The Densities of Solids and Liquids

The density of a material may be defined as mass per unit volume. The units generally used for solids and liquids are g/mL, for gases g/L. The density values of some solids, liquids and gases near room temperature are listed below (Table 1).

Substance	Density at 20°C
air	1.29 g/L
ethanol	0.7893 g/mL
acetone	0.7899 g/mL
water	1.0000 g/mL (4°C)
methanol	0.7928 g/mL
octane	0.7028 g/mL
glycerol	1.2613 g/mL
mercury	13.5939 g/mL

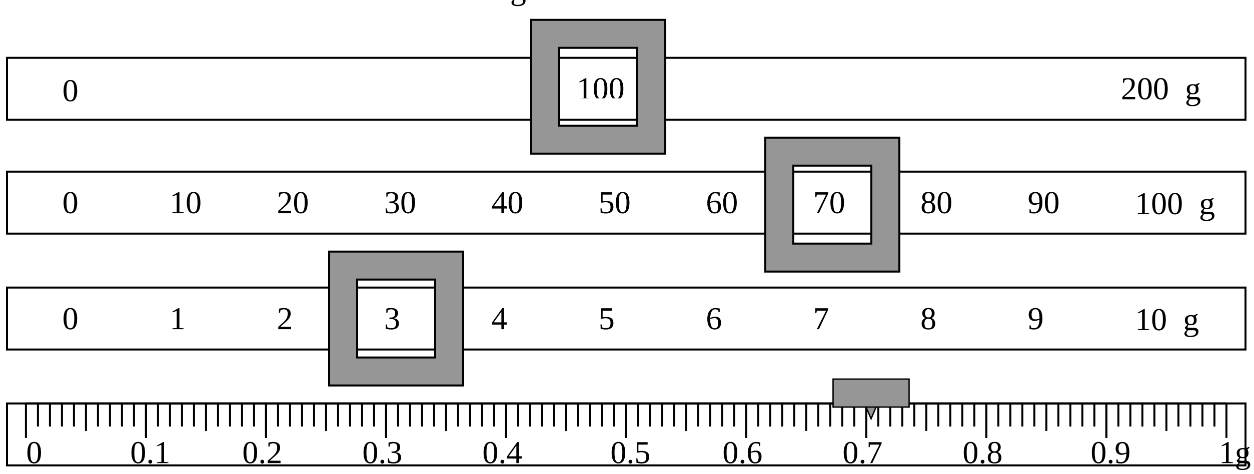
Substance	Density at 20°C
titanium	4.54 g/mL
gold	19.3 g/mL
iridium	22.65 g/mL
sodium	0.968 g/mL
iron	7.86 g/mL
nickel	8.90 g/mL
silicon	2.33 g/mL (25°C)
diamond	3.513 g/mL (25°C)

The densities of solids and liquids change slightly with temperature, in general, decreasing with increasing temperature. This can be explained by the change in volume with temperature, since the mass of a material does not depend on temperature. The density of gases varies greatly with temperature, since the volume of gases may vary considerably with temperature.

The mass of the material may be found in the laboratory by the use of a balance. Because of common convention, the mass determined will be called weight. The volume of a liquid material may be accurately obtained by the use of a pipet, whose volume may be exactly reproduced from experiment to experiment. Solid volumes may be determined by direct measurement if the solid has a regular geometric shape. The volume of irregularly shaped solids may be determined by measuring the amount of liquid that is displaced when the solid is placed in a liquid. This assumes, of course, that the solid neither reacts with the liquid nor floats in it.

