Science and Measurements

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~ When mathematics becomes the language of science and observation. ~

Measurement

- Observations can be **qualitative** or **quantitative**
  - **Qualitative** observations are non-numerical, they ask “what”
  - **Quantitative** observations are numerical, they ask “how much”
  - Quantitative observations are also called **measurements**

Scientific Measurements and Units

All measurements contain two essential pieces of information:

a number (the quantitative piece)

a unit (the qualitative piece)

The number 60 is somewhat meaningless without units. Consider this for one's wages:

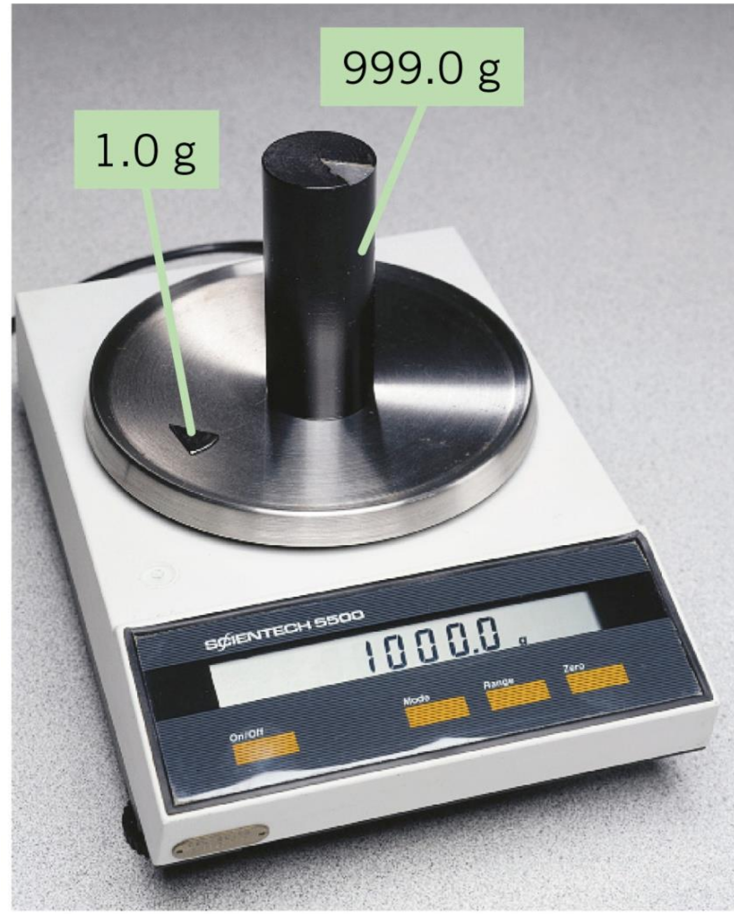
$ per week

$ per hour   which is preferable?!

The Role of Technology

Our ability to make observations is limited by our physical bodies.

Technology and tools extend and enhance our ability to make observations – both qualitative and quantitative.



- Measurements:
  - Always involve a comparison
  - Require units
  - Involve numbers that are **inexact** **(**numbers in mathematics are **exact**)
  - Include **uncertainty** due to the inherent physical limitations of the observer and the instruments used (to make the measurement)
  - Uncertainty is also called **error**

- Chemists use SI and metric units for measurements
- All SI and metric units are based on a set of measured **base units**:

Measurement	Unit	Symbol
Length	meter	m
Mass	gram	g
Time	second	s
Electrical current	ampere	A
Temperature	Kelvin	K
Amount of substance	mole	mol

- **Derived units** involve a combination of base units, including:

Measurement	Formula	SI Units
Area	length x width	m^2
Volume	length x width x height	m^3
Velocity	distance/time	m/s
Acceleration	velocity/time	m/s^2
Density	mass/volume	kg/m^3

Note: Many other derived units exist

- Base units are frequently too large or small for a measurement
- **Decimal multipliers** are used to adjust the size of base units, including

Prefix	Symbol	Factor	Power of 10
kilo	k	1000	10^3
deci	d	0.1	10^{-1}
centi	c	0.01	10^{-2}
milli	m	0.001	10^{-3}

(Use the handout for a more complete list.)

