5Density, Specific Gravity, and Specific Volume

密度、比重、比容積

Objectives

Upon successful completion of this chapter, the student will be able to:

- Define *density*, *specific gravity*, and *specific volume* and determine each through appropriate calculations.
- Calculate specific gravity from data derived from the use of a pycnometer.
- Apply specific gravity correctly in converting weight to volume and volume to weight.

DENSITY (d)

- Density (d):
  - is mass per unit volume of a substance.
  - is usually expressed as grams per cubic centimeter (g/cc).
- Because the gram is defined as the mass of 1 cc of water at 4°C, the density of water is 1 g/cc.
  - since the United States Pharmacopeia states that 1 mL may be used as the equivalent of 1 cc, for our purposes, the density of water may be expressed as 1 g/mL.
- one milliliter of mercury weighs 13.6 g
  - hence, its density is 13.6 g/mL.
- Density may be calculated by dividing mass by volume, that is:

  Density=mass/volume (D=M/V)
  - Thus, if 10 mL of sulfuric acid weigh 18 g, its density is:

    density = 18 (g)/10 (mL) = 1.8 g per mL

SPECIFIC GRAVITY (sp. gr.)

- is a ratio, expressed decimally, of the weight of a substance to the weight of an equal volume of a substance chosen as a standard, both substances at the same temperature or the temperature of each being definitely known.
- Water is used as the standard for the specific gravities of liquids and solids;
  - the most useful standard for gases is hydrogen, although sometimes air is used.
- may be calculated by dividing the weight of a given substance by the weight of an equal volume of water, that is:

$$specific\ gravity = \frac{weight\ of\ substance}{weight\ of\ equal\ volume\ of\ water}$$

- *If 10 mL of sulfuric acid weigh 18 g, and 10 mL of water, under similar conditions, weigh 10 g, the specific gravity of the acid is*:

  specific gravity=18 (g)/10 (mL) = 1.8

- *Substances that have a specific gravity of less than 1 are lighter than water.*
- *Substances that have a specific gravity greater than 1 are heavier than water.*
- Table 5.1, presents some representative specific gravities.
- Figure 5.1 depicts the layering of immiscible liquids due to their relative weights.

TABLE 5.1 SOME REPRESENTATIVE SPECIFIC GRAVITIES AT 25°C

AGENT	SP GR
Ether (at 20°C)	0.71
Isopropyl alcohol	0.78
Acetone	0.79
Alcohol	0.81
Liquid petrolatum	0.87
Peppermint oil	0.90
Olive oil	0.91
Peanut oil	0.92
Cod liver oil	0.92
Castor oil	0.96
Water	**1.00**
Propylene glycol	1.03
Clove oil	1.04
Liquefied phenol	1.07
Polysorbate 80	1.08
Polyethylene glycol 400	1.13
Glycerin	1.25
Syrup	1.31
Hydrochloric acid	1.37
Nitric acid	1.42
Chloroform	1.47
Nitroglycerin	1.59
Phosphoric acid	1.70
Mercury	13.6

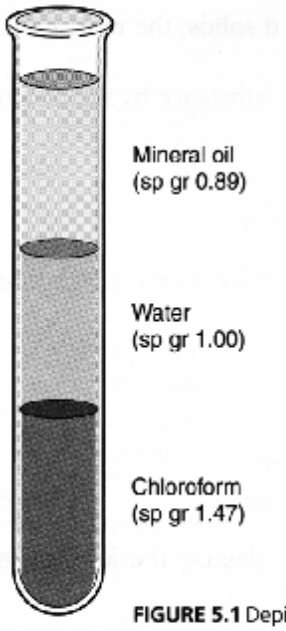

FIGURE 5.1 Depiction of layering of immiscible liquids in a test tube, mineral oil being lighter than water and chloroform being heavier.

- Specific gravities may be expressed decimally to as many places as the accuracy of their determination warrants.
  - In pharmaceutical work, this expression may be to two, three, or four decimal places.
- Because substances expand or contract at different rates when their temperatures change, accurate work necessitates allowing carefully for variations in the specific gravity of a substance.
  - In the United States Pharmacopeia, the standard temperature for specific gravities is 25°C, except for that of alcohol, which is 15.56°C by government regulation.