Reading a High-Form Balance

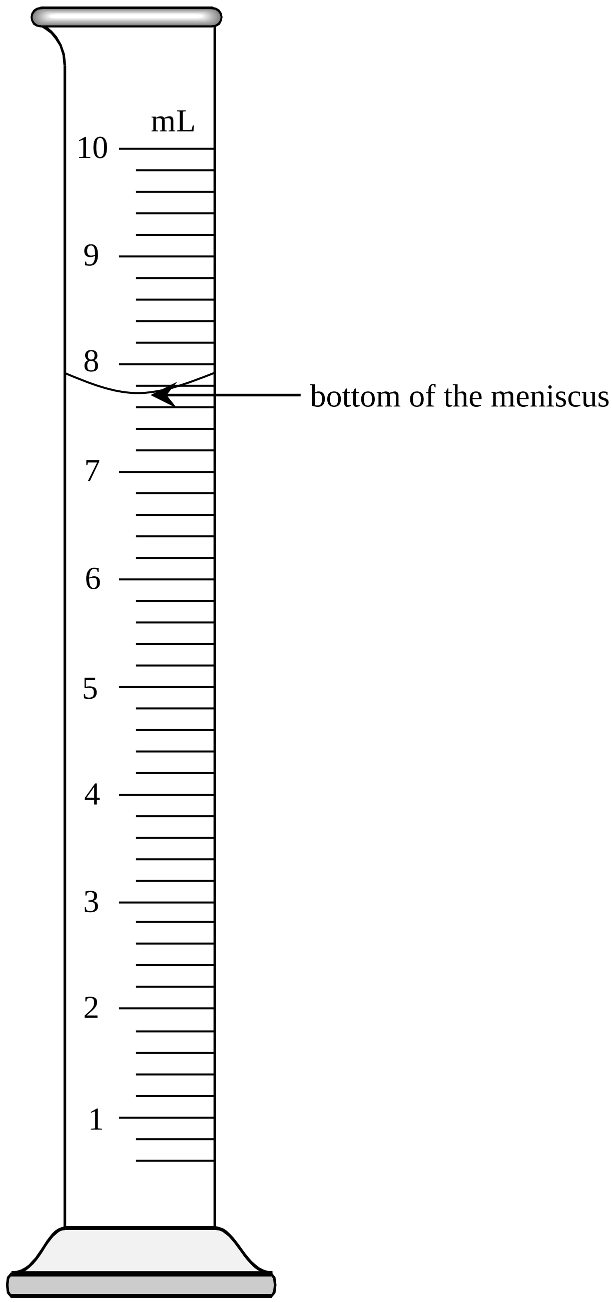
All measurements made on the high-form balance should be made to the thousandth of a gram. That is, all the masses must have three digits after the decimal point. The idealized balance below shows a mass of 173.704 g.



The Densities of Solids and Liquids

Reading a Graduated Cylinder

The 10 mL graduated cylinder you will use typically can be read to 0.02 mL. Each reading from it must therefore have two digits after the decimal point. The volume must be read from the bottom of the meniscus, shown in the picture below by the arrow. The idealized graduated cylinder below contains a volume of 7.72 mL. (If your graduated cylinder is different from the one pictured below, see the instructor.)



The Densities of Solids and Liquids

Table 2: Absolute Density of Water (g/mL)