- English and Metric units are related using *conversion factors.*
- ***There are many, but there are five that you should memorize:***

Measurement	English to Metric	
Length	*1 in. = 2.54 cm	(defined)
Mass	1 lb = 454 g	(3 sig figs)
Volume	1 gal = 3.785 L	(4 sig figs)

Other helpful conversions:

*1mL = 1 cm^3

*1g = 1 mL (water @ 4º C)

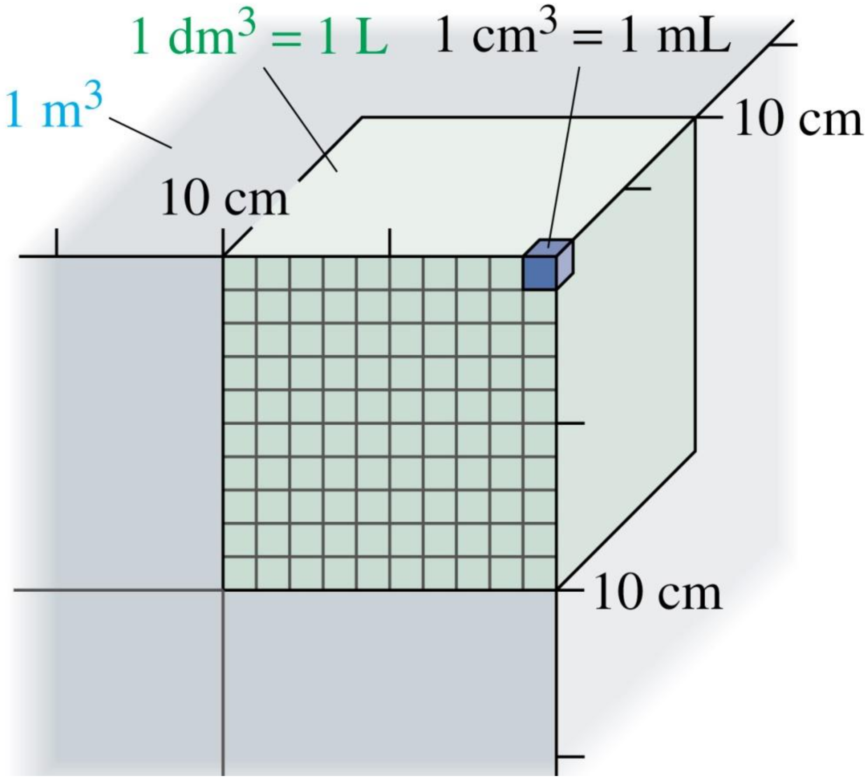
(* = defined quantity)

Measuring Volume

Volume is the amount of space an object occupies.
Volume units typically use the Liters base unit

Very convenient for measuring the volume of irregularly shaped containers

Measuring Volume, cont.

