Andrews University
PHYSICS ENTERPRISES

Density Identification Set

Experiment Guide

Table of Contents

Designed by

TRANSPARENT DEVICES LLC
FOR SCIENCE EDUCATION

Manufactured by

Andrews University
PHYSICS ENTERPRISES

Introduction

Description

This set contains 16 different material samples. Students are challenged to identify the materials by measuring density. Some materials are easily distinguishable while others have nearly identical densities. This leads to discussions of precision, accuracy, and measurement uncertainty.

Density is found by measuring the mass and volume of each material. A balance will be needed to find the mass. Volume may be found by submersion in water (displacement method) or by measuring the samples with a metric ruler or calipers (dimensional method). Worksheets are provided for each method.

Other Experiments and Demonstrations

The set can be used to test students' abilities to properly find the dimensions, volume, and mass of a solid. These samples can also serve as examples of different materials used in industry. Some are familiar, while others are not commonly seen or recognized. A short description of each substance and its role in industry is provided in the Appendix.

Care and Use

Some samples in the set are heavy and can break the graduated cylinder if dropped in. Place an eraser or similar object at the bottom of the cylinder to cushion the sample's fall. Tilt the graduated cylinder to let the sample slide in. See Figures 1-3 in the instructions for more details.

The wood sample is prone to absorbing water during submersion and moisture from the air. This can affect its density. The sample has been treated with wax to make it water resistant, but the treatment may wear off over time, especially if submerged in water. If you decide to use this sample with the displacement method, measure the mass before placing it in water and do not leave it in the water long. Remove promptly, shake off excess water, and gently pat dry (avoid wiping). Allow it to thoroughly dry out before using again.

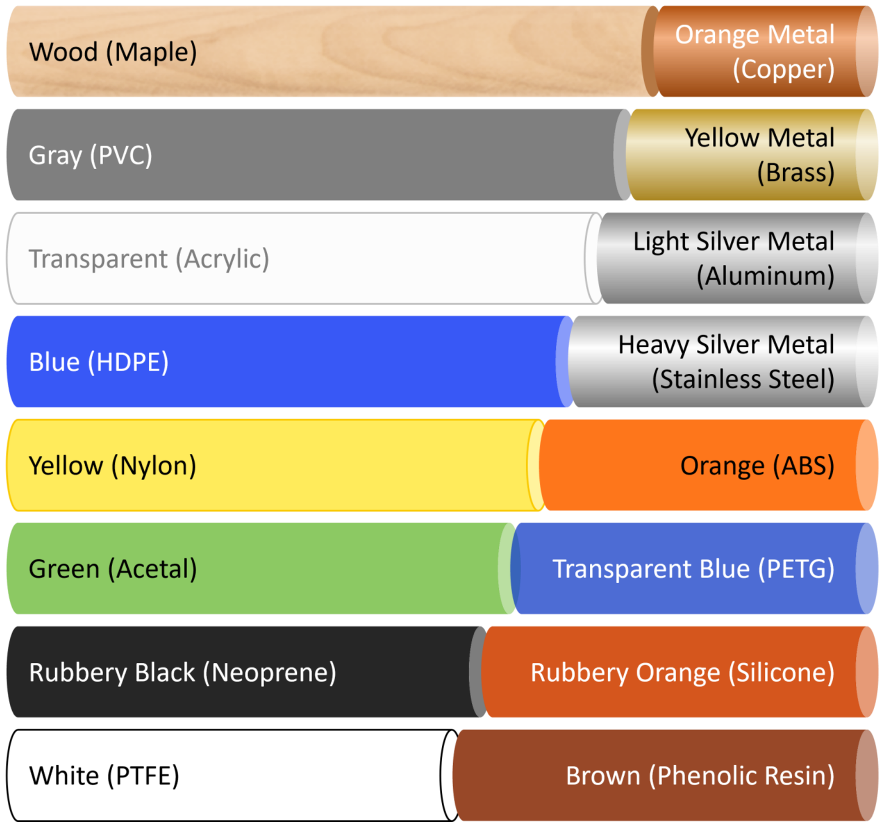
Safety

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 set contains small objects and thus is not suitable for use with young children. This product is not a toy. It is for educational and laboratory use only. It is not intended for use by students age 12 years and under without competent adult supervision.

