Chem 2990 **Density and Specific Gravity** Dr. Edward Walker

Density, the ratio of mass/voume, has many applications in the chemical industry. The relationship between mass and volume is an important aspect of the characterization and specification of both solids and liquids. For example, valuable metals and gem stones are characterized by their densities. Bulk chemicals are shipped in drums and totes weighing hundreds of pounds. Conversion of pounds to gallons or into metric equivalents is a critical aspect of trade. Shipping costs are most often determined by weight. Density can be used to quantify the dissolved solids in liquids. For example, high concentrations of salt in brines increase the density of these solutions.

$$Density = \rho = \frac{m}{V}, \qquad where\ m = mass\ and\ V = volume$$

The most common laboratory units for density are g/cm^3 (g/mL), while industrially, a variety of different units are encountered: lb/gal, lb/ft^3, and lb/in^3.

Specific gravity is the density of a substance divided by the density of water. The density units cancel, leaving specific gravity a unitless number. Since we often assume the density of pure water to be 1.0 g/mL, the specific gravity usually agrees closely with density. Temperature changes affect the density of water, resulting in differences between density and specific gravity of the material being tested.

$$Specific\ Gravity = \frac{Density\ of\ sample\ liquid}{Density\ of\ water}$$

Density of Solids

Measurement of the density of an unknown solid is relatively easy. Determine both the mass and the volume of a substance, then divide the mass by the volume to calculate its density.

Archimedes (ca. 287-212 BC) was a Greek mathematician who is credited with first discovering and characterizing the mass-to-volume relationship of materials. The king Hiero supposedly challenged Archimedes to find out if his goldsmith had replaced some of the king's gold with silver when making a wreath-like crown. But, of course, the king will not allow Archimedes to ruin the crown by cutting into it. While struggling with this, he notices that as he gets into a bathtub, the water rises up (overflows) by a volume equal to his own body's volume. Realizing he has found a way to measure the volume of irregular objects such as the crown, he jumps from the tub and runs through the streets screaming "Eureka! Eureka!" ("I've found it!" I've found it.") Knowing the mass and the volume allows the calculation of density. By comparing the different densities of gold and other pure metals, he was able to determine the purity of the gold in the crown. History is somewhat ambivalent on the fate of the goldsmith.

Archimedes continued his studies and eventually went on to write his law of buoyancy, "The buoyant force on an object is equal to the weight of the fluid displaced by the object." So, in the case of water, the mass of the water displaced is essentially also the volume of water displaced (assuming 1 mL of pure water has a mass of 1 gram.) In other words, solid masses weigh less when submerged in water than they do in air. The difference in the two masses is the mass of the displaced liquid and in the case of water the volume of the mass. So, by dividing the mass of the solid in air by the *difference* between its mass in air and its mass suspended in water, the density is obtained. Of course, if the liquid is not water, then the density of the liquid must be taken into account and the density of the liquid must be used to convert the displaced mass into displaced volume before the density of the suspended solid can be calculated:

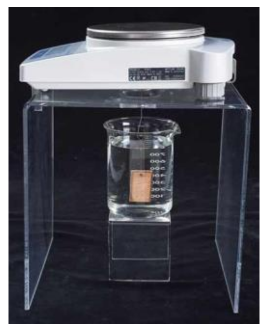
$$Density\ of\ the\ solid = \rho_{solid} = \frac{m_{air}}{m_{air} - m_{in\ liquid}} (\rho_{ref\ liq}),$$

Where ρ_{solid} is the density of the solid being measured, m_{air} is the mass of the solid in air, and $m_{inliquid}$ is the mass of the solid while suspended in liquid. The $\rho_{ref\ liq}$ is the density of the reference liquid at the temperature during the analysis. *(Data available in attached tables for water and alcohol.)*

Specific Gravity Balance – Using Sinker

An interesting application of this same equation is the determination of the density of a liquid by weighing a suspended solid of known mass and volume in the liquid. Some electronic balances have a hook under the balance to weigh masses suspended on a string. By attaching a glass or metal "sinker" to a thin line, it can be easily weighed in the air and when submerged in liquid.



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https://www.canada.ca/en/conservation-institute/services/conservation-preservation-publications/canadian-conservation-institute-notes/metal-density.html

The difference between these two masses is the mass of displaced liquid. The volume of the sinker is first calculated from its displaced mass when suspended in pure water. Knowing the volume of the sinker and its mass in air, the density of a liquid may be determined by simply weighing the sinker in the sample liquid.

$$\rho_{unkliq} = \frac{m_{sinker\ in\ air} - m_{sinker\ in\ unknown\ liquid}}{V_{sinker}}$$

Pycnometer Measurement of Specific Gravity

A pycnometer is a simple container used to compare the densities of liquids. A simple pycnometer could be a graduated cylinder or volumetric flask. However, most often it is a carefully designed container than can be easily filled with an exact, fixed volume of liquid. A few of the most common designs are shown below:

Figure 1. Various types of Pycnometers.