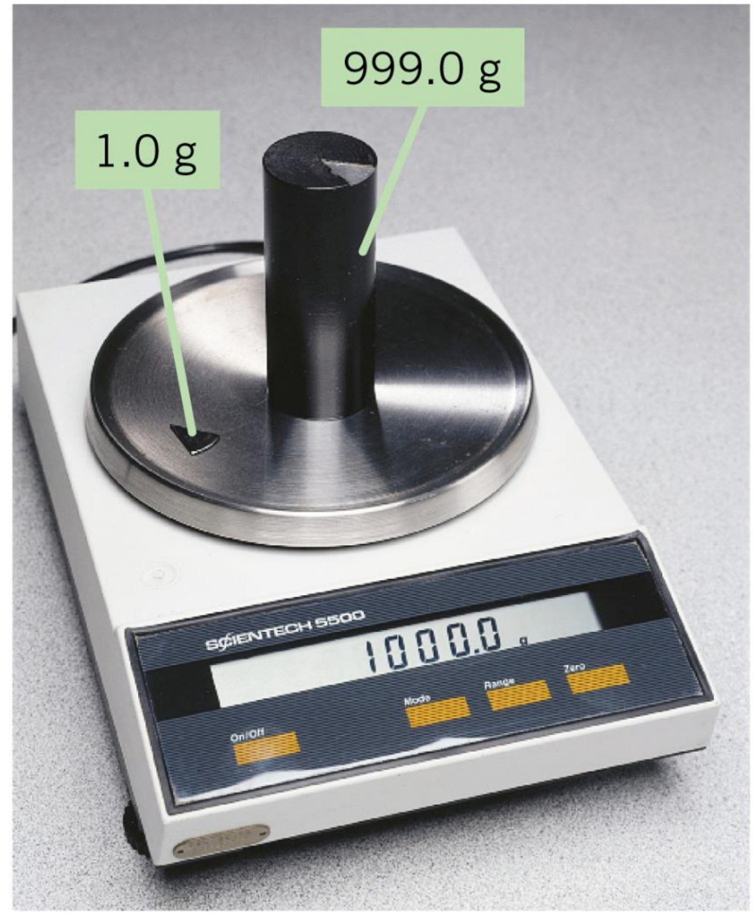


Regularly shaped objects can use a variant of the volume unit … cubic distance units

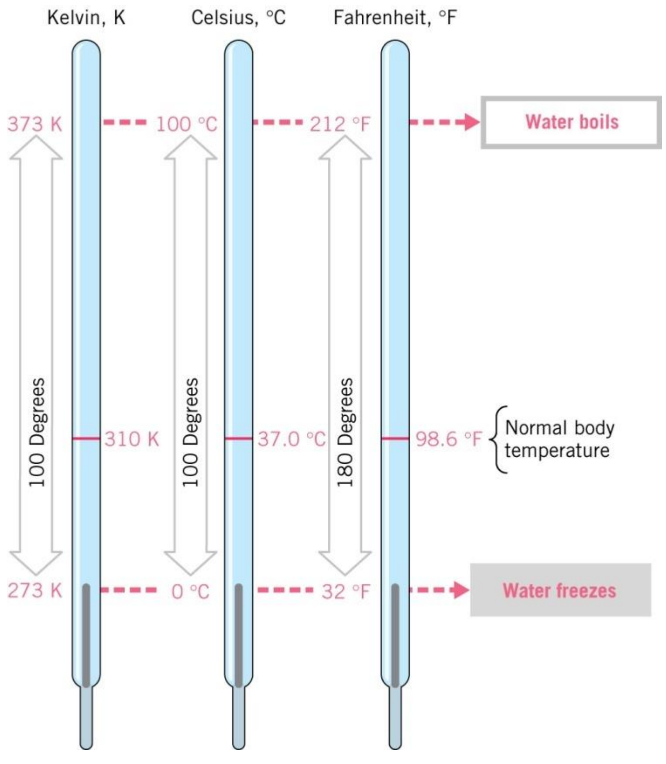
e.g., m^3, cm^3, etc.

Measuring Mass

- Mass is the amount of matter an object contains.
- The base unit for mass is the gram (or kilogram in the SI System.)
- Mass is determined by weighing the object using a **balance**
- Mass differs from wiegght because weight includes a factor for gravity.



- Temperature is measured in degrees Celsius or Fahrenheit using a **thermometer**



