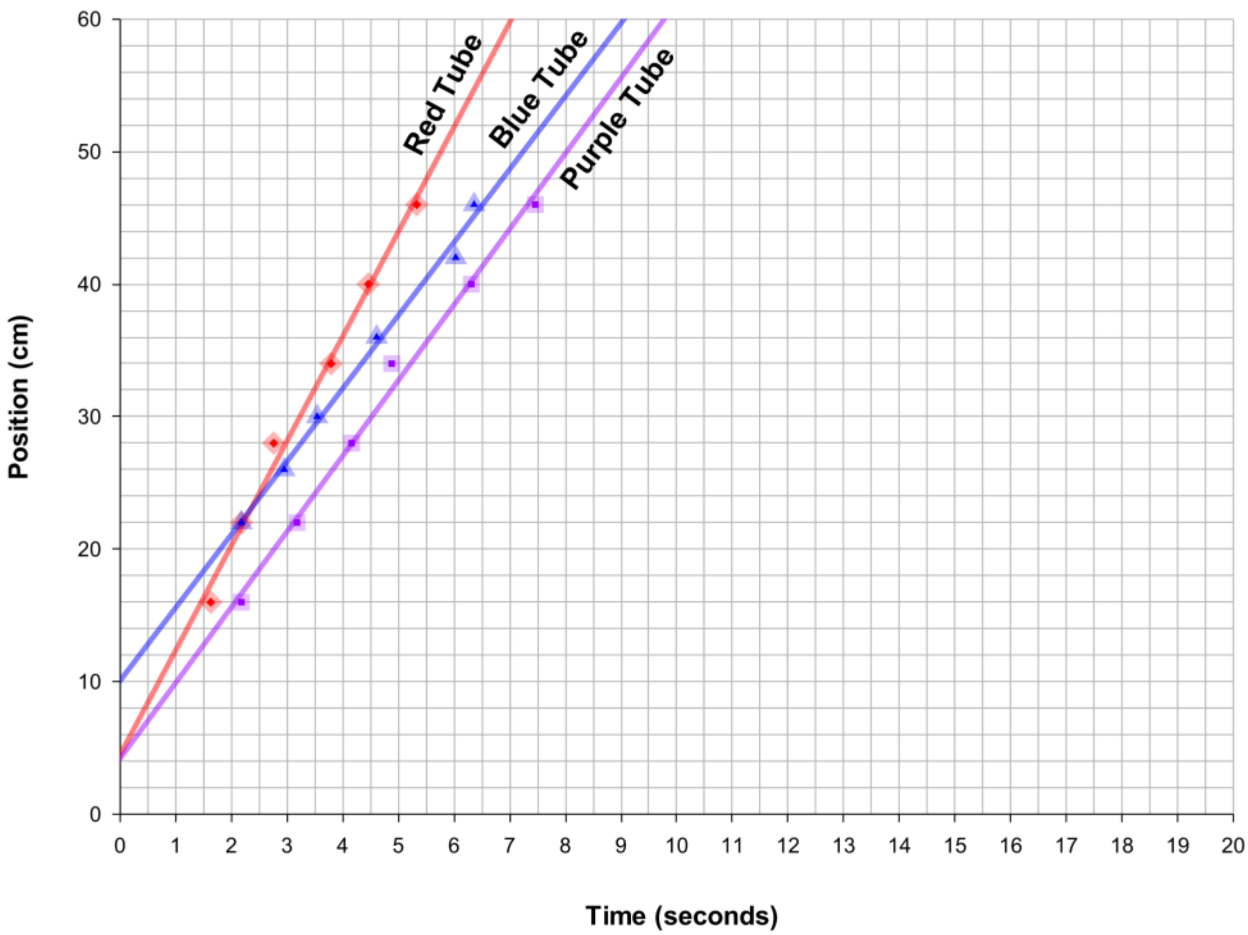


11. The data points from each tube follow <u>straight lines</u>. Straight lines have constant slope, and since the slope was the speed, the speed was constant.