Pycnometers are calibrated by filling completely with pure water and weighing the net mass of water. The density of water is then used to calculate the exact volume of the pycnometer. After cleaning and drying, an unknown liquid is added to the pycnometer and weighed. The net mass is then used to calculate the density of the unknown liquid:

$$Density = \rho = \frac{m}{V}, \qquad where\ m = mass\ and\ V = volume$$

Frequently, the specific gravity of a liquid is desired. Since the pycnometer volume, *V*, is constant for all liquids and the mass of water from its calibration is known, the only measurement required is the mass of the unknown liquid:

$$Specific\ Gravity = \frac{Density\ of\ sample\ liquid}{Density\ of\ water} = \frac{m_{sample}/V_{sample}}{m_{water}/V_{water}} = \frac{m_{sample}}{m_{water}}$$

Discussion Questions:

1. How would the volume of the sinker affect the reproducibility of the determination? Is it better to use a large sinker or a smaller one? Explain.
2. How would the density of the sinker affect the accuracy and reproducibility of the determination? Is it better to use a more-dense or less-dense solid material?

Reference Materials

1. Determining Density of Solids Equations *(Mettler Toledo Balance Manual)*
2. Density Table for Distilled Water, from *"American institute of Physics Handbook."*
3. Density Table for Ethyl Alcohol, from *"American institute of Physics Handbook."*
4. Densities and Specific Gravities of Common Pure Metals

Formulae for determining the density of solids with compensation for air density

$$\rho = \frac{A}{A-B}(\rho_0 - \rho_L) + \rho_L$$

$$V = \alpha \frac{A - B}{\rho_0 - \rho_L}$$

ρ	=	Density of the sample
A	=	Weight of the sample in air
B	=	Weight of the sample in the auxiliary liquid
V	=	Volume of the sample
ρ_0	=	Density of the auxiliary liquid
ρ_L	=	Density of Air (0.0012 g/cm^3)
α	=	Weight correction factor (0.99985), to take the atmospheric buoyancy of the adjustment weight into account

Formula for determining the density of liquids with compensation for air density

$$\rho = \alpha \frac{P}{V} + \rho_L$$

ρ	=	Density of the liquid
P	=	Weight of the displaced liquid
V	=	Volume of the sinker
ρ_L	=	Density of air (0.0012 g/cm^3)
α	=	Weight correction factor (0.99985), to take the atmospheric buoyancy of the adjustment weight into account

Density Table for Distilled Water

T/°C	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
10.	0.99973	0.99972	0.99971	0.99970	0.99969	0.99968	0.99967	0.99966	0.99965	0.99964
11.	0.99963	0.99962	0.99961	0.99960	0.99959	0.99958	0.99957	0.99956	0.99955	0.99954
12.	0.99953	0.99951	0.99950	0.99949	0.99948	0.99947	0.99946	0.99944	0.99943	0.99942
13.	0.99941	0.99939	0.99938	0.99937	0.99935	0.99934	0.99933	0.99931	0.99930	0.99929
14.	0.99927	0.99926	0.99924	0.99923	0.99922	0.99920	0.99919	0.99917	0.99916	0.99914
15.	0.99913	0.99911	0.99910	0.99908	0.99907	0.99905	0.99904	0.99902	0.99900	0.99899
16.	0.99897	0.99896	0.99894	0.99892	0.99891	0.99889	0.99887	0.99885	0.99884	0.99882
17.	0.99880	0.99879	0.99877	0.99875	0.99873	0.99871	0.99870	0.99868	0.99866	0.99864
18.	0.99862	0.99860	0.99859	0.99857	0.99855	0.99853	0.99851	0.99849	0.99847	0.99845
19.	0.99843	0.99841	0.99839	0.99837	0.99835	0.99833	0.99831	0.99829	0.99827	0.99825
20.	0.99823	0.99821	0.99819	0.99817	0.99815	0.99813	0.99811	0.99808	0.99806	0.99804
21.	0.99802	0.99800	0.99798	0.99795	0.99793	0.99791	0.99789	0.99786	0.99784	0.99782
22.	0.99780	0.99777	0.99775	0.99773	0.99771	0.99768	0.99766	0.99764	0.99761	0.99759
23.	0.99756	0.99754	0.99752	0.99749	0.99747	0.99744	0.99742	0.99740	0.99737	0.99735
24.	0.99732	0.99730	0.99727	0.99725	0.99722	0.99720	0.99717	0.99715	0.99712	0.99710
25.	0.99707	0.99704	0.99702	0.99699	0.99697	0.99694	0.99691	0.99689	0.99686	0.99684
26.	0.99681	0.99678	0.99676	0.99673	0.99670	0.99668	0.99665	0.99662	0.99659	0.99657
27.	0.99654	0.99651	0.99648	0.99646	0.99643	0.99640	0.99637	0.99634	0.99632	0.99629
28.	0.99626	0.99623	0.99620	0.99617	0.99614	0.99612	0.99609	0.99606	0.99603	0.99600
29.	0.99597	0.99594	0.99591	0.99588	0.99585	0.99582	0.99579	0.99576	0.99573	0.99570
30.	0.99567	0.99564	0.99561	0.99558	0.99555	0.99552	0.99549	0.99546	0.99543	0.99540