DENSITY VERSUS SPECIFIC GRAVITY

- The density of a substance:
  - is a concrete (具體) number (1.8 g/mL in the example),
  - varies with the units of measure used
  - the density of water may be variously expressed as 1 g/mL, 1000 g/L, or 62½ lb/cu ft,
- specific gravity:
  - a ratio between like quantities, is an abstract (抽象) number (1.8 in the example).
  - has no dimension and is therefore a constant value for each substance (when measured under controlled conditions).
  - the specific gravity of water is always 1.

Calculating the Specific Gravity of Liquids

Known weight and volume

$$\text{Specific gravity} = \frac{\text{Weight of substance}}{\text{Weight of equal volume of water}}$$

Examples: *If 54.96 mL of an oil weigh 52.78 g, what is the specific gravity of the oil?*

54.96 mL of water weigh 54.96 g
Specific gravity of oil = 52.78 g/54.96 = 0.9603, answer.

CALCULATING THE SPECIFIC GRAVITY OF LIQUIDS

1. ***Known Weight and Volume***.
   - *If a pint of a certain liquid weighs 601 g, what is the specific gravity of the liquid?*

     1 pint = 16 fl. oz.

     16 fl. oz. of water weigh 473 g

     Specific gravity of liquid = 601 g/473 g =1.27, answer.

Pycnometer or Specific Gravity Bottle

- ***Pycnometers:***
  - are a special glass bottle used to determine specific gravity (Fig. 5.2).
  - are generally available for laboratory use in volumes ranging from 1 mL to 50 mL.
  - have fitted glass stoppers with a capillary opening to allow trapped air and excess fluid to escape.
  - Some pycnometers have thermometers affixed, because temperature is a factor in specific gravity determinations.

FIGURE 5.2 Examples of *pycnometers* used to determine the specific gravity of liquids. Shown are 1-mL and 25-mL sizes. See text for description of their use. (Courtesy of Thomas Scientific.)

1. Pycnometer or Specific Gravity Bottle.

- the container is filled and weighed first with water and then with the liquid.
- By subtracting the weight of the empty container from the two weights,
- we have the weights of equal volumes, even though we may not know the volumes exactly.

Density of Semi-Solid Bitumous Materials (Pycnometer Method)

半固態瀝青材料密度試驗法(比重瓶法)

Example: *A specific gravity bottle weighs 23.66 g. When filled with water, it weighs 72.95 g; when filled with another liquid, it weighs 73.56 g. What is the specific gravity of the liquid?*

- 73.56 g - 23.66 g = 49.90 g of liquid
- 72.95 g - 23.66 g = 49.29 g of water
- Specific gravity of liquid
  = 49 90 (g)/ 49.29 (g)
  = 1.012, answer.

2. *Displacement or Plummet Method*.

- is based on the Archimedes' principle
  - a body immersed in a liquid displaces an amount of the liquid equal to its own volume
  - suffers an apparent loss in weight equal to the weight of the displaced liquid.
- We can weigh a plummet when suspended in water and when suspended in a liquid the specific gravity of which is to be determined,
- by subtracting these weights from the weight of the plummet in air, we get the weights of equal volumes of the liquids needed.

Example: ***A glass plummet weighs 12.64 g in air, 8.57 g when immersed in water, and 9.12 g when immersed in an oil. Calculate, the specific gravity of the oil.***

- 12.64 g - 9.12 g = 3.52 g of displaced oil
- 12.64 g - 8.57 g = 4.07 g of displaced water
- Specific gravity of oil
  = 3.52 g/4.07 g
  = 0.865, answer.

Calculating the Specific Gravity of Solids

- ***Solids Heavier Than and Insoluble in Water***.
  - simply divide the weight of the solid in air by the weight of water that it displaces when immersed in it.
  - The weight of water displaced (apparent loss of weight in water) is equal to the weight of an equal volume of water.

Calculating the Specific Gravity of Solids

- ***Solids Heavier Than and Insoluble in Water***.
  - Example: *A piece of glass weighs 38.525 g in air and 23.525 g when immersed in water. What is its specific gravity?*

    38.525 g - 23.525 g = 15.000 g of displaced water (weight of an equal volume of water)

    Specific gravity of glass

    = 38.525 g/15.000

    = 2.568, answer.

