Andrews University
PHYSICS ENTERPRISES

Viscosity of Oil Tube Set

Experiment Guide

Table of Contents

Designed by

TRANSPARENT DEVICES LLC
FOR SCIENCE EDUCATION

Manufactured by

Andrews University
PHYSICS ENTERPRISES

Introduction

Description

The Viscosity of Oil Tube Set consists of five transparent plastic tubes containing oils of different viscosities. Each tube also contains a white plastic ball and a chrome steel ball. The balls fall through the tube at a constant speed that depends on the oil viscosity, the angle at which the tube is inclined, and to some extent, the temperature. Colored caps identify the type of oil in each tube. Two O-rings may be slid to predetermined locations on the tubes to assist in timing the motion of the ball. The experiment may be done with either a stopwatch or a clock with a second hand.

Purpose

The Viscosity Tube Set provides students with practice setting up experiments and graphing data. When given the viscosities of three of the tubes, students can use the processes of interpolation and extrapolation to discover the viscosities of the other two tubes.

The tube viscosities in ISO viscosity grade numbers are as follows:

Red:	10
Blue:	32
Green:	46
Black:	22 (students find this experimentally)
Gray:	68 (students find this experimentally)

ISO viscosity grades are a measure of *kinematic viscosity* at 40°C and are expressed in units of centistokes (1 cSt = 1 mm^2/s).

Other Experiments

Students may be challenged to predict the effect of temperature or angle on the travel time of the balls, and to design and conduct experiments to test their hypotheses.

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. 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.

Copyright Notice and Copy Permission

Experiment
Viscosity of Oil

Introduction

In this lab experiment, you will use tubes filled with petroleum-based oils to explore the concept of viscosity. You will learn how graphs can organize experimental data and provide additional insights through the use of graphical interpolation and extrapolation.

Viscosity may be measured using a variety of units. The units used in this experiment are assigned by the International Standards Organization (ISO). They are termed ISO viscosity grade numbers. On this scale, the viscosities of the oil in each tube are as follows:

Red:	10
Blue:	32
Green:	46
Black:	to be determined
Gray:	to be determined

You will graph time vs. viscosity for the red, blue, and green tubes. Finally, using the process of interpolation or extrapolation, you will estimate the viscosity of the oil in the black and gray tubes. These values are not provided, as it is your job to determine their viscosities.

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

- 5 tubes with different colored end-caps
- Magnet
- Stopwatch (preferred) or a clock with sweep-style second hand (not the ticking kind)
- Metric ruler

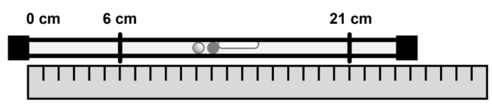
Procedure

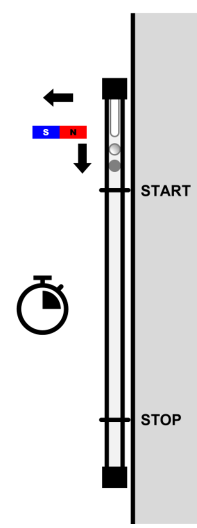
A well-planned experiment shows how one variable (the *independent* or *control* variable) affects another variable (the *dependent* variable). Anything else that might possibly vary must not be allowed to. In this experiment, that means you should:

- Hold the tubes exactly vertical every time.
- Ensure the tubes remain at the same temperature.
  (Hold the tubes by the caps to avoid warming them with your hands.)
- The ball should travel the same distance every time.

Working with a partner, follow the instructions for each of the five tubes. The tubes are color-coded to indicate the type of oil they contain. You will measure the time it takes for the white ball to travel 15 cm through the oil and record the time in the table on page 6. If time permits, repeat the measurement several times and record the average (repeated time measurements in the “Notes” column and average time in the “Time” column).

1. Use a metric ruler to position the two O-rings 6 cm and 21 cm from the end of the tube (measured from the edge of the cap). The 6 cm O-ring should be on the end closest to the white ball as shown, and the two rings should be 15 cm apart.





