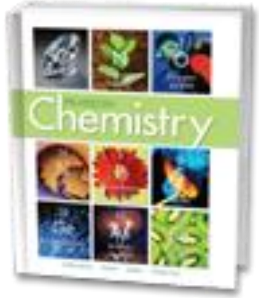


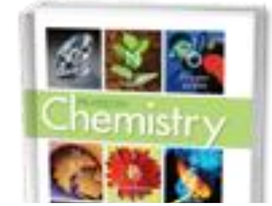
Chapter 3
Scientific Measurement

Using & Expressing Measurements

*Units of Measurement

*Solving Conversion Problems

*Density (Mass/Volume)



Measurement Chapter 3B

Topics:

1. Scientific Measurement

Objectives:

1. Use the Metric System versus the English System
2. Write numbers & do calculations in scientific notation.
3. Evaluate Accuracy & Precision in Measurements (significant figures)
4. Calculate Percent Error as a Measure of Precision
5. Understand & Use Units of Mass, Volume, Distance (emphasize Metric)
6. Identify the temperature units scientists commonly use
7. Understand & Calculate Density
8. Learn to solve problems using dimensional analysis (factor Labeling)

Measurement

What is the metric progression from milli to kilo?

Write 34597 in scientific notation

Write 0.000128 in scientific notation

Write 89.3 x 10^3 in standard notation

Write 26.9 x 10^{-4} in standard notation

Measurement

What is the metric progression from milli to kilo?

milli, centi, deci, standard, deka, hecta, kilo

Write 34597 in scientific notation

3.4597×10^4 (#↓ E↑)

Write 0.000128 in scientific notation

1.28×10^{-4} (#↑ E↓)

Write 89.3×10^3 in standard notation

89300 (E↓ #↑)

Write 26.9×10^{-4} in standard notation

0.00269 (E↑ #↓)

WARM-UP

Measurement

The boiling point of ethanol is known to be 78.0 C. A student observes the following temperatures for the boiling point of ethanol: 69.43 C, 73.8 C, and 74 C. Are these numbers accurate and/or precise? Explain.

Use the value, 73.8 to determine how accurate the student's temperature is.

Measurement

The boiling point of ethanol is known to be 78.0 C. A student observes the following temperatures for the boiling point of ethanol: 69.43 C, 73.8 C, and 74 C. Are these numbers accurate and/or precise? Explain.

Inaccurate → they miss the target (accepted value)

Not precise → all different decimal places

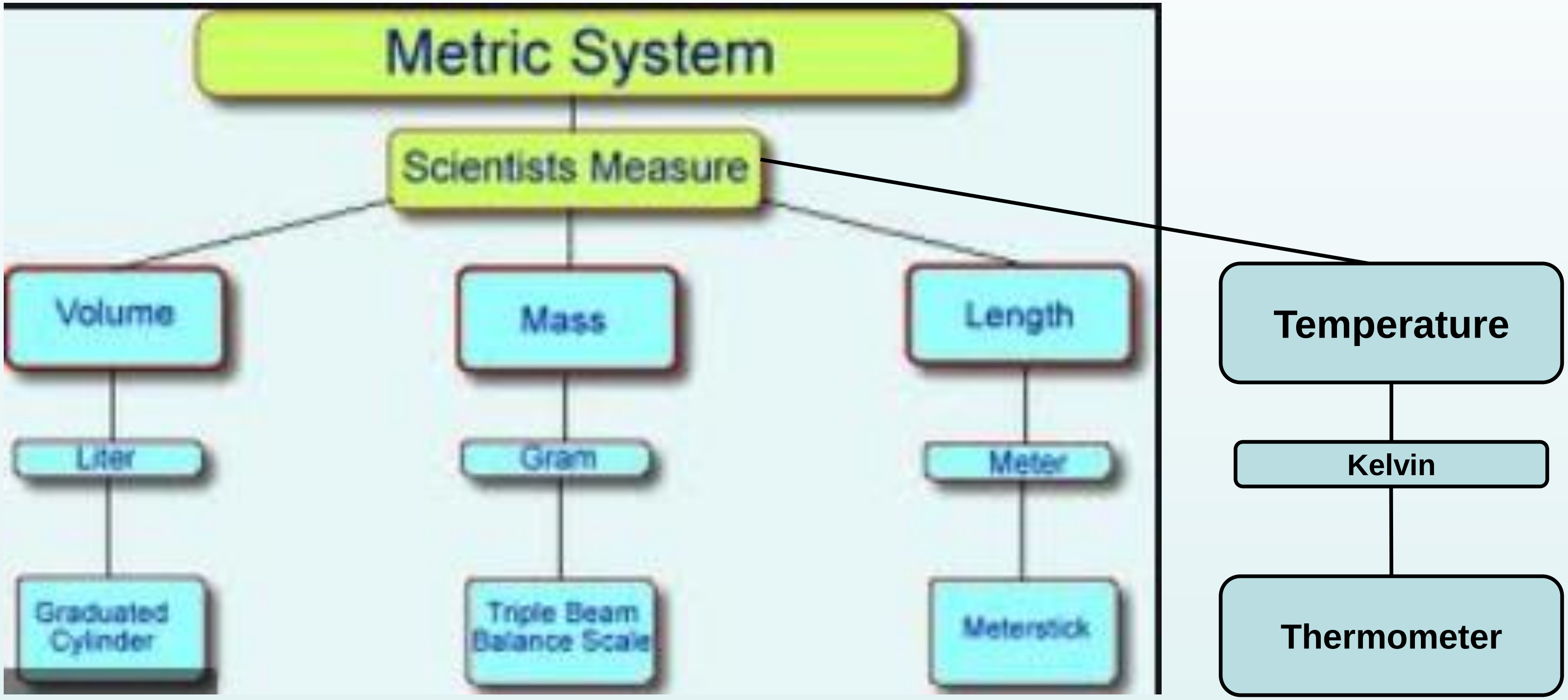
Use the value, 73.8 to determine how accurate the student's temperature is.

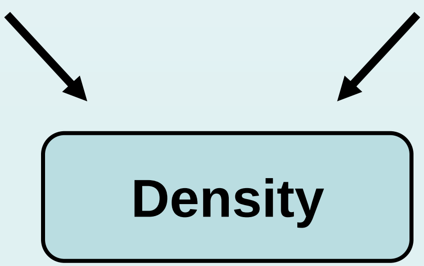
$$\% \text{ Error} = \left| \frac{\text{accepted value} - \text{observed value}}{\text{accepted value}} \right| \times 100\%$$

% Error = (78.0 C – 73.8 C) / 78.0 C x 100% = 5.38%

Units of Measurement

Measures





$d = m / v$

$d = g / L = g / m^3$

Units of **Volume** - liter

Volume is the amount of space a substance occupies.

Volume measurements depend on the state of matter (solid (s), liquid (l), or gas (g), and the shape of the matter.

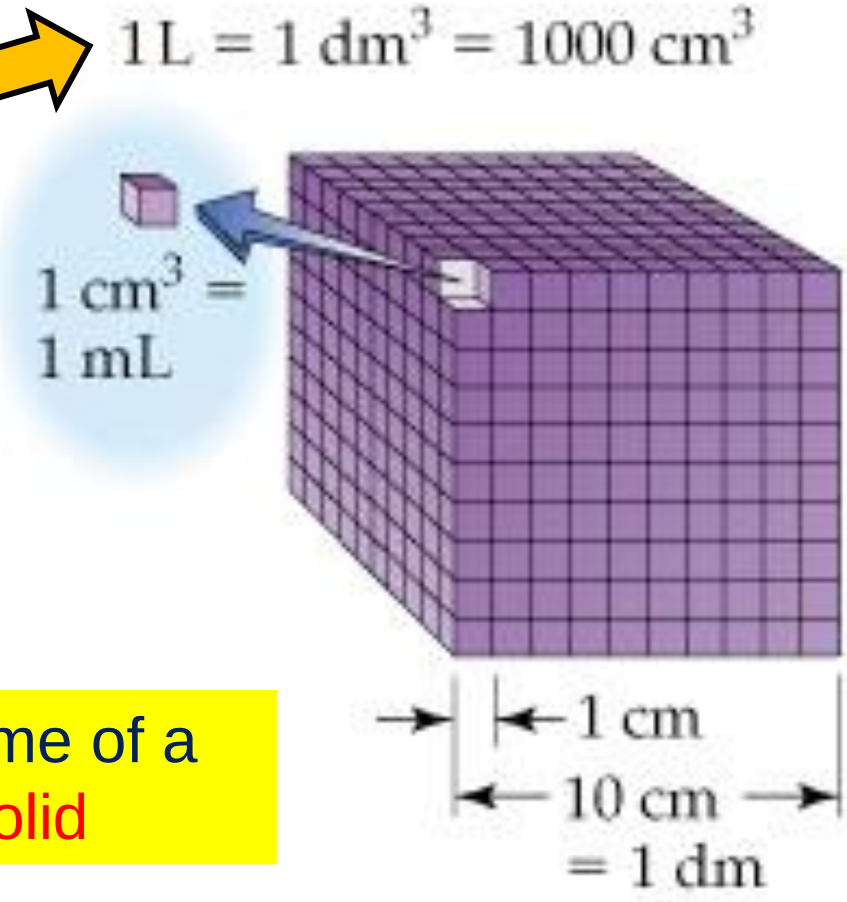
Volume measurements are obtained related to:

- REGULARLY shaped solids
- Liquids
- Irregularly shaped solids

Units of Volume - liter

Length (L) x Width (W) x Height (H) calculates volume.