Experiment 2: Part 1

Procedure

Sample Graph:



Analysis (typical results based on sample graph)

1. Answers will vary. Typical results might be:

   Red Tube y-intercept: 4.5 cm
   Blue Tube y-intercept: 10.1 cm
   Purple Tube y-intercept: 4.2 cm

   The y-intercepts should be close to the positions of the bottom ring on each tube (Table 1), but factors such as experimental technique and user delay may shift the intercept up/down slightly. The procedure is designed to minimize these errors, but some error will always be present.

2. Slope (speed) varies slightly depending on room temperature and the angle of the tube (it should be held perfectly vertical). Typical values might be:

Red Tube

First Point	
x_1 = 2.5 s	y_1 = 24 cm
Second Point	
x_2 = 6.0 s	y_2 = 52 cm
Run = x_2 - x_1	**Rise = y_2 - y_1**
3.5 s	28 cm
Slope = Rise/Run	
8.0 cm/s	

Blue Tube

First Point	
x_1 = 2.5 s	y_1 = 24 cm
Second Point	
x_2 = 6.5 s	y_2 = 46 cm
Run = x_2 - x_1	**Rise = y_2 - y_1**
4.0 s	22 cm
Slope = Rise/Run	
5.5 cm/s	

Purple Tube

First Point	
x_1 = 1.0 s	y_1 = 10 cm
Second Point	
x_2 = 8.0 s	y_2 = 50 cm
Run = x_2 - x_1	**Rise = y_2 - y_1**
7.0 s	40 cm
Slope = Rise/Run	
5.7 cm/s	

3. The y-intercept is the *initial position* of the bubble (position at time = 0).

4. The best-fit line for the red tube is steeper than that of the purple tube, because the red-colored oil has a lower viscosity, allowing the bubble to move faster.

5. The best-fit line for the blue tube has the same slope as the purple tube, because both contain oil of the same viscosity. The blue y-intercept is greater than the other two, because its starting position (bottom ring) is higher than on the other tubes.

Checkpoint:
Take a look at your students' graphs and note whether they have properly extrapolated their y-intercepts. (Students may try to force their data through the origin.) This gives the instructor an excellent opportunity to discuss the value of extrapolation from a graph (and the danger of unsubstantiated assumptions!)

7. Answers will vary

8. Answers will vary

9. Possible arguments: (1) The faster bubble had a greater slope. (2) The dimensional units of the slope are appropriate for speed. (3) Slope equals *rise* divided by *run*, or, for this experiment, change in position (distance) divided by change in time (elapsed time). *Distance* divided by *time* is the formula for speed.