2. Hold the tube vertically against a wall, and use a magnet to hold both balls at the top of the tube. (The white plastic ball should be on top of the metal ball.)
3. With your lab partner watching the clock (not the tube), pull the magnet away to release the balls.
4. As the bottom of the white ball comes even with the first O-ring, say “START.” Your partner should start the stopwatch (or note the position of the second hand on the clock).
5. As the bottom of the white ball comes even with the second O-ring, say “STOP.” Your partner will stop the stopwatch (or note the position of the second hand on the clock).
6. Record the time it took for the white ball to travel the distance between the two O-rings. If you measured the time with a clock, record the difference of the two clock readings.

Repeat these steps for each of the 5 tubes.

Graphing and Analysis of Results

1. Plot the data points for the red, blue, and green tubes. Make the points small and clear; then circle them neatly. (Your instructor may give different instructions on how to mark them.)

2. Sketch a best-fit line. This line may be straight or a smooth curve, as appropriate, but it should follow the pattern of the data.

3. Predict the viscosity of the oil in the black tube:

    a. On the vertical axis of the graph, locate the time you recorded for the black tube.

    b. Trace a line horizontally to the right until you reach the best-fit line.

    c. Trace a line straight down to the horizontal axis and record the viscosity at this point.

    This is your prediction of the viscosity in the black tube. When we make a prediction by examining a graph *between* two data points, the process is called *interpolation*.

4. Predict the viscosity of the oil in the gray tube:

    a. Extend the best-fit line farther to the right (beyond the data points). Without additional points to guide you, this will be an educated guess for where the line should go.

    b. On the vertical axis of the graph, locate the time you recorded for the gray tube.

    c. Trace a line horizontally to the right until you reach the best-fit line.

    d. Trace a line straight down to the horizontal axis and record the viscosity at this point.

    This is your prediction of the viscosity in the gray tube. When we make a prediction by examining a graph in a region that is *not between* two data points, the process is called *extrapolation*.

Extended Experiment: Measure the Steel Ball

1. Watch how the two balls fall. Describe and compare the motion of each ball.

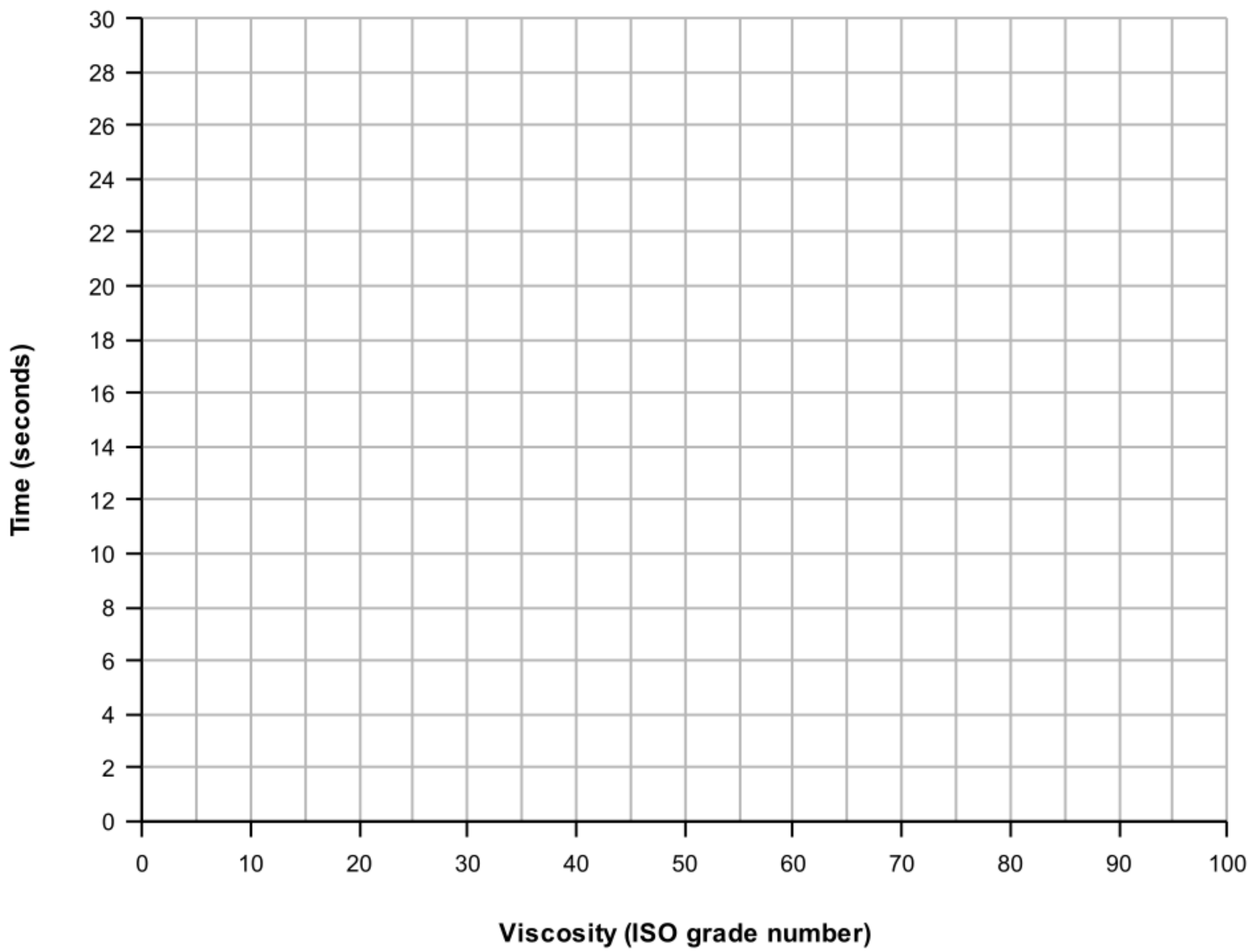
2. Collect and plot data for the steel ball in all five tubes. Use the viscosities you previously determined for the black and gray tubes. Plot the data on the same graph as before. You may want to use a different color or symbol for the new data.