Notice the equalities



cm^3 is used to find the volume of a REGULARLY shaped solid

How do these two volumes compare?

1 mL

Units of Measurement

Volume (liquids)

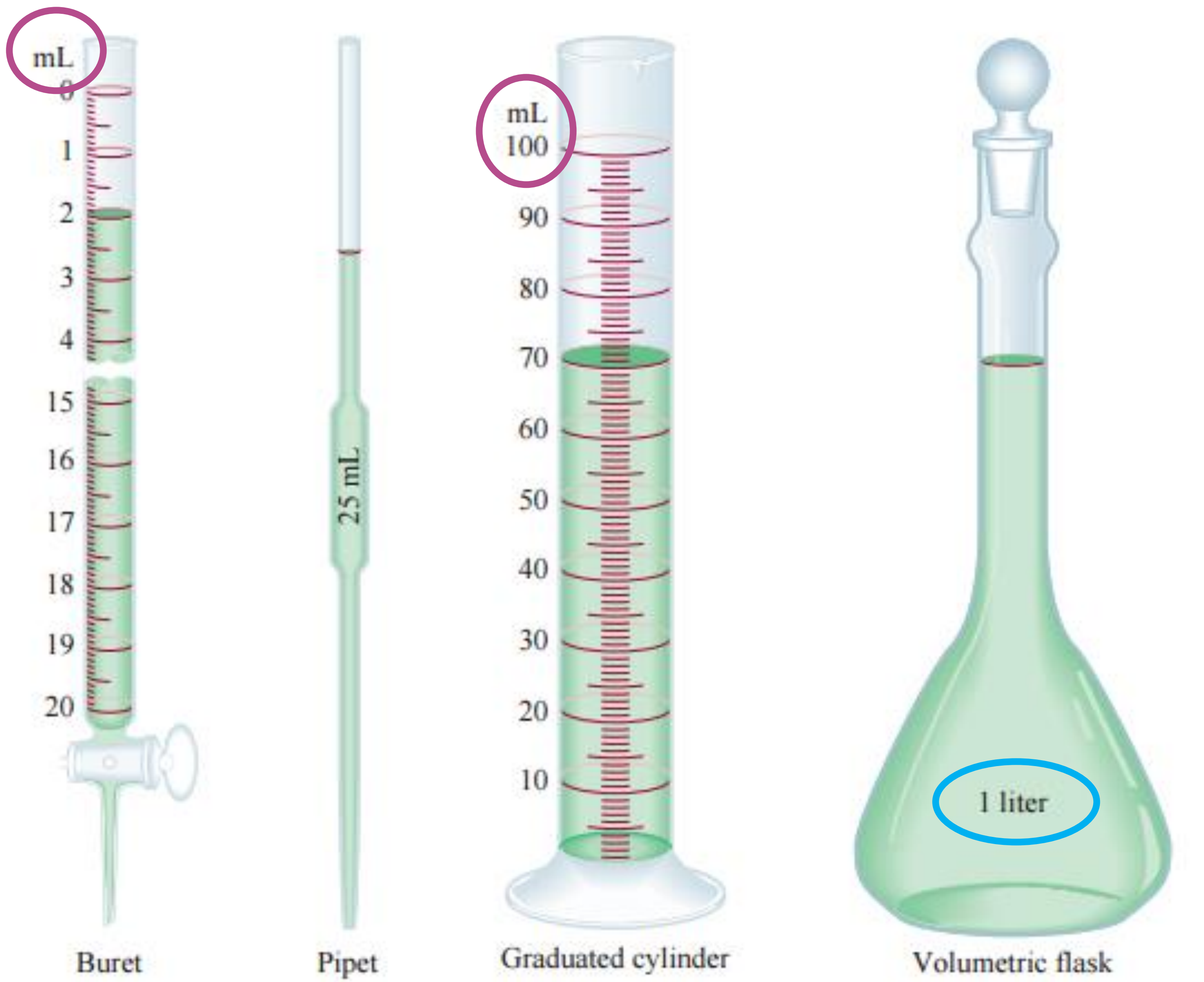
1 L = 1000 ml

↓ ↑ *liters are the bigger unit and have a smaller number*

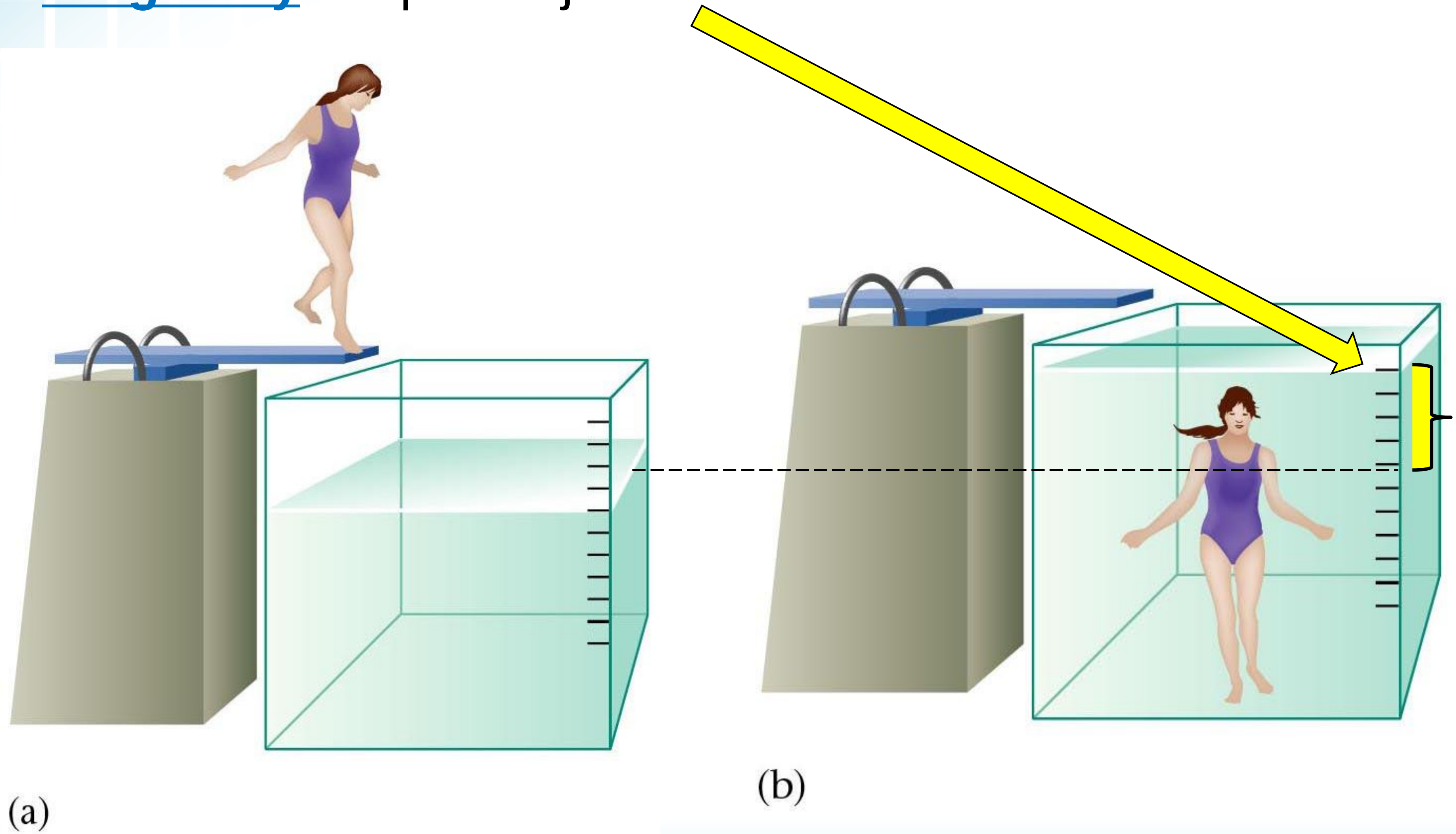
↑ ↓ *milliliters are the smaller unit and have a bigger number*

1 mL

Laboratory glassware used in measuring liquids



Water displacement can be used to find volume of **irregularly** shaped objects.



