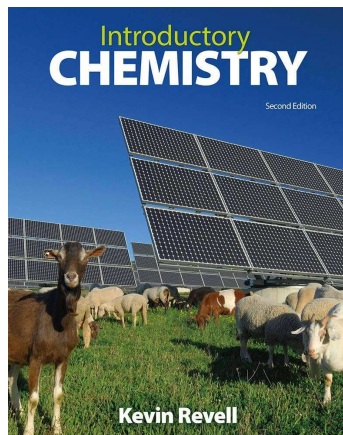


Introductory Chemistry
Chem 103

Chapter 1 – Foundations

Lecture Slides



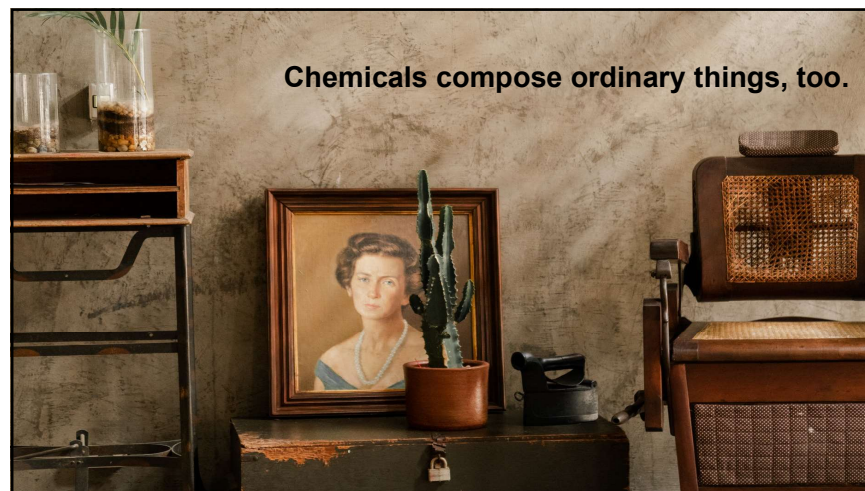
People often have a
very narrow
view of chemicals,
thinking of them only
as dangerous
poisons or pollutants.

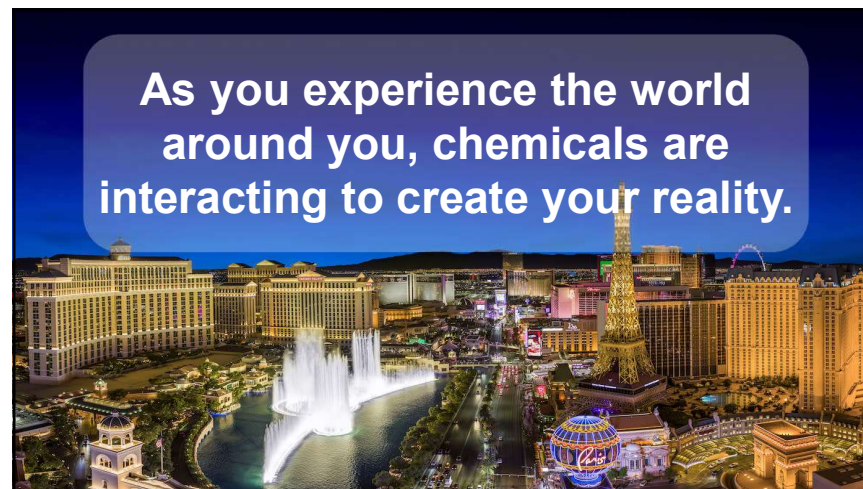
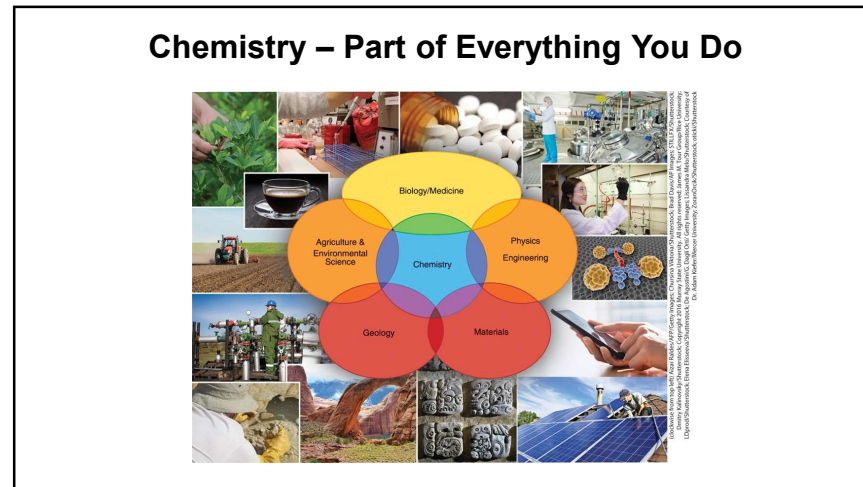


Are chemicals a
good or bad thing?



Chemicals compose ordinary things, too.





CLASS ACTIVITY

Describing Matter

Matter anything that has mass and takes up volume



Courtesy David Revell

Provide an example of chemistry
in your everyday life.

You can not repeat a previous answer.