10. Equations should use slope and y-intercept values from the previous questions:

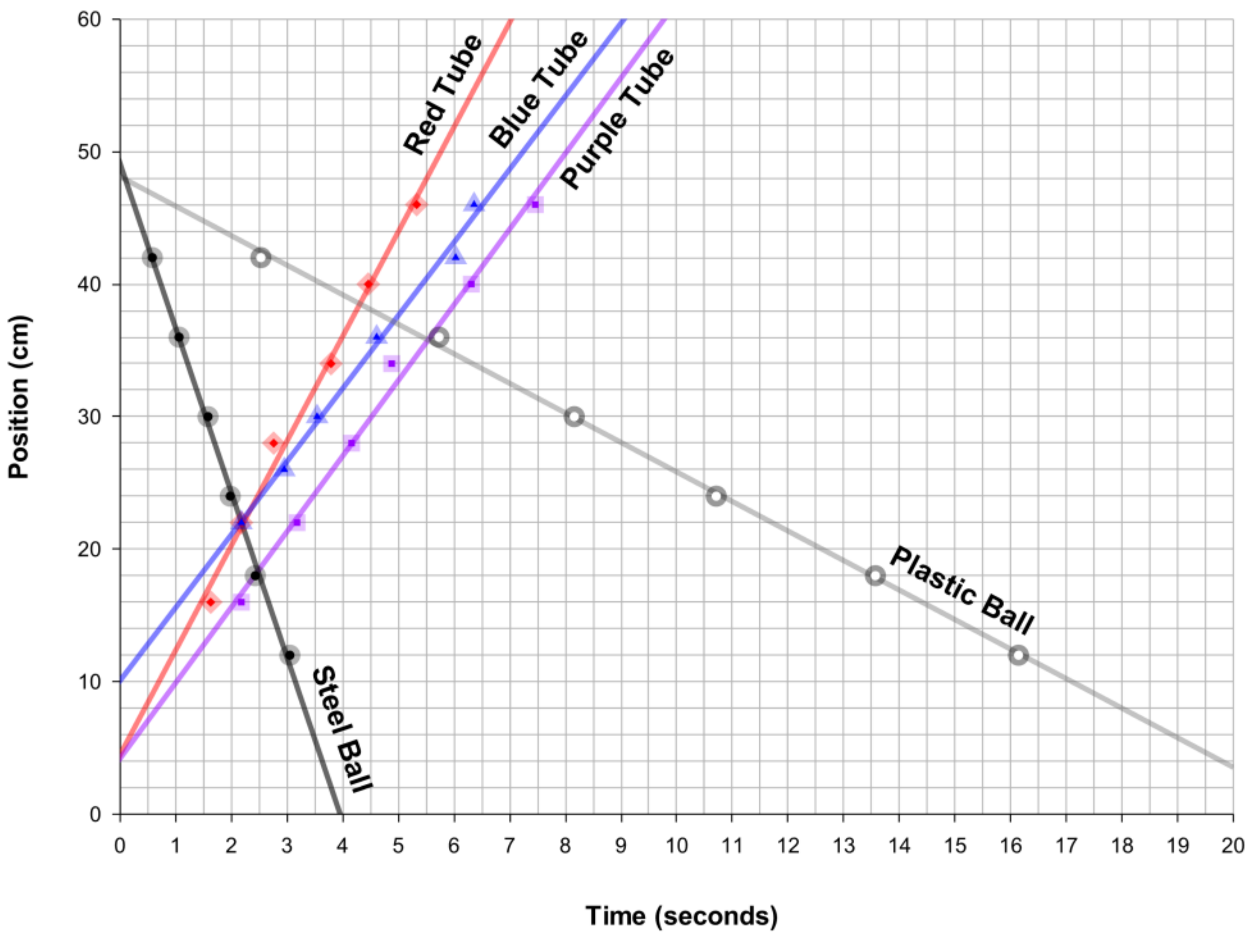
    Red Tube Equation: y = (8.0 cm/s) * t + 4.5 cm
    Blue Tube Equation: y = (5.5 cm/s) * t + 10.1 cm
    Purple Tube Equation: y = (5.7 cm/s) * t + 4.2 cm

11. position = velocity * time + initial position

Experiment 2: Part 2

Procedure

Sample Graph:



Analysis (typical results based on sample graph)

1. Both best-fit lines slope downward. The line for the steel ball is steeper than the plastic, because the steel ball weighs more and falls faster than the plastic ball. Both lines appear to have about the same y-intercept. This is because the time was started at the same point (top ring) for both balls.

2. Answers will vary. Typical results might be:

   Steel Ball y-intercept: 49.1 cm
   Plastic Ball y-intercept: 48.1 cm

   The y-intercepts should be close to each other and close to the position of the top ring (Table 1), but factors such as experimental technique and user delay may shift the intercept up/down slightly. The procedure is designed to minimize these errors, but some error will always be present.