Units of Volume

The relationships among common metric units of volume are shown in the table below.

Metric Units of Volume			
Unit	**Symbol**	**Relationship**	**Example**
Liter	L	base unit	quart of milk ≈ 1 L
Milliliter	mL	10^3 mL = 1 L	20 drops of water ≈ 1 mL
Cubic centimeter	cm^3	1 cm^3 = 1 mL	cube of sugar ≈ 1 cm^3
Microliter	μL	10^6 μL = 1 L	crystal of table salt ≈ 1 μL

TRY IT

Name three ways (with units) to measure volume.

TRY IT

Name three ways (with units) to measure volume.

- Regularly shaped objects

  cm^3

- Liquids

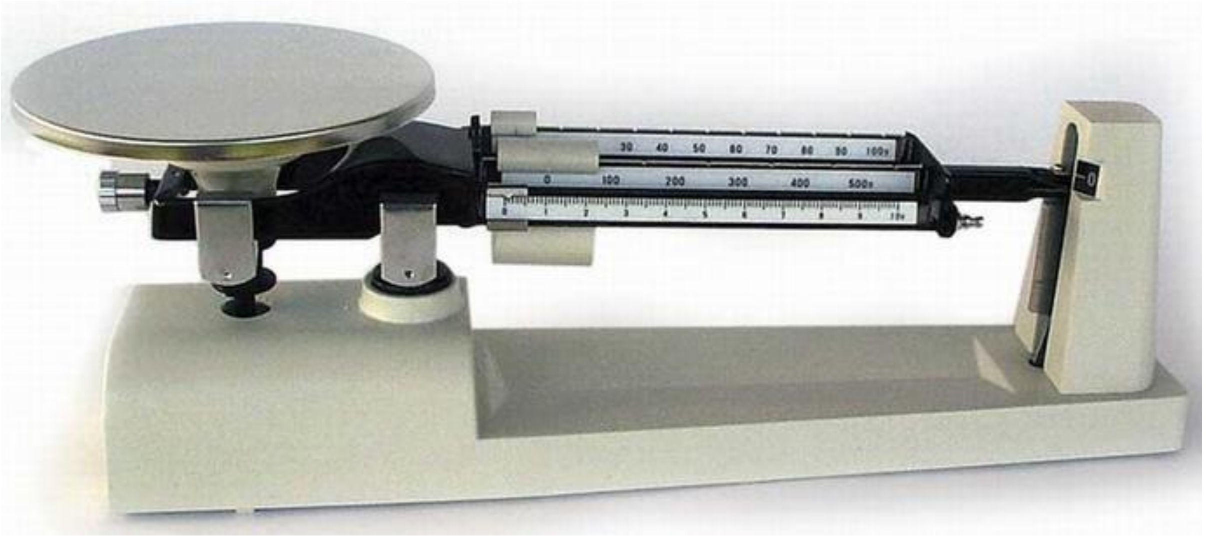
  ml

- Irregularly shaped objects

  water displacement (ml)

Units of Mass - kilogram

The mass of an object is the amount of matter an object contains. A typical classroom uses a triple beam balance to measure mass in grams.



1 **kilogram (kg)** is the basic SI unit of mass.

Units of Mass

The relationships among units of mass are shown in the table below.

Metric Units of Mass			
Unit	**Symbol**	**Relationship**	**Example**
Kilogram (base unit)	kg	1 kg = 10^3 g	small textbook ≈ 1 kg
Gram	g	1 g = 10^{-3} kg	dollar bill ≈ 1 g
Milligram	mg	10^3 mg = 1 g	ten grains of salt ≈ 1 mg
Microgram	μg	10^6 μg = 1 g	particle of baking powder ≈ 1 μg

Mass Versus Weight

Weight = mass x gravity

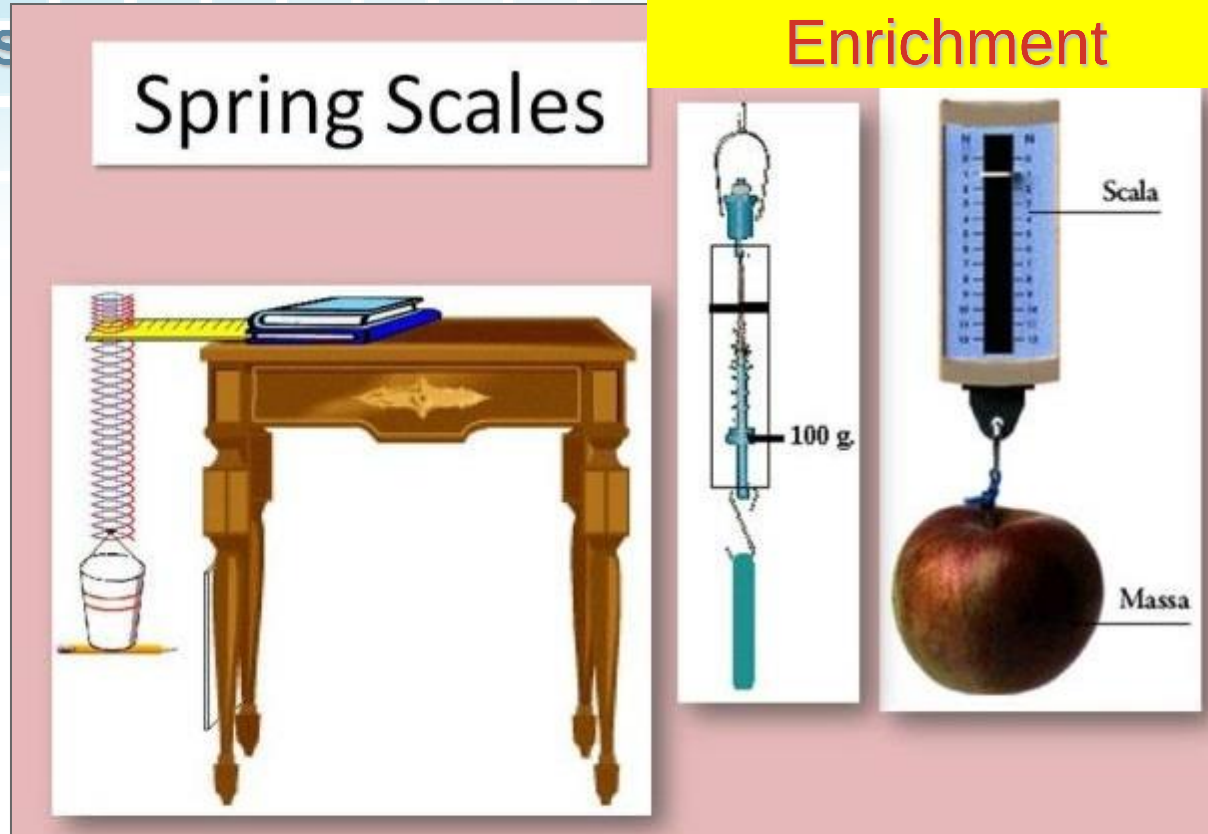
$$W = mg$$

The weight of an object can change with its location, but mass does not. *An astronaut in orbit is weightless, but not massless*.

Weight is a **FORCE**,

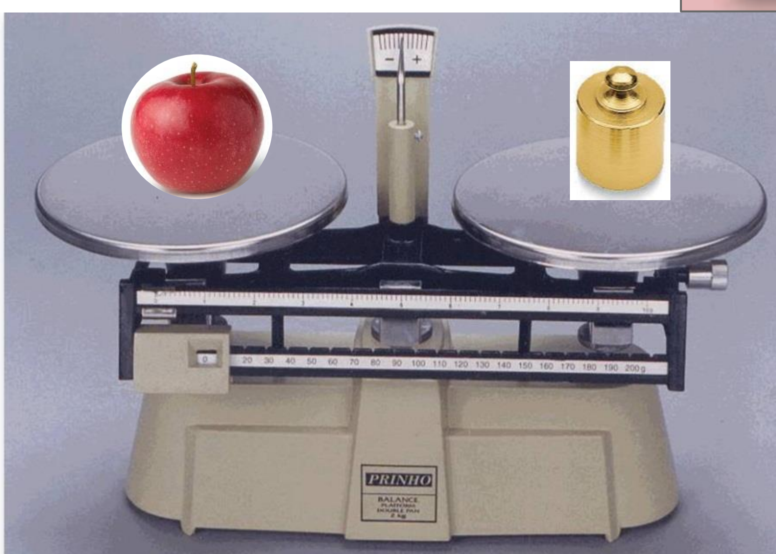
- measured in Newtons (SI unit) or pounds (English)

Enrichment



Measuring Mass vs. Weight

Two-pan balance



Mass – uses a balance

Weight – uses a spring scale (force).