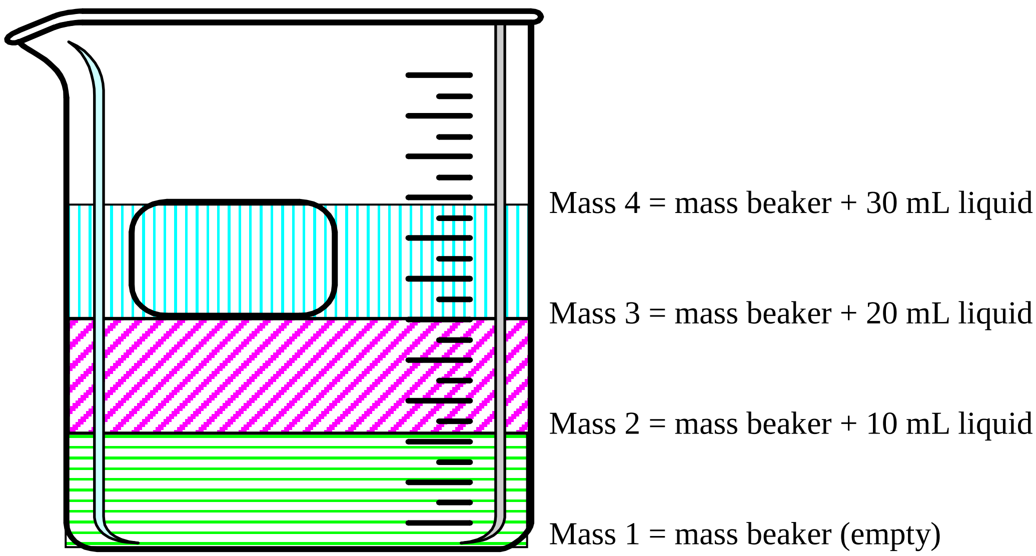
Degrees	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.999841	847	854	860	866	872	878	884	889	895
1	900	905	909	914	918	923	927	930	934	938
2	941	944	947	950	953	955	958	960	962	964
3	965	967	968	969	970	971	972	972	973	973
4	973	973	973	972	972	972	970	969	968	966
5	965	963	961	959	957	955	952	950	947	944
6	941	938	935	931	927	924	920	916	911	907
7	902	898	893	888	883	877	872	866	861	855
8	849	843	837	830	824	817	810	803	796	789
9	781	774	766	758	751	742	734	726	717	709
10	700	691	682	673	664	654	645	635	625	615
11	605	595	585	574	564	553	542	531	520	509
12	498	486	475	463	451	439	427	415	402	390
13	377	364	352	339	326	312	299	285	272	258
14	244	230	216	202	188	173	159	144	129	114
15	099	084	069	054	038	023	007	*991	*975	*959
16	0.998943	926	910	893	877	860	843	826	809	792
17	774	757	739	722	704	686	668	650	632	613
18	593	576	558	539	520	501	482	463	444	424
19	405	385	365	345	325	305	285	265	244	224
20	203	183	162	141	120	099	073	056	035	013
21	0.997992	970	948	926	904	882	860	837	815	792
22	770	747	724	701	678	655	632	608	585	561
23	538	514	490	466	442	418	394	369	345	320
24	296	271	246	221	196	171	146	120	095	069
25	044	018	*992	*967	*941	*914	*888	*862	*836	*809
26	0.996783	756	729	703	676	649	621	594	567	540
27	512	485	457	429	401	373	345	317	289	261
28	232	204	175	147	118	089	060	031	002	*973
29	0.995944	914	885	855	826	796	766	736	706	676
30	646	616	586	555	525	494	464	433	402	371

Each value from this table is good to six significant figures.

The Densities of Solids and Liquids

EXPERIMENTAL PROCEDURE:

Density of Liquids: (See figure below) A) Weigh a small, clean beaker on a platform balance and record the weight (Mass 1). Stop and get the instructor to check your measurement. Obtain an unknown liquid and record the unknown number. Pipet 10.00 mL of the unknown liquid into the beaker. Weigh the liquid and the beaker (Mass 2). Pipet another 10.00 mL of liquid into the beaker and weigh (Mass 3). Pipet a third 10.00 sample of liquid into the beaker and weigh (Mass 4). Return the liquid to the bottle. B) Rinse the beaker and reweigh. Rinse the pipet several times with distilled water. As with the unknown liquid, pipet three 10.00 mL aliquots of distilled water into the beaker, weighing after each 10.00 mL portion. Measure the temperature of the water to the nearest 0.1°C.



Density of a Solid: Obtain an unknown metal sample and record the unknown number. Clean and dry a 10 mL graduated cylinder. Add approximately 5 mL of distilled water to the cylinder and record the water level to 0.02 mL (2 digits after the decimal point). Record the mass (to 3 digits after the decimal point) of the water and the cylinder. Stop and get the instructor to check your measurements. Carefully, to avoid splattering, add metal to the water until one-third of the sample is used or the level of the water reaches about 9.5 mL, whichever comes first. The metal must be completely submerged and the water level must not exceed 10 mL. Record the new volume of water and metal and the new mass of water, metal and graduated cylinder. Carefully pour the water out of the graduated cylinder, making sure you do not pour any metal down the drain. Pour the wet metal onto a paper towel. Repeat the volume and mass measurements with the metal until you have three sets. Return all the wet metal to the original bottle.