- ***Solids Heavier Than and Soluble in Water***.
  - The weights of equal volumes of any two substances are proportional to their specific gravities.
  - Therefore, given a solid heavier than and soluble in water,
  - we may use the method just discussed, but substituting some liquid of known specific gravity in which the solid is insoluble.

Solids Heavier Than and Soluble in Water.

- Example: ***A crystal of a chemical salt weighs 6.423 g in air and 2.873 g when immersed in an oil having a specific gravity of 0.858. What is the specific gravity of the salt?***

  6.423 g - 2.873 g = 3.550 g of displaced oil

$$\frac{3.550(g\ of\ oil)}{6.423(g\ of\ salt)} = \frac{0.858(sp.gr.of\ oil)}{x(sp.gr.of\ salt)}$$

$$x = 1.55, answer.$$

Solids Lighter Than and Insoluble in Water.

- involves the use of a sinker, which is attached to the solid to prevent it from floating.
- The weight of the sinker in air is of no interest to us,
  - its weight when immersed in water alone must be known
- the combined weight of the solid in air and the sinker in water may be calculated.
- By subtracting from the weight of solid and sinker when immersed in water,
- the weight of the water displaced by the solid (and therefore the weight of an equal volume of water) .

Example: A piece of wax weighs 16.35 g in air, and a sinker weighs 32.84 g immersed in water. When they are fastened together and immersed in water, their combined weight is 29.68 g. Calculate the specific gravity of the wax.

- 32.84 g + 16.35 g = 49.19 g, combined weight of sinker in water and of wax in air
- 49.19 g - 29.68 g = 19.51 g, weight of water displaced by wax (weight of equal volume of water)
- Specific gravity of wax

  =16.35 g/19.51 g (wax weight in air/ weight of water displaced by wax).

  = 0.838, answer.

- ***Granulated Solids Heavier Than and Insoluble in Water***.
  - a specific gravity bottle can be used with **crystals, powders**, and **other forms of solids** the volume of which cannot be directly measured.
  - If such a substance is insoluble in water, we may weigh a portion of it,
    - introduce this amount into the bottle,
    - fill up the bottle with water,
    - weigh the mixture.
  - The solid will displace a volume of water equal to its own volume, and the weight of this displaced water can be calculated.

Example: ***A bottle weighs 50.0 g when empty and 96.8 g when filled with water. If 28.8 g of granulated metal are placed in the bottle and the bottle is filled with water, the total weight is 118.4 g. What is the specific gravity of the metal?***

- 96.8 g - 50.0 g = 46.8 g, weight of water filling the bottle
- 46.8 g + 28.8 g = 75.6 g, combined weight of water and metal
- 118.4 g - 50.0 g = 68.4 g, combined weight of water and metal in bottle
- 75.6 g - 68.4 g = 7.2 g, weight of water displaced by metal (weight of equal volume of water)
- Specific gravity of metal = 28.8 g/7.2 g = 4.0, answer.

USE OF SPECIFIC GRAVITY IN CALCULATIONS OF WEIGHT AND VOLUME

- The weights of equal volumes and the volumes of equal weights of liquids are proportional to their specific gravities.
- To calculate, therefore, the weight of a given volume or the volume of a given weight of a liquid, its specific gravity must be known.
- *When specific gravity is used as a factor in a calculation, the result should contain no more significant figures than the number in the factor.*
- Such problems are solved simply and easily when only metric quantities are involved, but they become more complex when units of the common systems are used.

Weight of a Liquid with Known Volume and Specific Gravity. The weight of any given volume of a liquid of known specific gravity can be calculated by this proportion*:*

$$\frac{Specific\ gravity\ of\ water}{Specific\ gravity\ of\ liquid} = \frac{Weight\ of\ equal\ volume\ of\ water}{x}$$

$$x = Weight\ of\ liquid$$

- From this calculation, we may derive a useful equation:
  Weight of liquid = Weight of equal volume of water X Specific gravity of liquid

Calculating weight, knowing the volume and specific gravity (Grams=Milliliters X Specific gravity)

- *What is the weight, in grams, of 3620 mL of alcohol with a specific gravity of0.820 ?*

  3620 mL of water weigh 3620 g
  3620 g X 0.820 = 2968 g, answer.