Units of Energy

The capacity to do work or to produce heat is called **energy**.

The SI unit of energy is the **Joule (J)**

One **calorie (cal)** is the quantity of heat that raises the temperature of 1 g of pure water by 1° C.

Conversions between joules and calories can be carried out using the following relationships.

1 J = 0.2390 cal

1 cal = 4.184 J

1 kilojoule (KJ) = 1000 joules

1 kilocalorie (Kcal) = 1000 calories … "food calorie"

Temperature

A measure of the average kinetic energy (motion) of molecules in a substance.

Most people equate temperature with how “hot” or “cold” an object is. *But an Alaskan or an Egyptian would define hot and cold differently than you and I.*

80 ºF (27 ºC) would be “hot” to an Alaskan
But “cool” to an Egyptian

Temperature

A measure of the average kinetic energy (motion) of molecules in a substance.

Most substances expand with an increase in temperature and contract as the temperature decreases. (e.g. sidewalks in winter versus summer).

This explains how thermometers work (*the liquid inside expands & contracts*).

The SI (Metric) unit of temperature is the **Kelvin scale, K**, also known as the **absolute temperature scale because it begins at zero …** equal to –273.15° C.

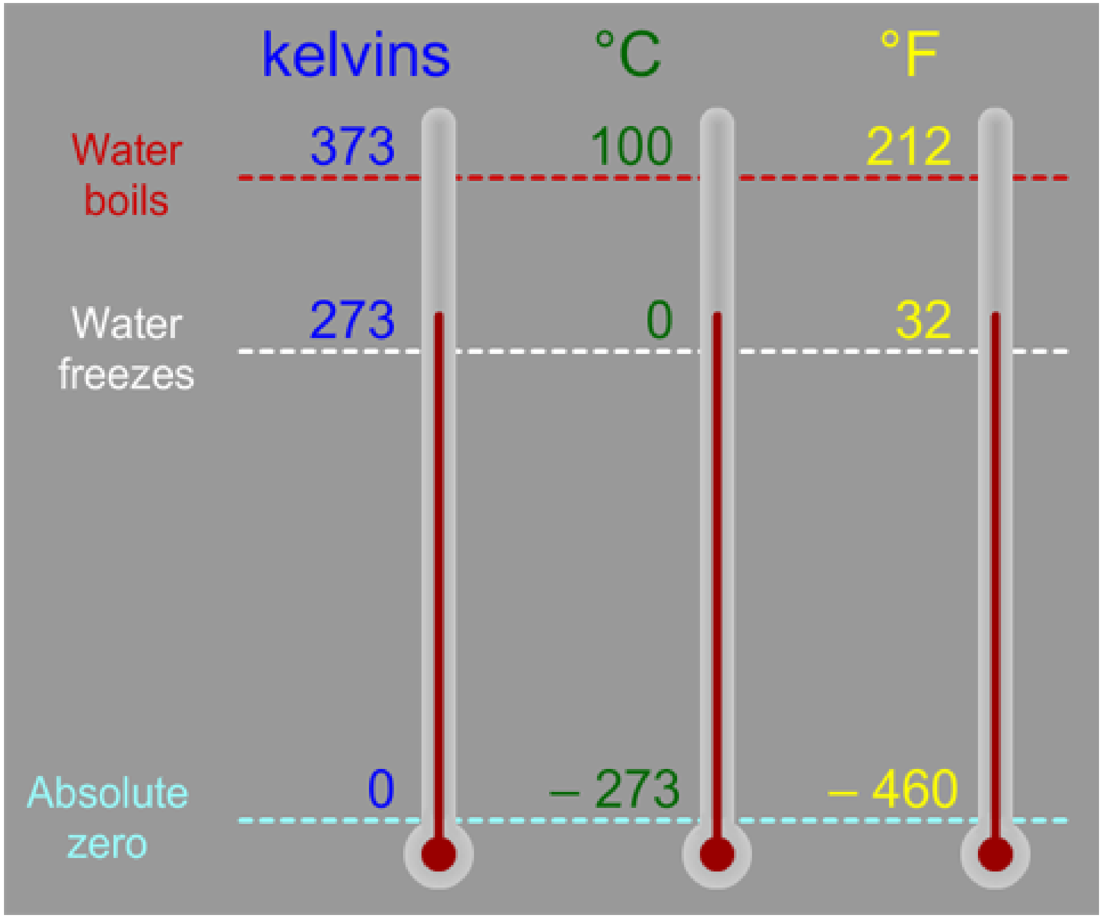
CONVERSIONS:

$$K = {}^{o}C + 273.15$$

$$ {}^{o}C = K - 273.15$$

$$ {}^{o}F = 9/5\ {}^{o}C + 32$$

$$ {}^{o}C = 5/9({}^{o}F - 32)$$



TRY IT

°C	K
0	
	0
100	
	100

Convert 80 °F to °C

Convert 100 °C to °F

Temperature

The measure of heat intensity: describes the average kinetic energy (KE) of the molecules in a system