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The Densities of Solids and Liquids

DATA AND CALCULATIONS

Density of Liquids

	Trial 1	**Trial 2**	**Trial 3**
Unknown # of liquid		______________	
Mass of beaker (g)		______________ (Mass 1)	
Mass of beaker & liquid (g)	______________ (Mass 2)	______________ (Mass 3)	______________ (Mass 4)
Mass of 10.00 mL of liquid (g)	______________ (Mass 2 – Mass 1)	______________ (Mass 3 – Mass 2)	______________ (Mass 4 – Mass 3)
Density of liquid (g/mL)	______________	______________	______________
Average density of liquid		______________	
Mass of beaker (g)		______________ (Mass 1w)	
Mass of beaker & water (g)	______________ (Mass 2w)	______________ (Mass 3w)	______________ (Mass 4w)
Mass of 10.00 mL of water (g)	______________ (Mass 2w – Mass 1w)	______________ (Mass 3w – Mass 2w)	______________ (Mass 4w – Mass 3w)
Density of water (g/mL)	______________	______________	______________
Average density of water		______________	
Temperature of water (°C)		______________	
Density of water from Table 2		______________	

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The Densities of Solids and Liquids

What is the percent error of the density of the water? $\left(\% \text{ error} = \frac{|\text{actual} - \text{experimental}|}{\text{actual}} \text{ x } 100 \right)$

Density of a Solid

Unknown # ____________

	Trial 1	Trial 2	Trial 3
Volume of water (mL)			
Volume of water & metal (mL)			
Volume of metal (mL)			
Mass of water & cylinder (g)			
Mass of water, cylinder & metal (g)			
Mass of metal (g)			
Density of metal (g/mL)			

Average density (g/mL) ____________________

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The Densities of Solids and Liquids

The Electronic Balance

There are several ways to use the electronic balances to weigh out materials. You will try three different methods. The last two make use of the tare feature of the balances and are the methods with which you should become most familiar.

When given an amount of a material to be measured, unless there are specific directions as to a minimum or maximum amount, you can generally differ by about 5% in either direction. For example, when you are asked to weigh 2 g of a substance, do not waste your time trying to get 2.000 g. Five percent of 2 g is 0.1 g so weigh out between 1.9 g and 2.1 g. Make sure that you record ALL the digits that the balance gives you. (For less than 60 g on the balance pan, you should have three digits after the decimal point. For more than 60 g, you will only have two.)

A. DIRECT WEIGHING WITHOUT USING THE TARE BUTTON

Use either a plastic weighing boat or a piece of weighing paper.

1. Weigh the weighing boat or paper. Record the mass. _________________
2. Add 2 g of the salt to the boat or paper. Record the mass. _________________
3. Subtract the mass of the boat from the mass of the salt and boat. _________________

B. DIRECT WEIGHING USING THE TARE BUTTON

1. Weigh the weighing boat or paper. Hit the TARE button. The mass will be set to zero g.
2. Add 2 g of the salt to the boat or paper. Record the mass. _________________

C. INDIRECT WEIGHING USING THE TARE BUTTON

1. Weigh the bottle of salt. Hit the TARE button.
2. Pour 2 g of the salt out of the bottle. In this case, pour out a small amount in the manner demonstrated by the instructor. Place the bottle back on the balance pan. The amount you have poured out will be the negative of the mass shown. Continue pouring until you have reached 2 g. Record the mass. _________________

Before returning the salt to the bottle, show the instructor at least one of your weighed samples.

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The Densities of Solids and Liquids

Graphing and Deriving a Conversion Factor for Temperature

Collecting data and graphing it to understand relationships between two variables is common in science. Often graphs also serve as a concise and easily understood format for disseminating results. In this experiment you will measure the temperature of four water samples using a Fahrenheit thermometer and a Celsius thermometer. You will graph these results and then derive the conversion from degrees Celsius to degrees Fahrenheit.