Included Equipment

- 16 Density samples (see below) - specifications listed in the appendix



Additional Equipment Needed

- Balance or Scale
- Calculator
- Equipment to Measure Volume (choose one):
    - Metric Ruler or Calipers
    - 100 mL Graduated Cylinder, Water, Small Eraser (or similar), Pencil (sharpened or mechanical), and Pipette (optional)

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Density Identification

Introduction

A property of a material is an attribute that describes it, such as color, hardness, or density. Density is a numerical property that quantifies the space an object occupies (volume) compared to how much matter is in the object (mass). It is calculated by dividing the sample's mass by its volume.

In this experiment, you will measure unknown samples, calculate their densities, and identify the material of each.

Equipment

- Balance or Scale
- Calculator
- Equipment to Measure Volume (choose one):
  - Metric Ruler or Calipers
  - 100 mL Graduated Cylinder, Water, Small Eraser (or similar), Pencil (sharpened or mechanical), and Pipette (optional)

Procedure

For each sample, record the following data in the table on your worksheet.

1. Determine the mass (grams) of the sample using a balance or scale. Record the mass on your worksheet.
2. Using the method approved by your instructor, determine the volume (cm^3) of the sample. Be sure to show your calculations.

   Dimensional Method

   a. Use a metric ruler or calipers to measure the diameter and length of the sample (cm) . Record the measurements on your worksheet.

      Tip: If the sample is not perfectly round, record the average of its largest and smallest diameters. This will be a close approximation.

   b. Use the equation below to determine the volume:

      $$V_{sample} = \pi r^2 L$$

      where V_{sample} is the volume, r is the radius, and L is the length. Recall that the radius is half the diameter (r=D/2).

Displacement Method

a. Some samples are heavy and may break the glass when dropped in. To prevent this, place a small eraser (or similar object) at the bottom of the cylinder to act as a cushion (see Figure 1). The eraser does not affect the final measurement because it is the change in volume that matters.

b. Fill the 100 mL graduated cylinder about half-way with water and carefully record the volume, V_1 (cm^3), as shown in Figure 1. (Note that 1 mL = 1 cm^3.)

Tip: Use a pipette to precisely adjust V_1 to a whole number measurement (easier to read).

c. Tilt the graduated cylinder and carefully slide the sample in. Do not allow water to splash out.

IMPORTANT: Do NOT leave the wood sample in the water long. Remove promptly, shake off water, and gently pat dry.

d. Record the volume, V_2 (cm^3), as shown in Figure 2. If the sample floats, use a sharp pencil to keep it submerged it as shown in Figure 3.

e. Use the equation below to determine the sample volume (change in total volume):