Fahrenheit and Celsius

- F = 9/5 C + 32 ... 100 °C = 212 °F
- C = 5/9 (F - 32) ... 80 °F = 26.7 °C

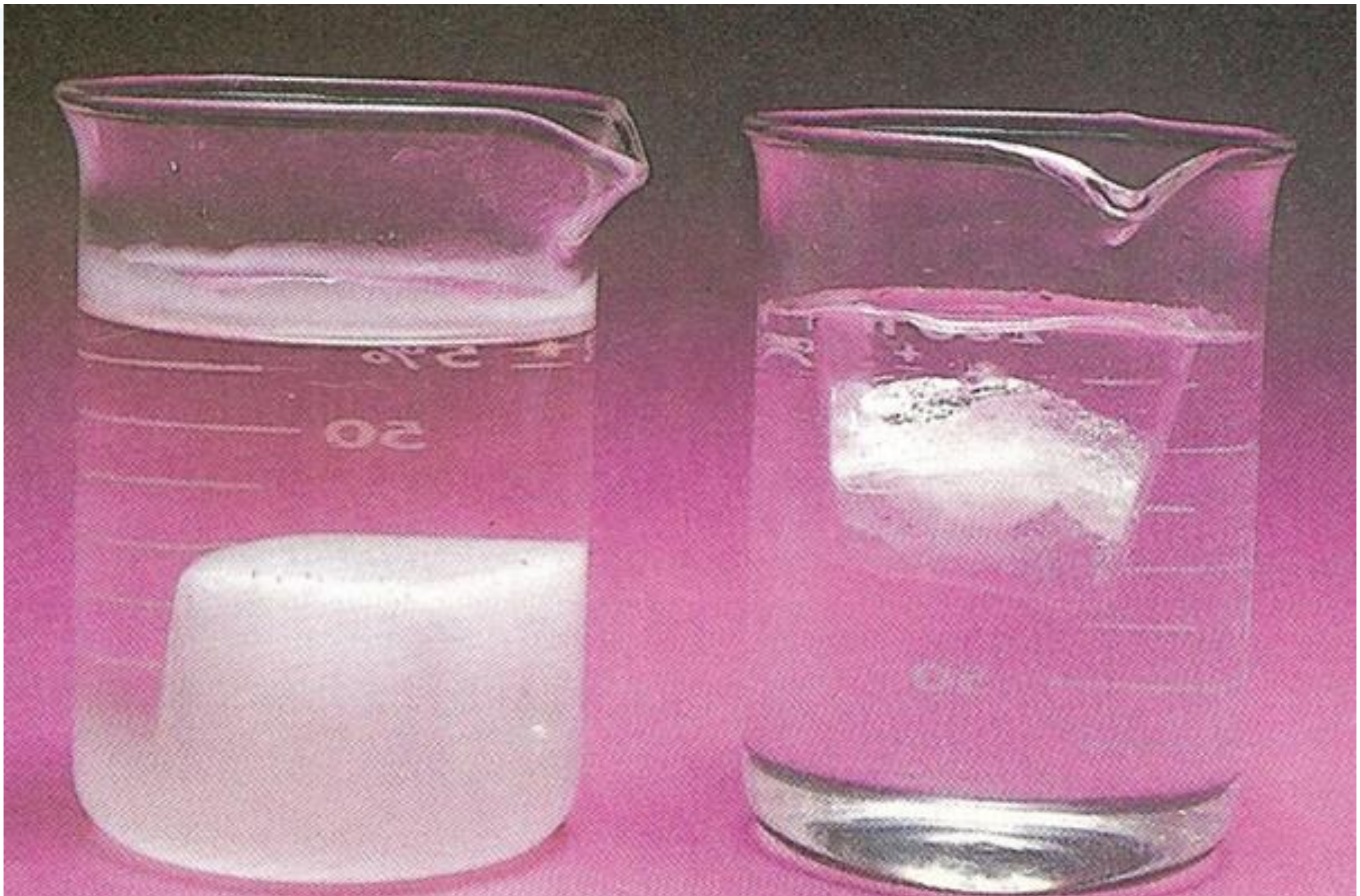
Kelvin vs. Celsius

- K = C + 273 C = K - 273
- 1 K increment = 1 C

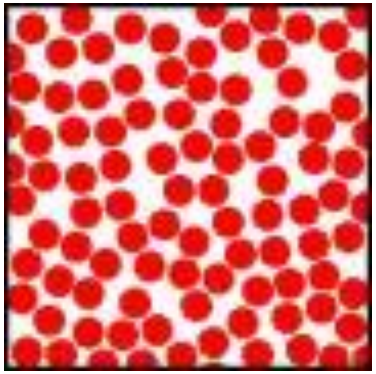
C	K
0	273
-273	0
100	373
-173	100

THINK ABOUT IT

What accounts for the difference in the two beakers?



Density – A measure of how tightly packed matter is;

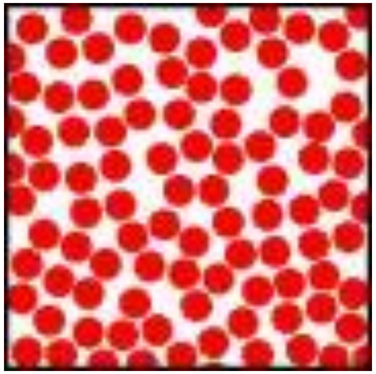


Defined as an object's mass divided by its volume.

Write an equation for density:

Density – A measure of how tightly packed matter is;

More DENSE

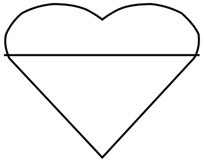


Less DENSE

Defined as an object's mass divided by its volume.

$$\rho = m / V$$

"d" is also fine



I "love" density

Density Overview

Soda Pop Cans in a Beaker of water. (1:02)

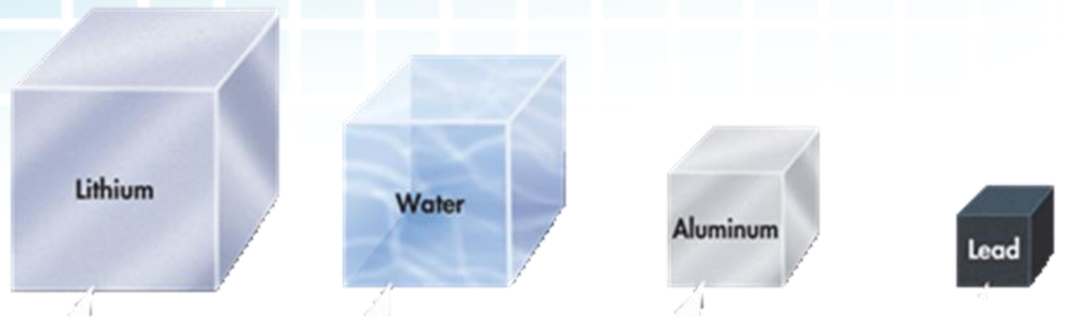
https://screencast-o-matic.com/watch/cFQ6reqGli

Density An Intensive Property

Beware of Whacky Scientist. (1:12)

https://screencast-o-matic.com/watch/cFQi2Cqp7O

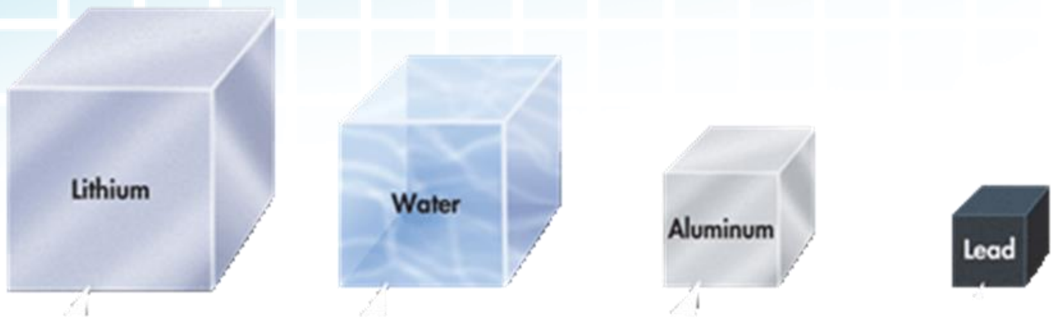
THINK ABOUT IT



$\frac{10\ g}{19\ cm^3}$	$\frac{10\ g}{10\ cm^3}$	$\frac{10\ g}{3.7\ cm^3}$	$\frac{10\ g}{0.88\ cm^3}$
$0.53\ g/cm^3$	$1.0\ g/cm^3$	$2.7\ g/cm^3$	$8.8\ g/cm^3$

Describe the relationship between volume and mass for the cubes above. Notice the densities.

THINK ABOUT IT



Lithium	Water	Aluminum	Lead
$\frac{10\ g}{19\ cm^3}$	$\frac{10\ g}{10\ cm^3}$	$\frac{10\ g}{3.7\ cm^3}$	$\frac{10\ g}{0.88\ cm^3}$
$0.53\ g/cm^3$	$1.0\ g/cm^3$	$2.7\ g/cm^3$	*8.8* g/cm^3

Density and volume are inversely proportional: ↑ ↓

If one keeps the mass the same, as the density increases, the volume the substance occupies decreases.

Density is an **intensive property** that **depends only on the composition of a substance**, not the size of the sample.

Measuring Density 1: (0:17)

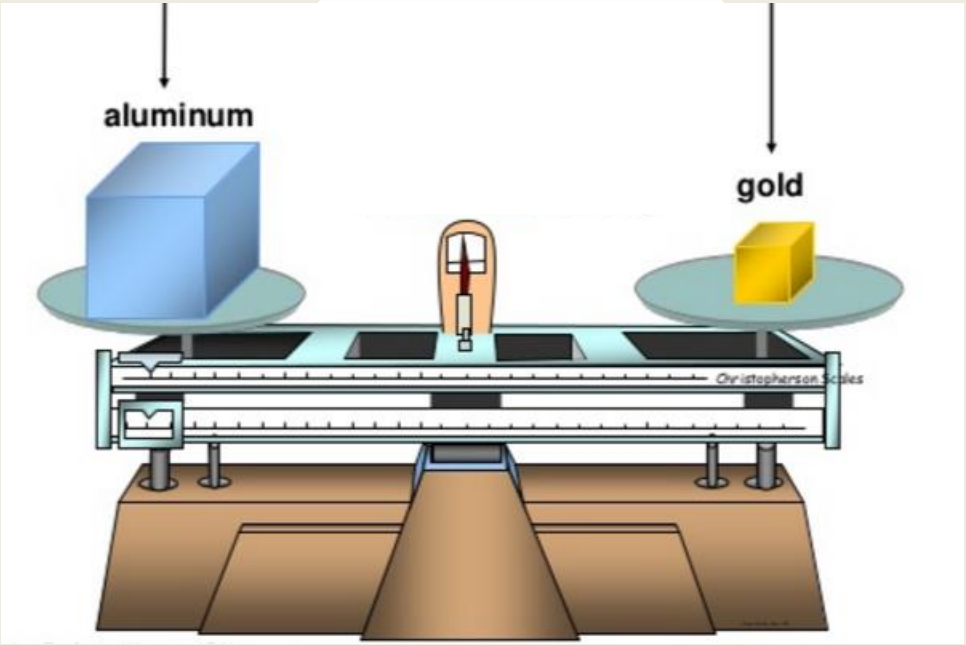
https://screencast-o-matic.com/watch/cFQ6r3qGIz