- *What is the weight, in grams, of 2 fluidounces of a liquid having a specific gravity of 1.118?*
  - In this type of problem, it is best to convert the given volume to its metric equivalent first and then solve the problem in the metric system.

    2 X 29.57 mL = 59.14 mL
    59.14 mL of water weigh 59.14 g
    59.14 g X 1.118 = 66.12 g, answer.

Calculating volume, knowing the weight and specific gravity (Milliliters= Grams/ Specific gravity)

What is the volume, in milliliters, of 492 g of nitric acid with a specific gravity of 1.40?

492 g of water measure 492 mL

492 mL/1.4=351 mL, answer.

Examples

- *What is the volume, in milliliters, of 1 lb of methyl salicylate with a specific gravity of1.185?*

  1 lb = 454 g

  454 g of water measure 454 mL

  454 mL/1.185=383.1 mL, answer.

- *What is the volume, in pints, of 50 lb of glycerin having a specific gravity of 1.25?*

  50 lb = 454 X 50 = 22700 g

  22700 g of water measure 22700 mL and 1 pint = 473 mL

  22,700/1.25= 18,160 mL ÷ 473 mL = 38.4 pints, answer.

Cost of Given Volume of Liquid by Weight

- Examples*: What is the cost of 1000 mL of glycerin, specific gravity 1.25, bought at $54.25 per pound?*

1000 mL of water weigh 1000 g
Weight of 1000 mL of glycerin
=1000g X 1.25 = 1250 g
1 lb = 454 g

$$\frac{454(g)}{1250(g)} = \frac{54.25(\$)}{x(\$)}$$

$$x = \$149.37, \textit{answer}.$$

What is the cost of 1 pint of chloroform, specific gravity 1.475, bought at $25.25 per pound?

1 pint =473 mL
473 mL of water weigh 473 g
Weight of 473 mL of chloroform
= 473 g X 1.475 = 697.7 g
1 lb = 454 g

$$\frac{454(g)}{697.7(g)} = \frac{25.25(\$)}{x(\$)}$$

$$x = \$38.80, \textit{answer}.$$

Special Considerations of Specific Gravity

Pharmaceutical Applications

- Specific gravity is employed when a pharmacist wishes to convert the weight of an ingredient or preparation to volume or vice versa.
  - liquid materials are usually the objects of the conversions.
- Specific gravity is also used to calculate the equivalent strength of a preparation on the basis of either weight or volume.
- Specific gravity is in automated pharmaceutical equipment used by pharmacists to prepare total parenteral nutrition (TPN) admixtures.
  - The purpose of the specific gravity of the large-volume liquids being mixed is to determine the **weights of components** (e.g., dextrose, amino acids, and water).
  - The component weights are automatically calculated, based on the specific gravity, volume, and percentage concentration of the solutions used (e.g., 70% dextrose injection) in the admixture.
  - The automatic compounder then uses the *weight* to make the correct mixture rather than the *volume* of the solution being measured.

Clinical Application

- Specific gravity is an important factor in **urinalysis**.
  - In normal adults, the specific gravity of urine is usually within the range of 1.010 and 1.025 with a normal fluid intake (this range may vary with the reference source).
  - The specific gravity of urine generally decreases with age.
  - In newborns, it is generally within the range of 1.001 to 1.020.
  - Specific gravity is an indicator of both the concentration of particles in the urine and a patient's degree of hydration.
    - A higher-than-normal specific gravity indicates that the urine is concentrated.
      - This may be due to the presence of excess waste products or electrolytes in the urine, the presence of glucose (glucosuria) or protein (proteinuria), low fluid intake, excessive water loss, decreased fluid intake, ect.
    - A low specific gravity indicates that the urine is dilute, which may be a result of diabetes insipidus, renal disease (by virtue of the kidney's reduced ability to concentrate urine), increased fluid intake, intravenous hydration, or other factors.

CASE IN POINT 5.1[8]

℞ Lactic Acid
Salicylic Acid aa. 1.5 g
Flexible Collodion qs ad 15 mL
Sig: Apply one drop to wart twice a day.
Label: Wart remover. For external use only.

Lactic acid is available as a liquid containing 85 g of the acid in 100 g of solution (sp.gr. 1.21). Calculate the quantity of this solution, in milliliters, needed to fill the prescription.