3. Sketch a best-fit line. This line may be straight or a smooth curve, as appropriate, but it should follow the pattern of the data.

4. How does the pattern of the data compare to that of the plastic ball? Is the trend linear or does it follow some other pattern?

5. What factors do you think contribute to the differences in the two graphs?

Color	Viscosity	Plastic Time, t_P (s)	Steel Time, t_S (s)	Notes
Red	10			
Blue	32			
Green	46			
Black				
Gray				



Further Investigations

Effect of Temperature on Viscosity

Lubricating oils work by creating a film between moving surfaces, preventing them from making direct contact and reducing friction and wear. The oil must be viscous enough that it won't flow too quickly, but not so much that friction within the oil wastes energy. Oil viscosity changes with temperature, requiring different oils to be used in extreme temperature conditions, such as in the Arctic or the tropics.

Design an experiment to plot the effect of temperature on the fall time of a ball in oil. Keep the following considerations in mind as you make your plans:

- The tubes should not be exposed to extreme conditions. They can be damaged by both excessive heat and cold. Do not place the tubes where you would not be willing to put your hand for a significant time. Specifically, do not expose the tubes to temperatures below 0°C or above 45°C.

- How are you going to heat or cool the oil? The tubes should not be placed in water, and should not be left unattended, in order to avoid making them too hot or too cold. Perhaps you might use a hair dryer (while holding the tube to monitor temperature) or take it outside when the temperature varies between 0°C and 45°C.

- Consider how you are going to measure the oil temperature and how long you need to leave it in an area before it reaches the ambient temperature.

- How will you maintain the temperature while timing the ball. Perhaps you could put the tube in a refrigerator to chill it, but how do you keep it cool while timing the ball?

- Recall that there should only be two variables, temperature and time. Thus, you should not vary the distance, the kind of tube, the angle, or anything other than the temperature that might affect the time.

Get approval from your teacher before beginning the experiment. Present your results as a graph. After making such a graph, how could you use the tube, together with a stopwatch and the graph, to measure the temperature in the room or outside?