Measuring Density 2: (2:57)

https://screencast-o-matic.com/watch/cFQ60NqG0I

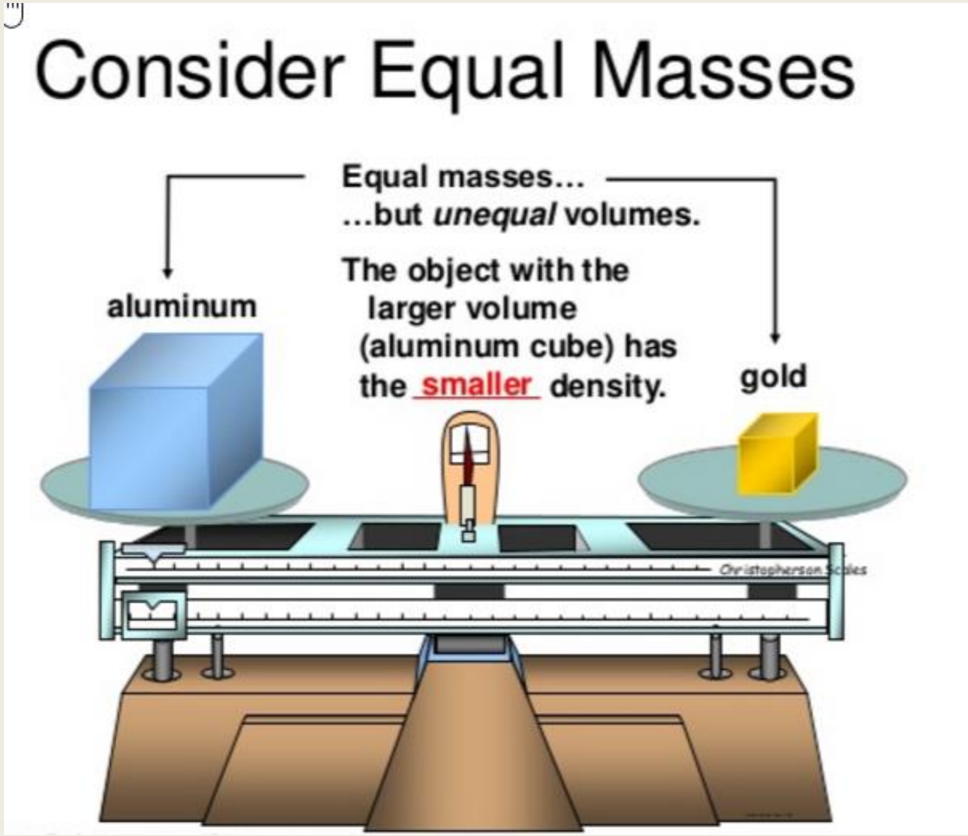
Density

- Why would the two sides be balanced (as shown in the picture)?



Density

- Why would the two sides be balanced (as shown in the picture)?
- **The mass of the objects must be the same since they balance out.**
- Aluminum has a larger **volume**, but a lesser density.
- **Density accounts for them being balanced**



Identify the Correct Units

A chemical reaction produces solid sulfur as a product. Which unit should be used to describe the mass of the sulfur produced?

O milliliters

O grams

O kilometers

O Kelvin

The volume of a gas must be measured at several points during an experiment. Which units should be used to describe the volume of the gas?

O liters

O centimeters

O degrees Celsius

O milligrams

Explain why one substance will float in another:

helium balloons in air

Ice or wood in water

Which has more mass, a ton of bricks or a ton of feathers? What measure would be different?

Identify the Correct Units

QUICK CHECK

A chemical reaction produces solid sulfur as a product. Which unit should be used to describe the mass of the sulfur produced?

- O milliliters … volume
- **O grams**
- O kilometers … distance
- O Kelvin … temperature

Explain why one substance will float in another:

helium balloons in air

Ice or wood in water

DENSITY

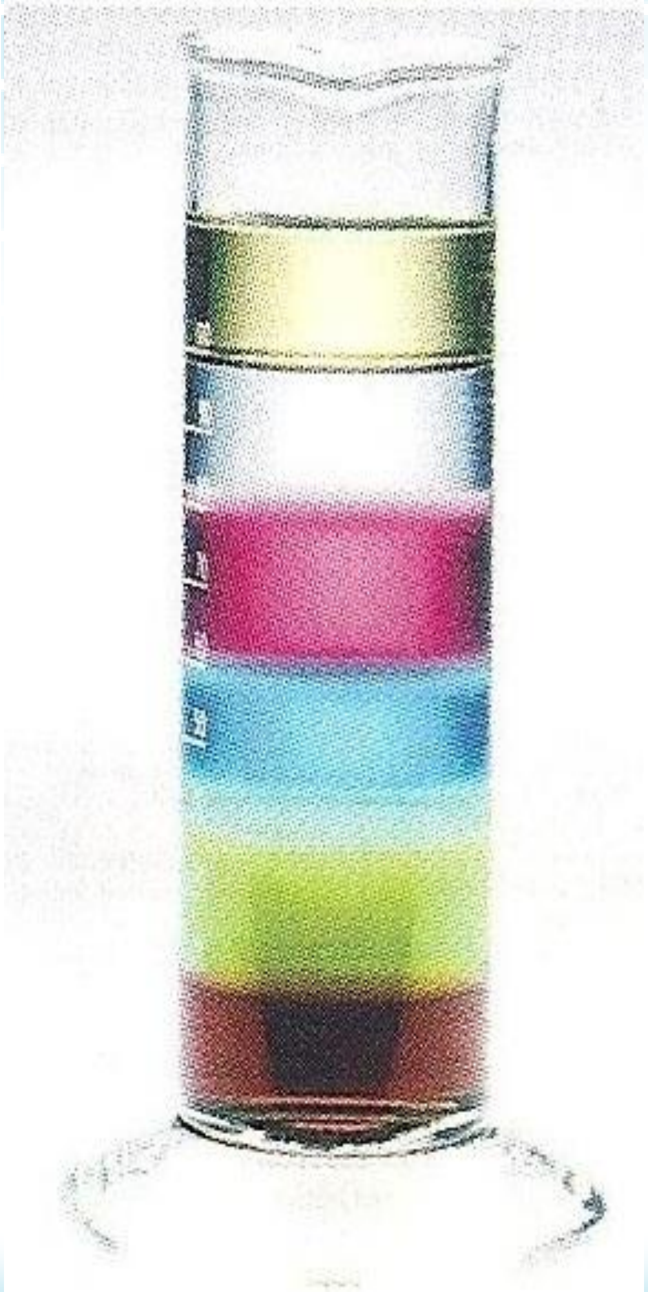
The volume of a gas must be measured at several points during an experiment. Which units should be used to describe the volume of the gas?

- **O liters**
- O centimeters … distance
- O degrees Celsius … temperature
- O milligrams … mass

Which has more mass, a ton of bricks or a ton of feathers? What measure would be different?

Same mass. The brick would take up a much smaller volume than the feathers because its density is so much larger.

TRY IT

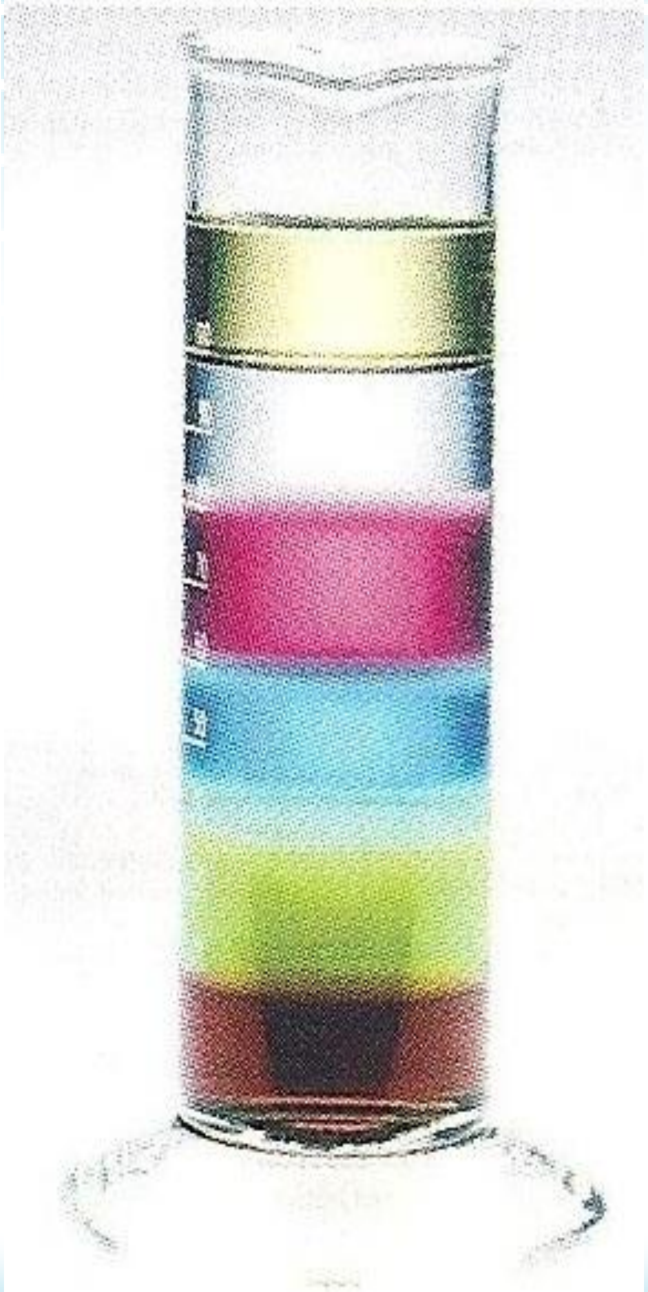


Experiment :
The Density of Liquids

Which layer represents which substance?