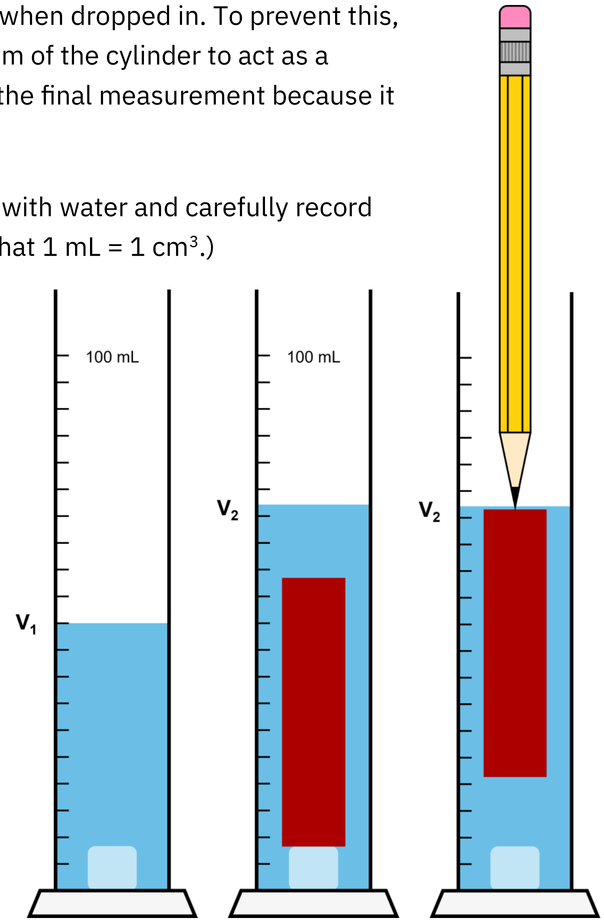

Figure 1 **Figure 2** **Figure 3**

$$V_{sample} = V_2 - V_1$$

where V_{sample} is the volume of the sample, V_1 is the volume of the water before inserting the sample, and V_2 is the total volume of the water and sample.

3. Use the equation below to calculate the density of your sample (both volume methods):

$$\rho = \frac{m}{V_{sample}}$$

where ρ is the density of the sample, m is the mass in grams, and V_{sample} is the sample volume in cm^3. Remember to show your calculations and use the proper units. Record the results on your worksheet.

4. Compare your density with the density table. Identify the material and record it on your worksheet.

Tip: It may help if you wait to identify the materials until all the densities have been found. Some materials have very similar densities and it may help to compare your experimental densities with each other when identifying the materials.

Analysis

1. How well did your calculated densities compare to the ones you identified in the Density Table?

2. How certain can you be that you have correctly identified the materials?

3. In science, it is common for experiment data to disagree with expected result. When your results differ from what was expected, it is important to identify the cause of this discrepancy. This is helpful for improving experimental techniques and identifying sources of error. Sometimes it even leads to new discoveries!

   Compare the materials you identified with the correct materials and expected densities on the Student Answer Key worksheet. If you correctly identified the material, write “correct”. If you were wrong, comment on the factors that might have caused this discrepancy.

4. How would you determine the average density of a human, and what difficulties might you encounter?

Density Reference Table

Use the following table to identify the materials of your density samples. Keep in mind that there may be natural variation in the actual densities, particularly in the case of wood (up to 0.1 g/cm^3). The values given in this table are averages of the possible densities for each material.

Many of the materials in this table are not included in your set. They are shown here for comparison only. The samples in your set are all different materials (no duplicates).

Material	Density (g/cm^3)
Balsa Wood	0.160
Cork Wood	0.240
Pine Wood	0.455
Maple Wood	0.690
Polypropylene	0.916
Low-Density Polyethylene (LDPE)	0.921
High-Density Polyethylene (HDPE)	0.944
Acrylonitrile Butadiene Styrene (ABS)	1.07
Polyamide (Nylon)	1.15
Acrylic	1.18
Polycarbonate	1.20
Polyethylene Terephthalate Glycol (PETG)	1.27
Polylactic Acid (PLA)	1.30
Phenolic Composite	1.36

Material	Density (g/cm^3)
Polyvinyl Chloride (PVC)	1.39
Polychloroprene (Neoprene)	1.42
Polyoxymethylene (Acetal)	1.43
Polysiloxane (Silicone)	1.55
Magnesium	1.74
Polytetrafluoroethylene (PTFE)	2.17
Aluminum	2.70
Titanium	4.51
Tin	7.29
Stainless Steel	7.81
Brass	8.50
Copper	8.96
Lead	11.3
Gold	19.3

Density Worksheet: Dimensional Method

Name: ______________________

This chart assumes the use of a ruler or calipers and the formulas for the volume of a cylinder to determine the density of each sample. The samples in your set are all different materials (no duplicates).

Sample	Diameter (cm)	Length (cm)	Volume (cm^3)	Mass (g)	Density (g/cm^3)	Material Name
Wood						
Gray						
Transparent						
Blue						
Yellow						
Green						
Rubbery Black						
White						
Brown						
Rubbery Orange						
Transparent Blue						
Orange						
Heavy Silver Metal						
Light Silver Metal						
Yellow Metal						
Orange Metal						

Density Worksheet: Displacement Method

Name: ______________________

This chart assumes the use of displacement (change in volume) to determine the density of each sample. The samples in your set are all different materials (no duplicates).