3. Slope (speed) varies slightly depending on room temperature and the angle of the tube (it should be held perfectly vertical). Typical values might be:

Steel Ball

First Point	
x_1 = 0.5 s	y_1 = 43 cm
Second Point	
x_2 = 3.0 s	y_2 = 12 cm
Run = x_2 - x_1	**Rise = y_2 - y_1**
2.5 s	-31 cm
Slope = Rise/Run	
-12.4 cm/s	

Plastic Ball

First Point	
x_1 = 4.5 s	y_1 = 38 cm
Second Point	
x_2 = 18 s	y_2 = 8.0 cm
Run = x_2 - x_1	**Rise = y_2 - y_1**
13.5 s	-30 cm
Slope = Rise/Run	
-2.2 cm/s	

4. The negative slopes tell us that the balls are moving downward, because in the reference frame we chose, upward is positive.

5. Equations should use slope and y-intercept values from the previous questions:

   Steel Ball Equation: y = (-12.4 cm/s) * t + 49.1 cm
   Plastic Ball Equation: y = (-2.2 cm/s) * t + 48.1 cm

6. Answers will vary depending on room temperature, but typical values might be:

   Time: 5.5 s Position: 35.8 cm

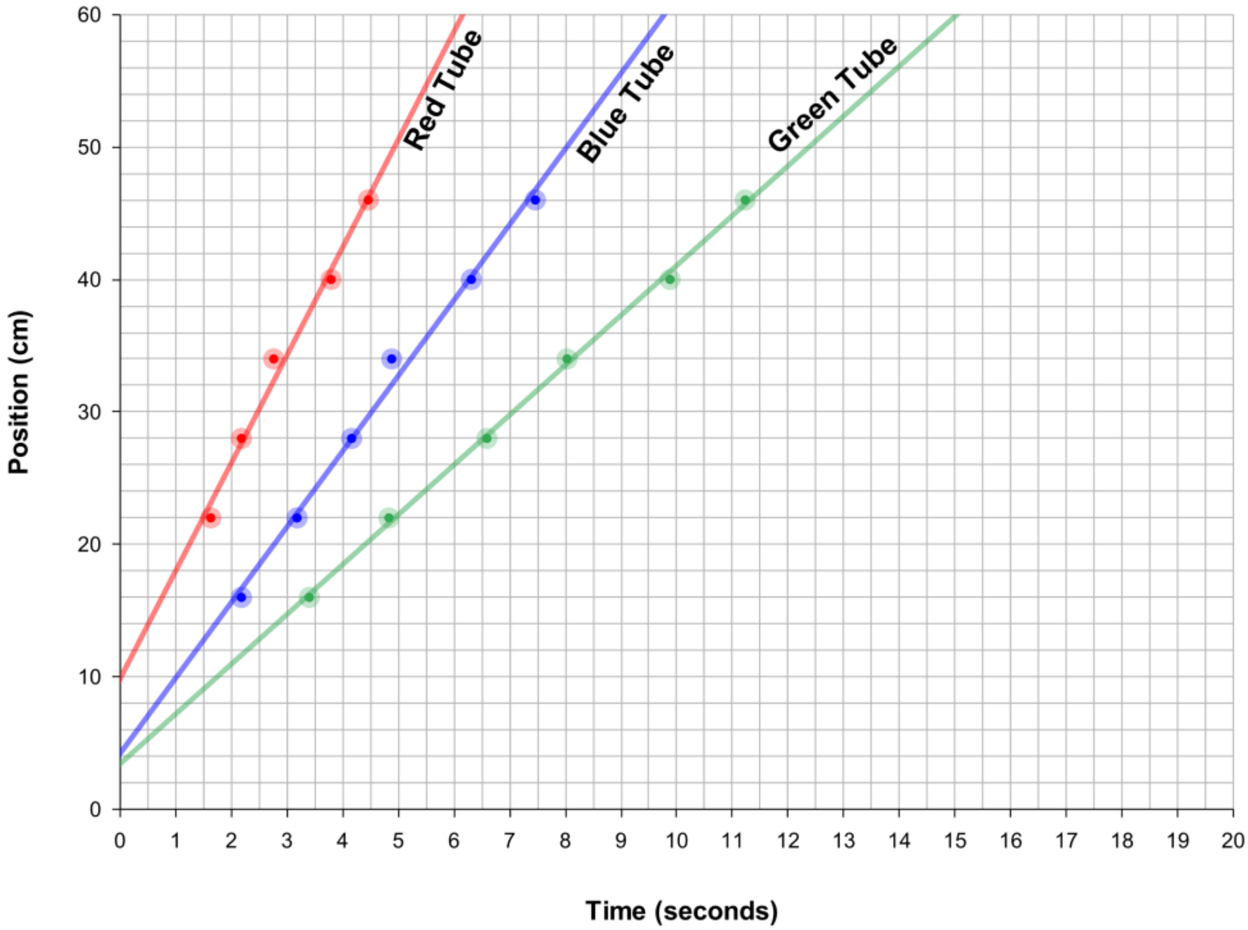
7. Answers will vary (sample answers found by solving equations algebraically)