Relationship between Time and Distance

Design an experiment to show the relationship between distance and fall time for a ball in oil. Since time and distance are the only variables involved, you should not change the kind of tube, the angle, the temperature, or anything other than the distance that might affect the time.

1. Display your data on a graph, putting time on the horizontal axis and distance on the vertical axis (even though it might seem more appropriate to do it the other way).
2. Do your data points fall approximately on a straight line?
3. Use a straightedge to draw a best fit line for the data.
4. Calculate the slope of this line. (Don't count squares to find rise and run. Instead, read the coordinates of two points on the line and find the change in y-coordinates divided by the change in x-coordinates.)
5. What is the meaning of the answer you obtained? (Not the mathematical meaning, but the meaning for what happened in the experiment.)

Relationship between Time and Angle

Design an experiment to show how the angle of the tube affects the time the ball takes to travel a known distance. Since time and angle are the only variables involved, you should not change the kind of tube, the distance, the temperature, or anything other than the angle that might affect the time.

1. Display your data on a graph, putting angle on the horizontal axis and time on the vertical axis.
2. Create a new plot of time vs 1/sin(angle).
3. Do your data points fall approximately on a straight line or a smooth curve?
   If so, draw a best fit line (or curve) for the data in each graph.
4. What kind of relationship do the graphs show (linear, inverse, exponential, etc.)?
5. Does the data demonstrate the same trend for all of the data or is there a region that behaves differently?

Viscosity Conversions

The viscosity of the oils used in these tubes have been given in units of ISO viscosity grade numbers (common for many machine/industrial oils). The viscosity of motor oil in the US is more often specified in units called SAE (Society of Automotive Engineers) crankcase oil viscosity grade numbers. These grades are often called “weights” of oils in everyday language, although the measurements have nothing to do with weight.

The following table lists the viscosities of various motor oils, given on both the SAE and ISO scales (some ISO viscosities are not given, for use in a later question):

SAE	ISO
5	?
10	46
20	?
30	105
40	146
50	223

Plot these data pairs on a graph, skipping the points with question marks. Draw a best fit line, which should be a smooth curve. Use your graph to make the following predictions:

1. What would be the ISO grade number of SAE 20 motor oil?
   What process did you use find this value, interpolation or extrapolation?

2. What would be the ISO grade number of SAE 5 motor oil?
   What process did you use find this value, interpolation or extrapolation?