Sample	V_1 (cm^3)	V_2 (cm^3)	V_{sample} (cm^3)	Mass (g)	Density (g/cm^3)	Material Name
Wood						
Gray						
Transparent						
Blue						
Yellow						
Green						
Rubbery Black						
White						
Brown						
Rubbery Orange						
Transparent Blue						
Orange						
Heavy Silver Metal						
Light Silver Metal						
Yellow Metal						
Orange Metal						

Density Worksheet: Student Answer Key

Name: ______________________

Do NOT use this worksheet until you have finished identifying the materials. Use this table to check your answers and comment on sources of error.

Sample	Expected Density (g/cm^3)	Material Name	Correct Result / Sources of Error
Wood	0.690	Maple Wood	
Gray	1.39	PVC	
Transparent	1.18	Acrylic	
Blue	0.944	HDPE	
Yellow	1.15	Nylon	
Green	1.43	Acetal	
Rubbery Black	1.42	Neoprene	
White	2.17	PTFE	
Brown	1.36	Phenolic	
Rubbery Orange	1.55	Silicone	
Transparent Blue	1.27	PETG	
Orange	1.07	ABS	
Heavy Silver Metal	7.81	Stainless Steel	
Light Silver Metal	2.70	Aluminum	
Yellow Metal	8.50	Brass	
Orange Metal	8.96	Copper	

Answer Key

Typical Results & Answers

The following answer key includes typical data for both methods described in the instructions. The actual densities of the samples may be less consistent than implied by the number of significant figures given, due to natural variance in some of the materials. If a sample is not perfectly round, students may record the average of its largest and smallest diameter. The displacement method is inherently less accurate than the dimensional method, but accurate results can be achieved if greater care is taken when measuring volume.

Density Worksheet: Dimensional Method Answers

The following measurements were taken with a digital balance and calipers. Notice that the experimental density for the transparent sample suggests it is polycarbonate, even though the material is acrylic. In this case, the discrepancy is due to natural variation in the material density. Both methods found the same result.

Sample	Diameter (cm)	Length (cm)	Volume (cm^3)	Mass (g)	Density (g/cm^3)	Material Name
Wood	1.59	11.03	21.90	14.3	0.65	Maple Wood
Gray	1.61	10.50	21.38	29.3	1.37	PVC
Transparent	1.56	10.00	19.11	23.0	1.20	~~Polycarbonate~~ Acrylic
Blue	1.62	9.51	19.60	18.6	0.95	HDPE
Yellow	1.59	9.04	17.95	20.5	1.14	Nylon
Green	1.59	8.52	16.92	24.2	1.43	Acetal
Rubbery Black	1.52	8.01	14.53	20.5	1.41	Neoprene
White	1.59	7.54	14.97	32.3	2.16	PTFE
Brown	1.59	7.01	13.92	18.7	1.34	Phenolic
Rubbery Orange	1.55	6.45	12.17	19.0	1.56	Silicone
Transparent Blue	1.59	6.05	12.01	15.0	1.25	PETG
Orange	1.59	5.52	10.96	11.4	1.04	ABS
Heavy Silver Metal	1.59	4.97	9.87	77.2	7.82	Stainless Steel
Light Silver Metal	1.59	4.53	8.99	24.2	2.69	Aluminum
Brass	1.58	4.03	7.90	67.1	8.49	Brass
Copper	1.59	3.48	6.91	61.5	8.90	Copper

Density Worksheet: Displacement Method Answers

The following measurements were taken with a digital balance and a 100 mL graduated cylinder. Notice that the experimental density for the transparent sample suggests it is polycarbonate, even though the material is acrylic. In this case, the discrepancy is due to natural variation in the material density. Both methods found the same result.