8. Answers will vary

Experiment 3: Part 1

Procedure

Sample Graph:



Analysis (typical results based on sample graph)

1. Answers will vary. Typical results might be:

Red Tube y-intercept:	10 cm
Green Tube y-intercept:	3.4 cm
Blue Tube y-intercept:	4.2 cm

The y-intercepts should be close to the positions of the bottom ring on each tube (Table 1), but factors such as experimental technique and user delay may shift the intercept up/down slightly. The procedure is designed to minimize these errors, but some error will always be present.

2. Slope (speed) varies slightly depending on room temperature and the angle of the tube (it should be held perfectly vertical). Typical values might be:

Red Tube

First Point	
x_1 = 1.0 s	y_1 = 18 cm
Second Point	
x_2 = 5.0 s	y_2 = 50.5 cm
Run = x_2 - x_1	**Rise = y_2 - y_1**
4.0 s	32.5 cm
Slope = Rise/Run	
8.1 cm/s	

Green Tube

First Point	
x_1 = 2.0 s	y_1 = 11cm
Second Point	
x_2 = 10.5 s	y_2 = 43 cm
Run = x_2 - x_1	**Rise = y_2 - y_1**
8.5 s	32 cm
Slope = Rise/Run	
3.8 cm/s	

Blue Tube

First Point	
x_1 = 1.0 s	y_1 = 10 cm
Second Point	
x_2 = 8.0 s	y_2 = 50 cm
Run = x_2 - x_1	**Rise = y_2 - y_1**
7.0 s	40 cm
Slope = Rise/Run	
5.7 cm/s	

3. The y-intercept is the *initial position* of the bubble (position at time = 0).

4. The best-fit line for the blue tube is steeper than that of the green tube, because the blue-colored oil has a lower viscosity, allowing the bubble to move faster. The best-fit lines for the blue and green tubes have the same y-intercept because they had the same starting position (bottom ring).

5. The best-fit line for the red tube is steeper than the other two tubes, because the red-colored oil has a lower viscosity than the other two. The best-fit line for the red tube also has a greater y-intercept, because its starting position (bottom ring) is higher than on the other tubes.

Checkpoint:
Take a look at your students' graphs and note whether they have properly extrapolated their y-intercepts. (Students may try to force their data through the origin.) This gives the instructor an excellent opportunity to discuss the value of extrapolation from a graph (and the danger of unsubstantiated assumptions!)

7. Answers will vary

8. Answers will vary

9. Possible arguments: (1) The faster bubble had a greater slope. (2) The dimensional units of the slope are appropriate for speed. (3) Slope equals *rise* divided by *run*, or, for this experiment, change in position (distance) divided by change in time (elapsed time). *Distance* divided by *time* is the formula for speed.