Antifreeze	*1.13 g/ml*
Corn oil	*0.93 g/ml*
Dish detergent	*1.03 g/ml*
Maple syrup	*1.32 g/ml*
Shampoo	*1.01 g/ml*
Water	*1.00 g/ml*

TRY IT



Experiment :
The Density of Liquids

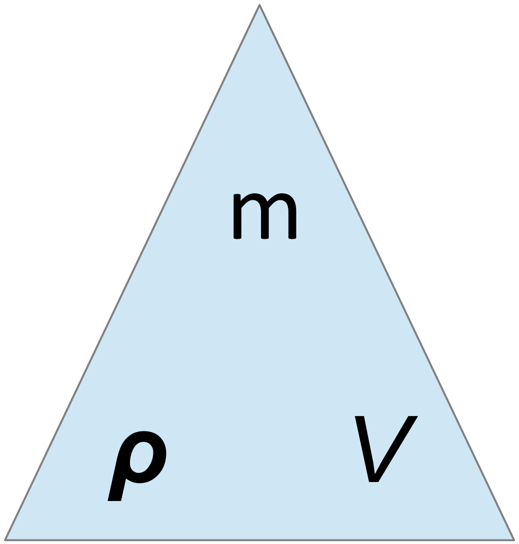
Which layer represents which substance?

Corn oil	*0.93 g/ml*
Water	*1.00 g/ml*
Shampoo	*1.01 g/ml*
Dish detergent	*1.03 g/ml*
Antifreeze	*1.13 g/ml*
Maple syrup	*1.32 g/ml*

Densities of Some Common Materials			
Solids and Liquids		Gases	
Material	Density at 20° C (g/cm^3)	Material	Density at 20° C (g/L)
Gold	19.3	Chlorine	2.95
Mercury	13.6	Carbon dioxide	1.83
Lead	11.3	Argon	1.66
Aluminum	2.70	Oxygen	1.33
Table sugar	1.59	Air	1.20
Corn syrup	1.35–1.38	Nitrogen	1.17
Water (4° C)	1.000	Neon	0.84
Corn oil	0.922	Ammonia	0.718
Ice (0° C)	0.917	Methane	0.665
Ethanol	0.789	Helium	0.166
Gasoline	0.66–0.69	Hydrogen	0.084

Calculating Density (1:19)

https://screencast-o-matic.com/watch/cFQ6r2qGIL



TRY IT

A copper penny has a mass of 3.1 g and a volume of 0.35 cm^3. What is the density of copper? ("AGES")

TRY IT

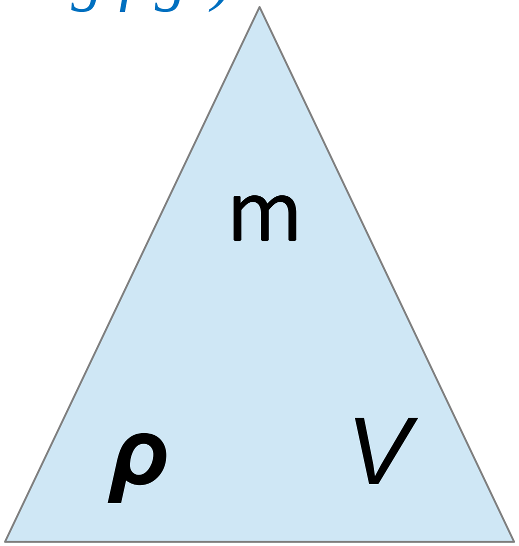
Calculating Density

A copper penny has a **mass** of 3.1 g *(2 sig figs)*

and a **volume** of 0.35 cm^3 *(2 sig figs).*

What is the **density** of copper?

$$\rho = m / V$$



$$\text{Density} = \frac{3.1\text{ g}}{0.35\text{ cm}^3} = 8.8571\text{ g/cm}^3 = \mathbf{8.9\text{ g/cm}^3}$$

(2 sig figs)

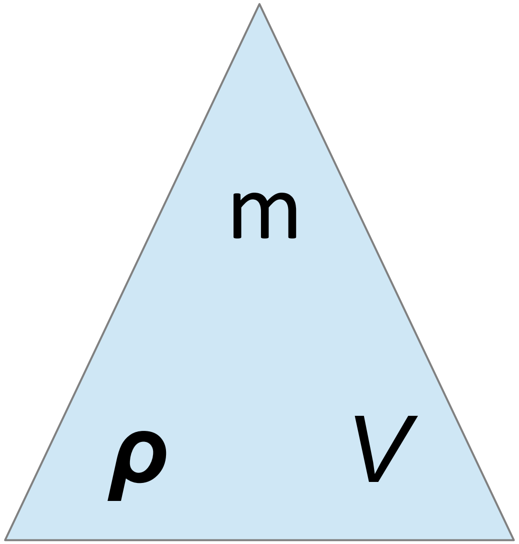
TRY IT

What is the volume of a pure silver coin that has a mass of 14.0 g? The density of silver (Ag) is 10.5 g/cm^3. ("AGES")

TRY IT

What is the **volume** of a pure silver coin that has a mass of 14.0 g *(3 sig figs)*? The density of silver (Ag) is 10.5 g/cm^3 *(3 sig figs)*.

$$V = m / \rho$$



V = 14.0 ~~g~~ / 10.5 ~~g~~/cm^3 = 1.33 cm^3

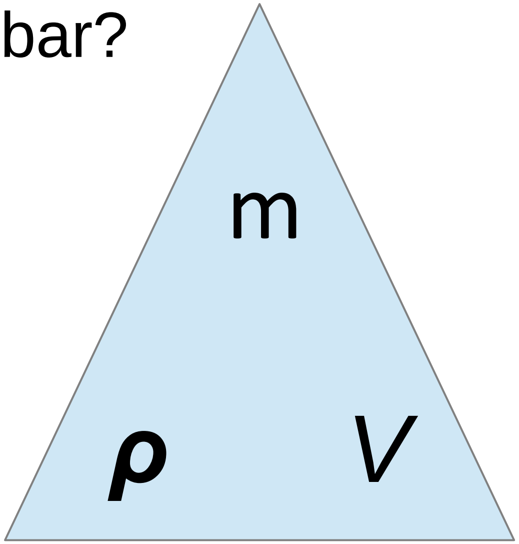
(3 sig figs)

TRY IT

A gold bar displaces water 4.7 ml. The density of gold (Au) is 19.0 g/cm^3. What is the mass of the gold bar? ("AGES")

TRY IT

A gold bar displaces water 4.7 ml. The density of gold (Au) is 19.0 g/cm^3. What is the mass of the gold bar?



Displacement → volume

$$m = \rho \times V$$

$1\ cm^3 = 1\ ml$

$$m = 19.0\ g/\cancel{cm^3} \times 4.7\ \cancel{ml} \times \cancel{1\ cm^3}/\cancel{1\ ml}$$

$$= 89.3\ g \rightarrow 89\ g$$ *(2 sig figs)*

Scientists constantly convert measurements according to units.

This is called dimensional analysis or factor labeling.

We are constantly converting measurements according to units.

1 U.S. dollars = 0.89 euros

For money we call it "exchange rate"

To convert units

- cancel out the undesired unit
- leave the desired unit.

Begin with **Equalities**.

1000 g = 1 kg

Create **Conversion Factors**.

?

To convert units

- cancel out the undesired unit
- leave the desired unit.

Begin with Equalities.

$$1000 \text{ g} = 1 \text{ kg}$$

Create Conversion Factors.

$$\frac{1000 \text{ g}}{1 \text{ kg}} \quad \text{and} \quad \frac{1 \text{ kg}}{1000 \text{ g}}$$

Conversion factors:

- Allow us to convert units
- Use equalities as a ratio of equivalent measurements
    - ✓ The measurement in the numerator is equivalent to the measurement in the denominator.
- Are MULTIPLYING by "ONE"

Convert 2.4 kg to g

Convert 2.4 kg to g

Kg are larger than g … # kg ↓ # g ↑

g → kg … milli, centi, deci, gram, deka, hecta, kilo

… 3 multiples of ten … move decimal to the right … E↓

2.4 = 2,400 g

Equality: 1000 g = 1 kg

Conversion Factor: 1000 g/1 kg

2.4 ~~kg~~ x 10^3 g/~~1 kg~~ = 2.4 x 10^3 g

NOTE: kg cancels out … g are left

In general, a calculated answer cannot be more precise than the least precise measurement from which it was calculated.