Sample	V_1 (cm^3)	V_2 (cm^3)	V_{sample} (cm^3)	Mass (g)	Density (g/cm^3)	Material Name
Wood	64.0	86.0	22.0	14.7	0.67	Maple Wood
Gray	70.0	91.3	21.3	29.3	1.38	PVC
Transparent	70.0	89.0	19.0	23.0	1.21	~~Polycarbonate~~ Acrylic
Blue	65.0	84.8	19.8	18.6	0.94	HDPE
Yellow	75.0	93.0	18.0	20.6	1.14	Nylon
Green	70.0	86.9	16.9	24.2	1.43	Acetal
Rubbery Black	63.0	77.6	14.6	20.5	1.40	Neoprene
White	71.0	85.8	14.8	32.3	2.18	PTFE
Brown	65.0	79.0	14.0	18.8	1.34	Phenolic
Rubbery Orange	72.0	84.5	12.5	19.0	1.52	Silicone
Transparent Blue	70.0	81.9	11.9	15.0	1.26	PETG
Orange	68.0	79.0	11.0	11.4	1.03	ABS
Heavy Silver Metal	70.0	79.9	9.9	77.2	7.80	Stainless Steel
Light Silver Metal	65.0	73.8	8.8	24.1	2.74	Aluminum
Brass	65.0	73.0	8.0	67.1	8.39	Brass
Copper	67.0	73.9	6.9	61.5	8.91	Copper

Analysis

1. How well did your calculated densities compare to the ones you identified in the Density Table?

   Answers will vary

2. How certain can you be that you have correctly identified the materials?

   Answers will vary

3. In science, it is common for experiment data to disagree with expected result. When your results differ from what was expected, it is important to identify the cause of this discrepancy. This is helpful for improving experimental techniques and identifying sources of error. Sometimes it even leads to new discoveries!

   Compare the materials you identified with the correct materials and expected densities on the Student Answer Key worksheet. If you correctly identified the material, write “correct”. If you were wrong, comment on the factors that might have caused this discrepancy.

   Possible Sources of Error: (students will answer on the Student Answer Key worksheet)

   - *Density naturally varies for some materials, especially wood.*
   - *Some materials may be subject to thermal expansion.*
   - *A large discrepancy may represent measurement errors.*
   - *Some discussion of the precision (uncertainty) of measurement devices is appropriate.*

   Measurement uncertainty makes it difficult to distinguish between substances with very similar densities. In these cases, students will have to use their discretion or rely on other physical properties.

4. How would you determine the average density of a human being, and what difficulties might you encounter?

   Use a balance to determine the person’s mass, then immerse them in water to find their volume. It would be difficult to do this in a large pool since the change in water level would be minute. Since a human is made of differing materials, it is important to note that this would only be an average density. Students would also notice that, depending the person, some would either “barely float” or “barely sink.” In other words, the density of a human is very close to that of water (1 g/cm^3).

Appendix

Material Information

Maple Wood

Maple, a common hardwood, is widespread across the Eastern United States. Maples are responsible for much of the bright red foliage seen in the autumn. The finer grades are valued for furniture, flooring, and finish carpentry, while the poorer grades are used for industrial purposes, such as shipping pallets. Some species are "tapped" to make maple syrup.

Wood is somewhat porous, and will soak up water, changing its density. The wood samples in this set have been treated with wax to close the pores at the surface and make them water-resistant. These samples have been selected to have nearly the same density, but wood, being a natural mixture of many substances, has variable properties. The water-proofing is not perfect and the samples should not be allowed to soak for long periods of time.

Polyvinyl Chloride (PVC)

This plastic is produced for a variety of purposes, including water pipes, chemical tanks, hardware items, etc. It is naturally colorless and transparent, but is commonly pigmented to make it more resistant to UV light, which has an adverse effect on many plastics. This sample is an opaque dark gray color.

Acrylic

This plastic is extremely transparent, and is used for windows, drinking glasses, and a wide variety of other items. It is naturally colorless.

High-Density Polyethylene (HDPE)

This plastic is known for its high strength relative to its density, and is commonly used in plastic bottles and other packaging products. It is commonly recycled, and is identified by the number "2" as its recycling symbol. HDPE is naturally translucent but can be produced in opaque colors. The sample in this set has been dyed blue.

Polyamide (Nylon)

Nylon is known as an "engineering plastic" due to its properties that allow for demanding applications, such as machine parts. It can withstand a wide range of temperatures. It is strong, and it has low coefficient of friction when in contact with steel and other metals. Nylon can also be drawn into fine fibers for use in textiles. Its natural color is white, but the sample in this set has been dyed yellow.