10. Equations should use slope and y-intercept values from the previous questions:

Red Tube Equation:	y = (8.1 cm/s) * t + 10 cm
Green Tube Equation:	y = (3.8 cm/s) * t + 3.4 cm
Blue Tube Equation:	y = (5.7 cm/s) * t + 4.2 cm

11. position = velocity * time + initial position

Experiment 3: Part 2

Observations & Predictions

2. Answer should be close to the purple starting position or the red y-intercept. Typical result might be:

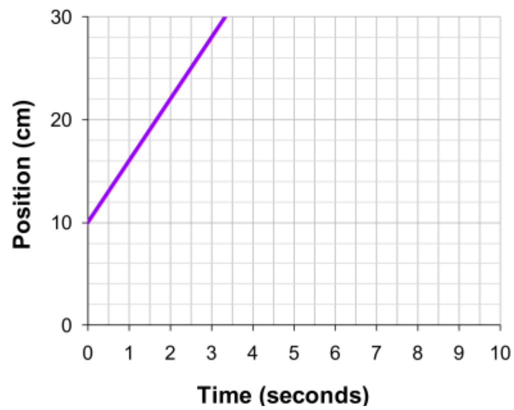
   Predicted Purple Tube y-intercept: 10 cm

3. Green Tube < Purple Tube < Red Tube

4. Answer should fall between red and green slopes. Typical result might be:

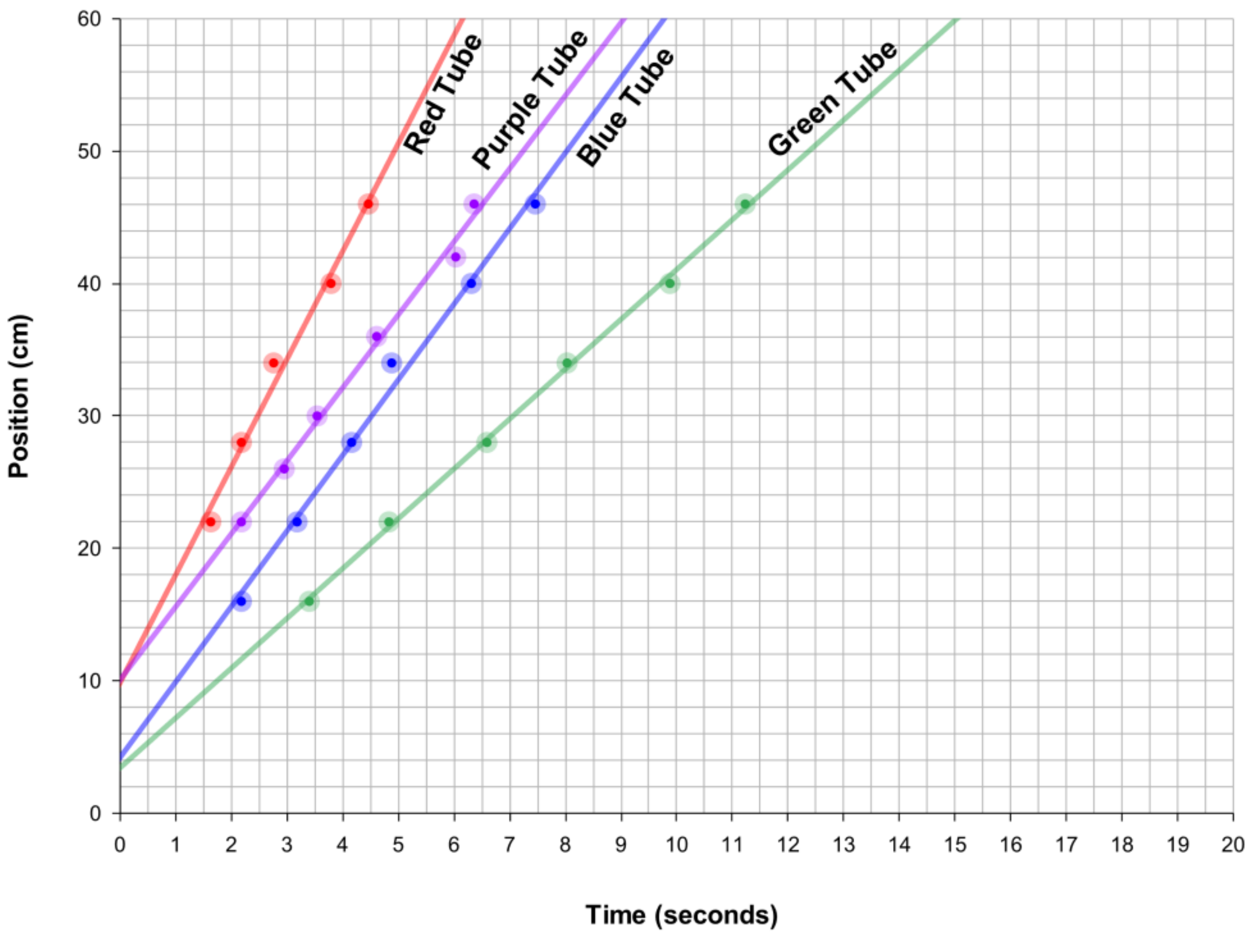
   Predicted Purple Tube Slope: 6 cm/s

5. Predicted line (small graph) should represent the predicted slope and y-intercept values.



Procedure

Sample Graph:



Analysis (typical results based on sample graph)

1. Answers will vary. Typical result might be:

   Purple Tube y-intercept: 10.1 cm

   The y-intercept should be close to the position of the bottom ring on the purple tube (Table 1) and/or close to the y-intercept for the red tube. Factors such as experimental technique and user delay may shift the intercept up/down slightly. The procedure is designed to minimize these errors, but some error will always be present.

2. Slope (speed) varies slightly depending on room temperature and the angle of the tube (it should be held perfectly vertical). Typical values might be:

Purple Tube

First Point	
x_1 = 0.5 s	y_1 = 13 cm
Second Point	
x_2 = 6.5 s	y_2 = 46 cm
Run = x_2 - x_1	**Rise = y_2 - y_1**
6.0 s	33 cm
Slope = Rise/Run	
5.5 cm/s	