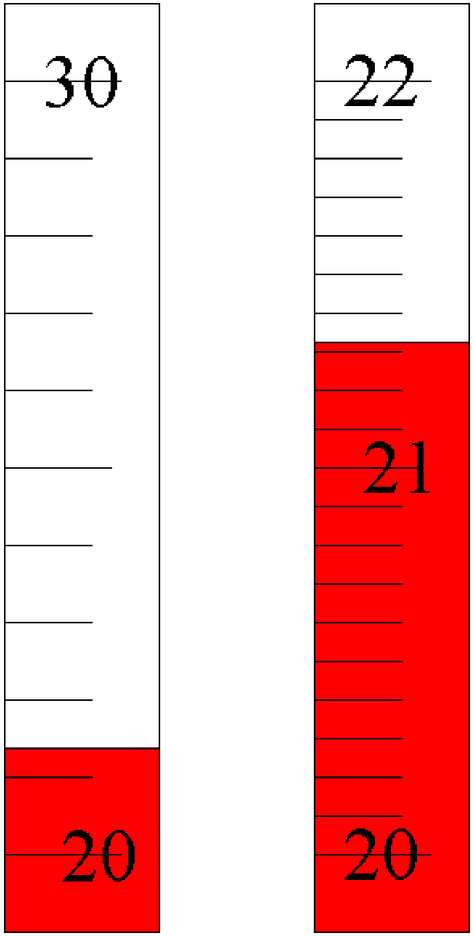
Relationship between the Kelvin (SI), Celsius, and Fahrenheit temperature scales. Kelvin temperature is also called the **absolute temperature** scale.

- The difference between a measurement and the “true” value we are attempting to measure is called the error
- Errors are due to limitations inherent in the measurement procedure
- In science, all digits in a measurement up to and including the first estimated digit are recorded
- These digits are called **significant digits** or **significant figures**

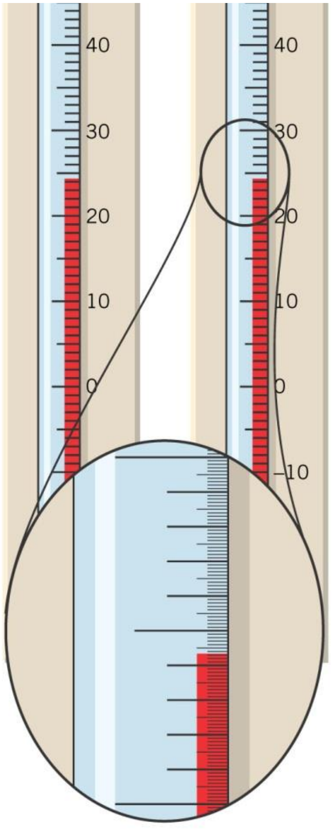
Significant Digits In A Measurement Are Limited By Instrument Precision

- Using the first thermometer, the temperature is 21.3 ^{o}C (3 significant digits)

- Using the more precise (second) thermometer, the temperature is 21.32 ^{o}C (4 significant digits)



- The number of significant digits in a measurement may be increased by using a more precise instrument



Using the first thermometer, the temperature is 24.3 ºC (3 significant digits).

Using the more precise (second) thermometer, the temperature is 24.32 ºC (4 significant digits)

Errors Arise From A Number Of Sources Including:

- Errors-inherent error due to the equipment or procedure
  - Changing volume due to thermal expansion or contraction (temperature changes)
  - Improperly calibrated equipment
  - procedural design allows variable measurements
- Mistakes-blunders that you know that you have made. Do not use these data
  - Spillage
  - Incomplete procedures
  - Reading scales incorrectly
  - Using the measuring device incorrectly

Reducing Error:

- Errors can often be detected by making repeated measurements
- Error can be reduced by calibrating equipment
- The ***average*** or ***mean*** reduces data variations: it helps find a central value

- **Minimizing Error:** Critically thinking about how measurements are made and how these may affect experimental results.

- **Accuracy** and **precision** are terms used to describe a collection of repeated measurements
  - An *accurate* measurement is close to the true or correct value
  - A *precise* measurement is close to the average of a series of repeated measurements

Accuracy vs. Precision

Good accuracy
Good precision

Poor accuracy
Good precision

Poor accuracy
Poor precision

- Measurements limit the precision of the results calculated from them.

- Rules for combining measurements depend on the type of operation performed:

Significant Figures

- All digits in a number that are known with certainty plus the first uncertain digit
- The more significant digits obtained, the better the precision of a measurement
- The concept of significant figures applies only to measurements
- *Exact values* have an unlimited number of significant figures

Rules for Significant Figures in Calculations

KEY POINT: A calculated quantity can be no more precise than the least precise data used in the calculation

… and the reported result should reflect this fact

Analogy: a chain is only as strong as its weakest link

Rules for “Sig Figs”

Atlantic and Pacific Rule:

- If the decimal is present, count the first non-zero number from the Pacific side.
- If the decimal is absent, count the first non-zero number from the Atlantic side.