Polyoxymethylene (Acetal)

Acetal is another “engineering plastic”, with properties that allow its use in demanding applications, such as machine parts. It can withstand a wide range of temperatures. Acetal is a popular substitute for metal parts due its strength, low coefficient of friction, and ease of machining. Its natural color is white, but the sample in this set has been dyed green.

Polychloroprene (Neoprene)

This is a synthetic rubber produced from chloroprene. Due to neoprene’s resistance to oil, the sample in this set was produced for use in O-rings, which are primarily used as seals on circular joints. Neoprene is non-permeable to water and is also used in fabric for dry suits. Neoprene is a fairly tough and flexible material, which makes it ideal for transfer belts in car engines and machine tools.

Polytetrafluoroethylene (PTFE)

This polymer has a variety of interesting properties, including resistance to extreme temperatures, very low coefficient of friction, non-stick characteristics, and resistance to many chemicals. PTFE was originally developed by DuPont under the trademarked name, Teflon®.

The sample in this set is made from recycled PTFE, which has the same density, but is slightly weaker than “virgin” PTFE. The material is naturally white, however, recycled PTFE has occasional spots and discoloration from impurities and contaminants.

Phenolic

Phenolic is one of the earliest plastics discovered and is different from most in that it is thermosetting. Most other plastics, such as nylon, are thermoplastics—they can be repeatedly heated, shaped, and cooled to hold a new form. Thermosetting plastics, like phenolic, are formed at elevated temperatures, but during the forming process, undergo chemical changes that do not permit them to soften if heated again. Phenolic is hard but brittle and is normally reinforced to give it better properties. Fillers include wood fibers, glass fibers, fabric, or paper. The sample in this set is reinforced with paper. Phenolic is widely used as an insulator in electrical appliances.

Polysiloxane (Silicone)

Silicone is a synthetic polymer of siloxanes, a molecule of alternating silicon and oxygen atoms. It is hydrophobic, rubbery, resistant to heat, and has many industrial uses, including being used for molds, glue, sealant, and lubricants. The chemical bonds between the silicon and oxygen atoms are very stable, and thus not very reactive.

Polyethylene Terephthalate Glycol (PETG)

PETG plastic can be easily molded, and is commonly used in food and beverage containers. Due to the glycol molecule, this plastic has high impact resistance and can withstand high temperatures. The material is transparent when produced, but the sample in this set has been dyed blue.

Acrylonitrile Butadiene Styrene (ABS)

ABS is used in water pipes, Lego bricks, and 3D printer filament, among other things. It is amorphous and does not have a specific melting point, but begins softening at 105°C. Natural ABS will degrade from exposure to UV light. This material is naturally off-white, but the sample in this set has been dyed orange.

Stainless Steel

Steel is an alloy comprised of iron and carbon. While iron is a strong material, steel is significantly stronger. Stainless Steel includes additional elements, primarily chromium and nickel, that make it highly resistant to corrosion. Machining stainless steel is more challenging compared to other metals, but it is worth the added durability.

Aluminum

Aluminum is a popular material for many applications, because it is lightweight, abundant, and inexpensive. Although it is quite chemically active, the thin oxide coating that quickly forms on its surface is impervious to air or water. This protects it from further corrosion. The sample in this set is an alloy consisting primarily of aluminum with a small percentage of other elements, including magnesium, copper, chromium, and silicon.

Brass

Brass is a family of alloys comprised of copper and zinc. This particular brass alloy is approximately 60% copper and 40% zinc. It is highly ductile, which makes it malleable and easy to form. Brass is commonly used in locks, doorknobs and other hardware, as well as musical instruments.

Copper

Copper is an excellent conductor of heat and electricity, better than almost any other metal. It is easily formed into sheets or drawn into wires or tubes. Prior to 1982, U.S. pennies were comprised of 95% copper and 5% zinc. As of mid-1982, they are now made of a zinc core covered with a thin layer of copper, as zinc is a much cheaper metal than copper.

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