3. Answers will vary

4. Answers will vary

5. The red and purple tubes should have the same y-intercept, because they have the same starting position.

6. Answers will vary

7. The bubbles in the blue and purple tubes should have the same speed, because they have the same slope.

8. Students should see that the bubbles in the blue and purple tubes rise together (same speed).

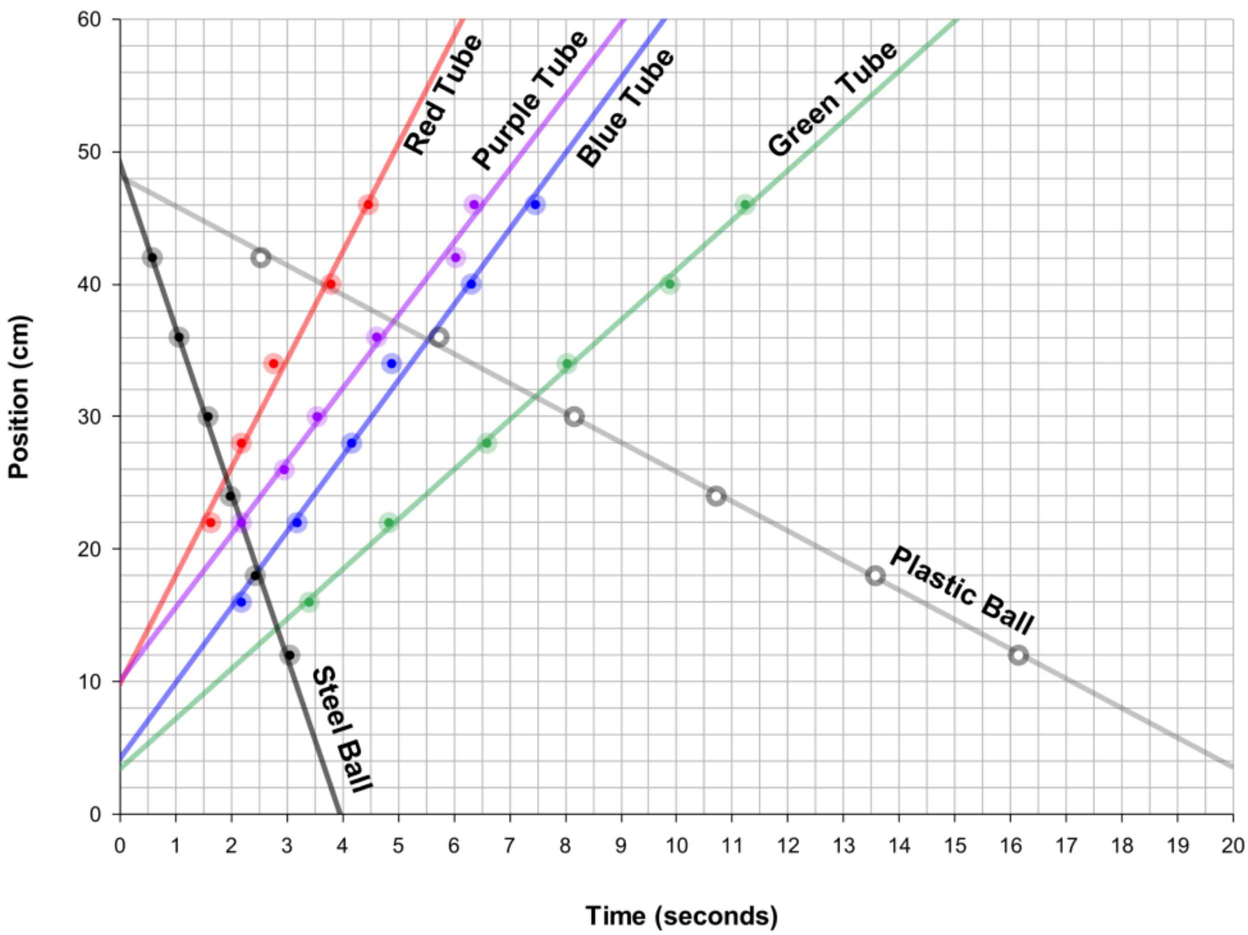
9. Equation should use slope and y-intercept values from the previous questions:

   Purple Tube Equation: y = (5.5 cm/s) * t + 10.1 cm

Experiment 3: Part 3

Procedure

Sample Graph:



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Second Point	
x_2 = 3.0 s	y_2 = 12 cm
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2.5 s	-31 cm
Slope = Rise/Run	
-12.4 cm/s	

Plastic Ball

First Point	
x_1 = 4.5 s	y_1 = 38 cm
Second Point	
x_2 = 18 s	y_2 = 8.0 cm
Run = x_2 - x_1	**Rise = y_2 - y_1**
13.5 s	-30 cm
Slope = Rise/Run	
-2.2 cm/s	

4. The negative slopes tell us that the balls are moving downward, because in the reference frame we chose, upward is positive.

5. Equations should use slope and y-intercept values from the previous questions:

   Steel Ball Equation: y = (-12.4 cm/s) * t + 49.1 cm
   Plastic Ball Equation: y = (-2.2 cm/s) * t + 48.1 cm

6. Answers will vary depending on room temperature, but typical values might be:

   Time: 4.9 s Position: 37.2 cm

7. Answers will vary (sample answers found by solving equations algebraically)

8. Answers will vary

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