The calculated value must be rounded to make it consistent with the measurements from which it was calculated.

Addition and Subtraction

The answer to an addition or subtraction calculation should be rounded to the same place (units, tens, etc.) as the **least precise** measurement.

TRY IT

$$\begin{array}{r} 12.52 \text{ meters} \\ 349.0 \text{ meters} \\ +\ \ 8.24 \text{ meters} \\ \hline \end{array}$$

In general, a calculated answer cannot be more precise than the least precise measurement from which it was calculated.

The calculated value must be rounded to make it consistent with the measurements from which it was calculated.

Addition and Subtraction

The answer to an addition or subtraction calculation should be rounded to the same place (units, tens, etc.) as the **least precise** measurement.

$$\begin{array}{r l} 12.52 & \text{meters} \\ 349.0 & \text{meters} \\ +\quad 8.24 & \text{meters} \\ \hline 369.76 & \text{meters} \end{array}$$

*369.**8** meters (nearest tenth)*

3.698×10^2 m

Multiplication and Division

In calculations involving multiplication and division, you need to round the answer to the same number of significant figures as the measurement with the **least number of significant figures**.

The position of the decimal point has nothing to do with the rounding process when multiplying and dividing measurements.

TRY IT

e.g. 7.55 meters x 0.34 meter = ?

Multiplication and Division

In calculations involving multiplication and division, you need to round the answer to the same number of significant figures as the measurement with the **least number of significant figures**.

The position of the decimal point has nothing to do with the rounding process when multiplying and dividing measurements.

TRY IT

e.g. 7.55 meters x 0.34 meter = 2.567 meters^2

3 Sig Figs **2 Sig Figs** = **2.6 meters^2**

2 Sig Figs

Converting Between Metric Units

The diameter of a sewing needle is 0.073 hm. What is the diameter in millimeters?

TRY IT

Convert 0.073 hm to mm

hm are larger than mm … # hm ↓ # mm ↑

mm → hm … milli, centi, deci, meter, deka, hecta, kilo

… 5 multiples of ten … move decimal to the right … E↓

0.073 = 7,300 mm

Equalities: 100 m = 1 hm; 1000 mm = 1 m

Create conversion factors.

Converting Between Metric Units

The diameter of a sewing needle is 0.073 hm. What is the diameter in millimeters?

A: mm

G: 0.073 hm

E: 1 hm = 10^2 m … go to the "standard"

10^3 mm = 1 m

S: begin with the amount GIVEN

0.073 hm … change to scientific notation

 # 1 to 9 7.3 (# ↑ , therefore Exp. ↓) x 10^{-2} dm

Prefix	Multiplier	Exponential
yotta	1,000,000,000,000,000,000,000,000	10^{24}
zetta	1,000,000,000,000,000,000,000	10^{21}
exa	1,000,000,000,000,000,000	10^{18}
peta	1,000,000,000,000,000	10^{15}
tera	1,000,000,000,000	10^{12}
giga	1,000,000,000	10^{9}
mega	1,000,000	10^{6}
kilo	1,000	10^{3}
hecto	100	10^{2}
deca	10	10^{1}
	1	10^{0}
deci	0.1	10^{-1}
centi	0.01	10^{-2}
milli	0.001	10^{-3}
micro	0.000001	10^{-6}
nano	0.000000001	10^{-9}
pico	0.000000000001	10^{-12}
femto	0.000000000000001	10^{-15}
atto	0.000000000000000001	10^{-18}
zepto	0.000000000000000000001	10^{-21}
yocto	0.000000000000000000000001	10^{-24}

m, l, g → standards

Converting Between Metric Units

The diameter of a sewing needle is 0.073 hm. What is the diameter in millimeters?

10^2 m = 1 hm … 10^3 mm = 1 m

7.3×10^{-2} hm = mm

Remember: when dividing exponents, subtract superscripts

when multiplying exponents, add superscripts

Converting Between Metric Units

The diameter of a sewing needle is 0.073 dm. What is the diameter in millimeters?

$$7.3 \times 10^{-2}\ \text{hm} \times \frac{10^{2}\ \text{m}}{1\ \text{hm}} \times \frac{10^{3}\ \text{mm}}{1\ \text{m}} = 7.3 \times 10^{2}\ \text{mm}$$

Remember: when dividing exponents, subtract superscripts

when multiplying exponents, add superscripts

NOTE: hm cancels out … mm are left

Converting Between Metric Units

The density of manganese (Mn), a metal, is 7.21 g/cm^3. What is the density of manganese expressed in units of kg/m^3?

Converting Between Metric Units

The density of manganese (Mn), a metal, is 7.21 g/cm^3. What is the density of manganese expressed in units of kg/m^3?

A: kg/m^3

G: 7.21 g/cm^3

E: 10^3 g = 1 kg

10^2 cm = 1 m … therefore, cube this relationship:

10^2 cm · 10^2 cm · 10^2 cm = **10^6 cm^3 = 1 m^3**

S: begin with the amount GIVEN: **7.21 g/cm^3**

Prefix	Multiplier	Exponential
yotta	1,000,000,000,000,000,000,000,000	10^{24}
zetta	1,000,000,000,000,000,000,000	10^{21}
exa	1,000,000,000,000,000,000	10^{18}
peta	1,000,000,000,000,000	10^{15}
tera	1,000,000,000,000	10^{12}
giga	1,000,000,000	10^{9}
mega	1,000,000	10^{6}
kilo	1,000	10^{3}
hecto	100	10^{2}
deca	10	10^{1}
	1	10^{0}
deci	0.1	10^{-1}
centi	0.01	10^{-2}
milli	0.001	10^{-3}
micro	0.000001	10^{-6}
nano	0.000000001	10^{-9}
pico	0.000000000001	10^{-12}
femto	0.000000000000001	10^{-15}
atto	0.000000000000000001	10^{-18}
zepto	0.000000000000000000001	10^{-21}
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m, l, g → standards

Converting Between Metric Units

The density of manganese (Mn), a metal, is 7.21 g/cm^3. What is the density of manganese expressed in units of kg/m^3?

10^3 g = 1 kg … **10^6 cm^3 = 1 m^3**

$$\frac{7.21\ \text{g}}{\text{cm}^3} = \text{kg/m}^3$$

Remember: Go ONE step at a time! (K. I. S.)

factor label grams to kg first, then deal with cm^3 to m^3

Converting Between Metric Units

The density of manganese (Mn), a metal, is 7.21 g/cm^3. What is the density of manganese expressed in units of kg/m^3?

$$\frac{7.21\ \cancel{g}}{1\ \cancel{cm^3}} \times \frac{1\ kg}{10^3\ \cancel{g}} \times \frac{10^6\ \cancel{cm^3}}{1\ m^3} = 7.21 \times 10^3\ kg/m^3$$

Practice: Convert 1453 g/cm^3 to kg/L

Practice: Convert 1453 g/cm^3 to kg/L

A: kg/L

G: 1453 g/cm^3

E: 10^3 g = 1 kg

1 cm^3 = 1 mL

10^3 mL = **1 L**

S: begin with the amount GIVEN: **1453 g/cm^3**

Prefix	Multiplier	Exponential
yotta	1,000,000,000,000,000,000,000,000	10^{24}
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m, l, g → standards

Practice: Convert $1453\ g/cm^3$ to kg/L

Use equalities and conversion factors to cancel undesired units and leave desired units.

$$1453\ g/cm^3 \times 1\ kg/10^3\ g$$

Practice: Convert 1453 g/cm^3 to kg/L

Use equalities and conversion factors to cancel undesired units and leave desired units.

$1453\ \text{g/cm}^3 \times 1\ \text{kg}/10^3\ \text{g}$

$1453\ \text{g/cm}^3 \times 1\ \text{kg}/10^3\ \text{g} \times \text{cm}^3/1\ \text{ml}$

$1453\ \text{g/cm}^3 \times 1\ \text{kg}/10^3\ \text{g} \times \text{cm}^3/1\ \text{ml} \times 10^3\ \text{ml} / 1\ \text{L} =$

1453 kg/L … change to scientific notation

= **1.453 x 10^3 kg/L**

(# ↓, therefore Exp. ↑)