Temperate Measurements: All measurements will be taken with a Fahrenheit thermometer and a Celsius thermometer. The temperature should be measured to the 0.1 degree.

Obtain 3 beakers. Fill one beaker half full with distilled water and place it on a hot plate. Heat the water until boiling. Measure the temperature of the boiling water.

Meanwhile, fill a second beaker half full with distilled water and measure the temperature. This is the temperature of the room temperature water. To this beaker, add ice until the beaker is ¾ full. Allow this beaker to sit and equilibrate for 5 minutes. After 5 minutes, there should be both water and ice present in the beaker. Measure the temperature of the ice water. If all of the ice has melted, pour out some of the water and add more ice. Wait an additional 5 minutes, then measure the temperature of the ice water.

While waiting for the ice water bath to cool, make a salt/ice/water bath by weighing approximately 10 grams of salt into a beaker and add 15 mL of water. Stir the mixture so that the salt dissolves. Once dissolved, add approximately 30 grams of ice to the beaker. Stir the mixture briefly. Wait 5 minutes (there should still be a little ice left in the beaker, if not add 10 grams more ice and wait an additional 5 minutes) and measure the temperature of the salt/ice/water bath.

	Temperature	
	^oC	^oF
Boiling water	________________	________________
Room temperature water	________________	________________
Ice water	________________	________________
Salt/ice/water	________________	________________

The Densities of Solids and Liquids

Graphing: Graph your data on the following graph paper. The temperature in degrees Celsius should be on the x-axis. The temperature in degrees Fahrenheit should be on the y-axis. Your graph should have the following properties.

a. Each axis should have a label that includes the quantity name and the unit in parenthesis. For example, Volume (mL).
b. The graph should have an appropriate title. The convention for a graph is to name the graph y-axis data vs. x-axis data.
c. Determine an appropriate and convenient scale for each axis on your graph. Scale means the number of units that each division represents along a particular axis. Use as much of the axis as possible planning your scale. You want your data to take up the majority of the graph.
d. Plot each point using a dot with a circle around it, making them more visible. Finally draw a best fit straight line with a ruler. This line does not necessarily go through all of the data points (do not "connect the dots" of your data). You should draw the line with a ruler such that the data points above and below the line are an approximate equal distance from the line, with an approximate equal number of points above and below the line.

The Densities of Solids and Liquids

1. What is the slope of your graph? Use two points on your best fit line to determine the slope. Mark the points you use with a colored X. These two points should be far apart on the line. (Recall: slope = m = $(y_2-y_1)/(x_2-x_1)$).

The Densities of Solids and Liquids

2. What is the y-intercept of your graph?

3. What is the equation for the line from your graph? Write it in the form $^{o}F = m^{*o}C + b$.

4. Use the equation determined in question 3 to calculate the temperature in degrees Fahrenheit for a temperature of 68.0 ^{o}C.

5. Use the equation $^{o}F = 9/5\ ^{o}C + 32$ to calculate the degrees Fahrenheit for a temperature of 68.0 ^{o}C.

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The Densities of Solids and Liquids

PRESTUDY

1. (3) Using the Absolute Density of Water table, answer the following questions.

a. Does the density of water increase or decrease as the temperature increases from 2.0 to 3.0°C?

b. Look up the densities of water at each of the following temperatures.

16.0°C ____________________ 11.8°C ____________________

2. (2) An empty graduated cylinder weighs 26.145 g. When the cylinder contains 48.3 mL of an unknown liquid, it weighs 65.055 g. What is the density of the unknown liquid? Show your work.

3. (5) a. A graduated cylinder is filled with 25.2 mL of water. After placing an unknown solid in the graduated cylinder, the water level rises to 35.9 mL. The mass of the cylinder and water before the solid was added was 51.345 g and after adding the solid, the mass is 131.488 g. Calculate the density of the solid. Show your work.

b. The unknown solid is iron; calculate the percent error of the density. Show your work.

$$\left(\text{\% error} = \frac{|\text{theoretical value} - \text{experimental value}|}{\text{theoretical value}} \text{ x } 100 \right)$$