3. In which of the two answers do you have more confidence? Why?

Answer Key

Typical Results & Answers

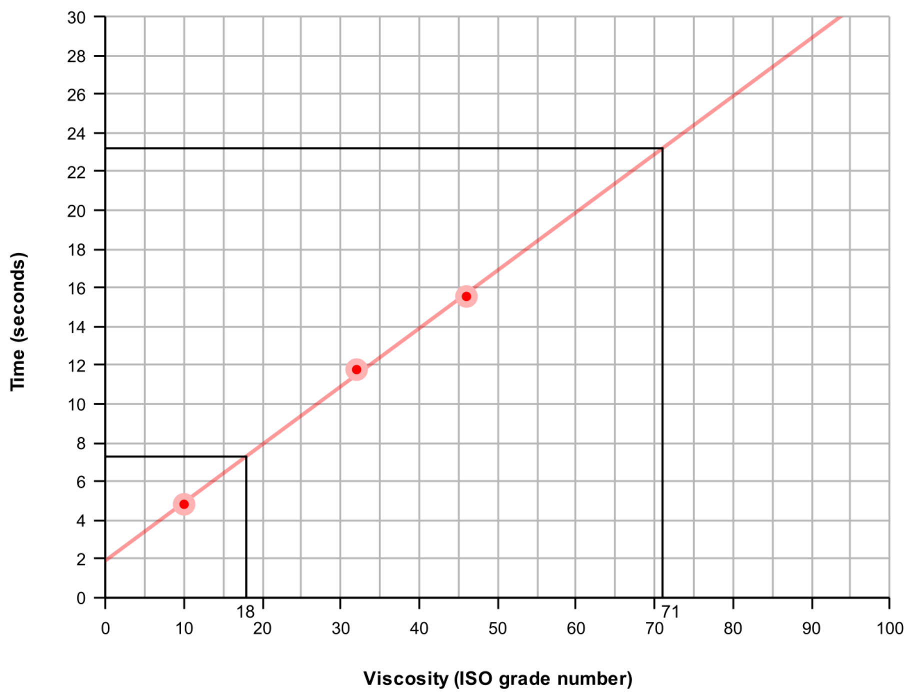
Viscosity of Oil Experiment

The graph below shows typical results for this experiment when performed carefully. Additional marks have been added for each question. These results were obtained at room temperature. Higher temperatures decrease viscosity and shorten the fall time (greater speed). Lower temperatures have the opposite effect.

Students' results may vary somewhat from those below, but should be in agreement with their own graphs.

Analysis

1. Sample Graph:



2. See graph above

3. Answers may vary

   Black Tube Viscosity (actual) = **22**

   Black Tube Viscosity (from sample graph) = **18**

4. Answers may vary

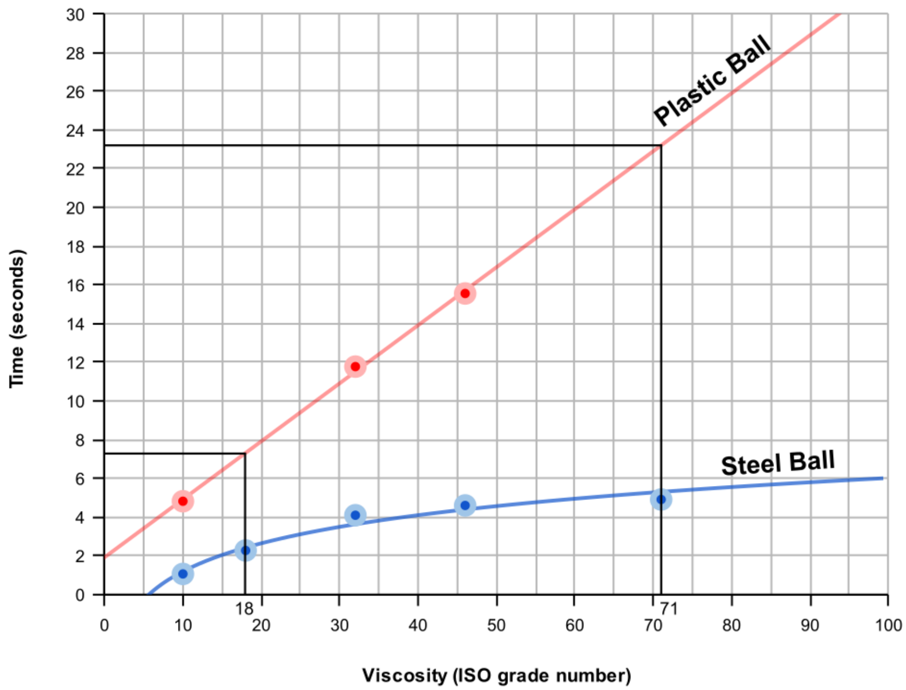
   Gray Tube Viscosity (actual) = **68**

   Gray Tube Viscosity (from sample graph) = **71**

Extended Experiment: Measure the Steel Ball

1. Students should see that the steel ball falls much faster and seems to wobble back and forth as it falls (turbulence).

2. Sample Graph:



3. See graph above

4. The data from the metal ball does not appear linear. The slope decreases with increasing viscosity. It may be a logarithmic relationship as the trendline suggests, but more data would be needed to confirm this hypothesis.

5. The fluid turbulence (wobbling) seen with the faster moving steel ball may cause nonlinear behavior in the viscosity relationship. The linear trend seen with the plastic ball may indicate that such a relationship only exists at low speeds. In fact, the data from the steel ball in the higher viscosity (lower speed) tubes appear much more linear, possibly supporting the low speed-linear relationship hypothesis.

   Note: Fluid dynamic equations show that the relationship between the velocity and viscosity in this experiment is quite complex. The study of these equations is beyond the scope of this experiment, but the results seen here demonstrate the effect.

Andrews University
PHYSICS ENTERPRISES