General Rules for Significant Figures

- Any number which represents a numerical count or an exact definition has an infinite number of significant figures.
- When adding or subtracting significant digits, arrange the numbers in a columnar form and retain no column to the right of a column that contains doubtful figures.

Ex.
```
 10.14
241.6
  3.42
  0.007
_______
255.1xx
```

- When multiplying or dividing sig. figs., the result may have no more sig figs than the factor with the least amount of significant figures.

Ex. 3x2=6 3x3=9 3x5 = 2x101

- Rounding rules:

  a. When rounding numbers < 5, the preceding digit is retained.

  b. When rounding numbers 5 or > 5, the preceding digit increases by one.

– Multiplication and division

- The number of significant figures in the answer should not be greater than the number of significant figures in the least precise measurement.

$$\frac{3.14 \times 2.751}{0.64} = 13$$

$$\frac{(3\ \text{sig.figs.}) \times (4\ \text{sig.figs.})}{(2\ \text{sig.figs.})} = (2\ \text{sig. figs.})$$

– Addition and Subtraction

- The answer should have the same number of decimal places as the quantity with the fewest number of decimal places

$$\begin{array}{rl} 3.247 & \leftarrow \text{3 decimal places} \\ 41.36 & \leftarrow \text{2 decimal places} \\ \underline{+125.2} & \leftarrow \text{1 decimal place} \\ 169.8 & \leftarrow \text{answer to 1 decimal place} \end{array}$$

Note: Remember that numbers are exact. Numbers that come from definitions or direct counts have no uncertainty and can be assumed to contain an **infinite number** of significant figures.

- The **factor-label method**, or **dimensional analysis**, can be used to help perform the correct arithmetic to solve a problem
- This involves treating a numerical problem as one involving a conversion from one kind of units to another
- This is done using one or more *conversion factors* to change the units of the given quantity to the units of the answer

- A **conversion factor** is a fraction formed from a *valid* relationship or equality between units
- Conversion factors are used to switch from one system of measure to another
  - Example: Convert 72.0 in. to cm using the equality 1 in. = 2.54 cm (exactly).

$$\frac{72.0 \text{ in.}}{1} \times \frac{2.54 \text{ cm}}{1 \text{ in.}} = 183 \text{ cm}$$

Note: Since the **units** cancel correctly the arithmetic is probably setup correctly.

- **Density** (d) is an intensive property defined as the ratio of an objects mass (m) to volume (v), $d = m/v$
- Each pure substance has its own characteristic density
- At room temperature:

Substance	Density(g/cm^3)
Water	1.00
Aluminum	2.70
Iron	7.86
Gold	19.3
Air	0.0012

- Most substances expand when heated
- This means density depends on temperature
- For water:

Temperature(ºC)	Density(g/cm^3)
10	0.999700
15	0.999099
20	0.998203
25	0.997044
30	0.995646

It is useful to remember the value 1.00 g/cm^3 for water at 4º C.

- Density relates a samples mass and volume
  - Blood has a density of 1.05 g/cm^3
  - We can say that 1.05 g blood is equivalent to 1.00 cm^3
  - Conversion factors can be constructed from this equivalence, which could be used in the factor-label method
  - The numerical value for the density of a substance depends on the units used for mass and volume

$$\frac{1.05\text{ g blood}}{1.00\text{ cm}^3\text{ blood}} \quad or \quad \frac{1.00\text{ cm}^3\text{ blood}}{1.05\text{ g blood}}$$

- In the same way, speeds and other derived unit measurements can be related to each other.

$$\frac{20 \text{ miles}}{1 \text{ hour}} \quad \textit{or} \quad \frac{1. \text{ hour}}{20 \text{ miles}}$$

- These relationships can also be used as conversion factors when solving problems.