Density Table for Ethanol

T/°C	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
10.	0.79784	0.79775	0.79767	0.79758	0.79750	0.79741	0.79733	0.79725	0.79716	0.79708
11.	0.79699	0.79691	0.79682	0.79674	0.79665	0.79657	0.79648	0.79640	0.79631	0.79623
12.	0.79614	0.79606	0.79598	0.79589	0.79581	0.79572	0.79564	0.79555	0.79547	0.79538
13.	0.79530	0.79521	0.79513	0.79504	0.79496	0.79487	0.79479	0.79470	0.79462	0.79453
14.	0.79445	0.79436	0.79428	0.79419	0.79411	0.79402	0.79394	0.79385	0.79377	0.79368
15.	0.79360	0.79352	0.79343	0.79335	0.79326	0.79318	0.79309	0.79301	0.79292	0.79284
16.	0.79275	0.79267	0.79258	0.79250	0.79241	0.79232	0.79224	0.79215	0.79207	0.79198
17.	0.79190	0.79181	0.79173	0.79164	0.79156	0.79147	0.79139	0.79130	0.79122	0.79113
18.	0.79105	0.79096	0.79088	0.79079	0.79071	0.79062	0.79054	0.79045	0.79037	0.79028
19.	0.79020	0.79011	0.79002	0.78994	0.78985	0.78977	0.78968	0.78960	0.78951	0.78943
20.	0.78934	0.78926	0.78917	0.78909	0.78900	0.78892	0.78883	0.78874	0.78866	0.78857
21.	0.78849	0.78840	0.78832	0.78823	0.78815	0.78806	0.78797	0.78789	0.78780	0.78772
22.	0.78763	0.78755	0.78746	0.78738	0.78729	0.78720	0.78712	0.78703	0.78695	0.78686
23.	0.78678	0.78669	0.78660	0.78652	0.78643	0.78635	0.78626	0.78618	0.78609	0.78600
24.	0.78592	0.78583	0.78575	0.78566	0.78558	0.78549	0.78540	0.78532	0.78523	0.78515
25.	0.78506	0.78497	0.78489	0.78480	0.78472	0.78463	0.78454	0.78446	0.78437	0.78429
26.	0.78420	0.78411	0.78403	0.78394	0.78386	0.78377	0.78368	0.78360	0.78351	0.78343
27.	0.78334	0.78325	0.78317	0.78308	0.78299	0.78291	0.78282	0.78274	0.78265	0.78256
28.	0.78248	0.78239	0.78230	0.78222	0.78213	0.78205	0.78196	0.78187	0.78179	0.78170
29.	0.78161	0.78153	0.78144	0.78136	0.78127	0.78118	0.78110	0.78101	0.78092	0.78084
30.	0.78075	0.78066	0.78058	0.78049	0.78040	0.78032	0.78023	0.78014	0.78006	0.77997

Density of C_2H_5OH according to the "American Institute of Physics Handbook".

Densities of Common Metals

Source: http://www.coolmagnetman.com/magconda.htm

Density ***(Measured in Various Units)***

metal	g/cm3	lb/in3	lb/ft3	lb/gal
water	1.00	0.036	62	8.35
aluminum	2.7	0.098	169	22.53
zinc	7.13	0.258	445	59.5
iron	7.87	0.284	491	65.68
copper	8.96	0.324	559	74.78
silver	10.49	0.379	655	87.54
lead	11.36	0.41	709	94.8
mercury	13.55	0.49	846	113.08
gold	19.32	0.698	1206	161.23

Specific Gravities ***(Density of Metal/Density of Water)***

water	1.00	1.00	1.00	1.00
aluminum	2.70	2.72	2.73	2.70
zinc	7.13	7.17	7.18	7.13
iron	7.87	7.89	7.92	7.87
copper	8.96	9.00	9.02	8.96
silver	10.49	10.53	10.56	10.48
lead	11.36	11.39	11.44	11.35
mercury	13.55	13.61	13.65	13.54
gold	19.32	19.39	19.45	19.31