Quantity of lactic acid needed to fill Rx: 1.5 g
Source of lactic acid: liquid containing 85 g/100 g; or, by using specific gravity: 100 g÷1.21 = 82.64 mL
Thus, 85 g of lactic acid are in 82.64 mL of the source liquid.
By proportion:

$$\frac{85\,g}{82.64\,mL} = \frac{1.5\,g}{x\,mL};\ x = 1.46\,mL,\ answer.$$

Clinical Application

- In the modem clinical laboratory, the specific gravity of urine is determined (using the refractive index method) as a component of a comprehensive urinalysis performed by sophisticated, fully automated equipment that determines, in seconds, urine chemistry, specific gravity, pH, color, and clarity.'

Urine Specific Gravity Refractometer

CALCULATIONS CAPSULE

Specific Gravity

The specific gravity (sp gr) of a substance or a pharmaceutical preparation may be determined by the following equation:

$$\text{Specific gravity} = \frac{\text{Weight of substance (g)}}{\text{Weight of equal volume of water (g)}}$$

The following equation may be used to convert the volume of a substance or pharmaceutical preparation to its weight:*

$$\text{Weight of substance} = \text{Volume of substance} \times \text{Specific gravity}$$

Or simply,

$$\mathbf{g = mL \times sp\ gr}$$

The following equation may be used to convert the weight of a substance or pharmaceutical preparation to its volume:*

$$\text{Volume of substance} = \frac{\text{Weight of substance}}{\text{Specific gravity}}$$

Or simply,

$$\mathbf{mL = \frac{g}{sp\ gr}}$$

* The full explanation on why these equations work may be found in the section "Use of Specific Gravity in Calculations of Weight and Volume," on page 73.

Calculating Specific Volume

- The volume of a unit weight of a substance may be expressed in any convenient denominations:
  - so many **cubic feet per pound** or **gallons per pound**,
  - more frequently as **milliliters per gram (mL/g).**
- Specific volume, in pharmaceutical practice, is usually defined as an abstract number representing the ratio, expressed decimally, of the volume of a substance to the volume of an equal weight of another substance taken as a standard, both having the same temperature.
  - Water is the standard for liquids and solids.
- Specific gravity is a comparison of weights of equal volumes,
- Specific volume is a comparison of volumes of equal weights.
- Specific gravity and specific volume are **reciprocals**, i.e., if they are *multiplied together*, the product is **1**.

- Specific volume:
  - tells us how much greater (or smaller) in volume a mass is than the same weight of water.
  - may be calculated by dividing the volume of a given mass by the volume of an equal weight of water.
  - If 25 g of glycerin measure 20 mL and 25 g of water measure 25 mL under the same conditions, the specific volume of the glycerin is:

$$\frac{Volume\ of\ 20\ g\ of\ glycerine}{Volume\ of\ 25\ g\ of\ water} = \frac{20(mL)}{25(mL)} = 0.8$$

- ***Volume of a Liquid, Given the Volume of a Specified Weight***.
  - Calculating the specific volume of a liquid, given the volume of a specified weight, involves the following.
  - Example: *Calculate the specific volume of a syrup, 91.0 mL of which weigh 107.16 g.*
    - 107.16 g of water measure 107.16 mL
    - Specific volume of syrup
      = 91.0 (mL)/107.16 (mL)
      = 0.849, answer.

- ***Specific Volume of a Liquid, Given its Specific Gravity and its Specific Gravity Given its Specific Volume***.
  - Because specific gravity and specific volume are reciprocals,
    - a substance that is heavier than water will have a higher specific gravity and a lower specific volume,
    - a substance that is lighter than water will have a lower specific gravity and a higher specific volume.
  - We may determine the specific volume of a substance by dividing 1 by its specific gravity,
  - We may determine the specific gravity of a substance by dividing 1 by its specific volume.

- *Examples: What is the specific volume of phosphoric acid having a specific gravity of 1.71?*

$$S.V. = \frac{1}{1.71} = 0.585, answer.$$

•If a liquid has specific volume of 1.396, what is its specific gravity?

$$s.g. = \frac{1}{1.396} = 0.716, answer.$$

- Thanks!