Composition and Structure

Composition

What something is made of

Structure

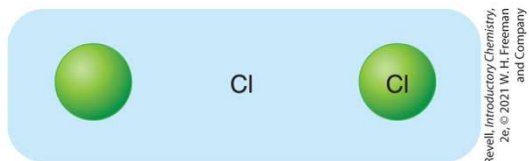
*What something is made of
and
How the components are arranged*



Left to Right: YanYang/Stock/Getty
Images, Joe Blin/Shutterstock,
David Lee/Shutterstock

Pure Substances: Elements and Compounds

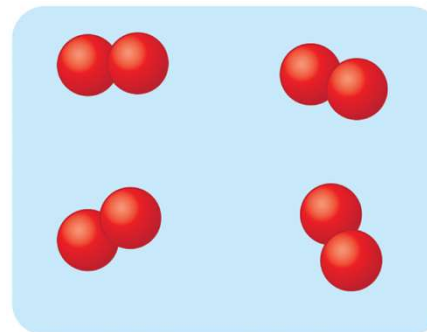
Atom: the fundamental unit of matter



Element: made of only one type of atom



Diatomic Molecules

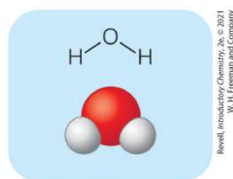


Some elements, such as hydrogen, nitrogen, and oxygen also exist as diatomic (two atom) molecules. For example, this image shows four molecules of oxygen. Each molecule contains two oxygen atoms bound together.

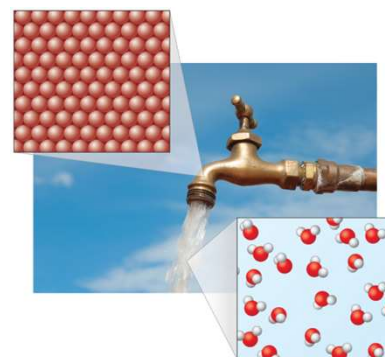
Compounds and Molecules

Compounds: composed of more than one element, bound in fixed ratios

Molecules: groups of atoms that bind tightly together, and behave as a single unit



Composition of Materials

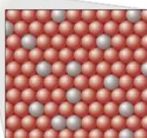


Mixtures

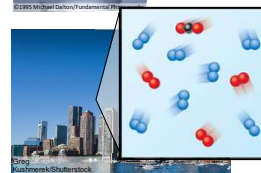
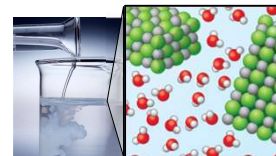
Contain more than one substance, not bound in a fixed ratio.



Bronze:
A mixture of copper and tin



Other mixtures...



Homogeneous and Heterogeneous Mixtures

Homogeneous mixtures – components mix evenly.

Heterogeneous mixtures – components do not mix evenly.



Homogeneous mixture
Salt mixes evenly with water



Heterogeneous mixture
Sand separates from water

Separating Mixtures:



Defining Matter

```
graph TD; Matter[Matter] --> PureSubstances[Pure substances<br/>one element or compound]; Matter --> Mixtures[Mixtures<br/>more than one substance]; PureSubstances --> Elements[Elements<br/>one type of atom]; PureSubstances --> Compounds[Compounds<br/>different types of atoms<br/>bound together]; Mixtures --> Homogeneous[Homogeneous<br/>components are<br/>evenly blended]; Mixtures --> Heterogeneous[Heterogeneous<br/>components are<br/>not evenly blended];
```

Left to right: element (gold bar), compound (water molecule), homogeneous mixture (clear liquid), heterogeneous mixture (salad).

Left to right: element (gold bar), compound (water molecule), homogeneous mixture (clear liquid), heterogeneous mixture (salad).

Transitions Between Three States of Matter

The diagram illustrates the transitions between the three states of matter: Gas, Liquid, and Solid. A vertical red arrow on the left indicates increasing temperature. The transitions are labeled as follows:

- Vaporization:** The process of a liquid turning into a gas.
- Condensation:** The process of a gas turning into a liquid.
- Melting:** The process of a solid turning into a liquid.
- Freezing:** The process of a liquid turning into a solid.


The diagram shows the following states of matter:

- Gas:** Represented by a few widely spaced blue spheres.
- Liquid:** Represented by a cluster of blue spheres with wavy lines around them.
- Solid:** Represented by a tightly packed lattice of blue spheres.


Small text on the right side of the diagram reads: "Holt, Rinehart & Winston, Inc. © 2004 by Holt, Rinehart & Winston."

Three States of Matter


Solid Definite shape, definite volume



Liquid Definite volume, but no definite shape

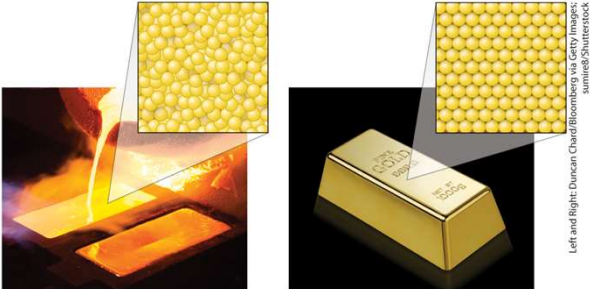


Gas No definite shape or volume



Particle Arrangement

The behavior of any substance is determined by the arrangement of the particles that compose the substance.



Left and Right: Duncan Chard/Bloomberg via Getty Images; summed/Shutterstock

Properties and Changes, Part 1

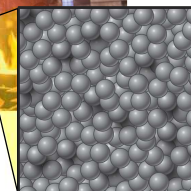
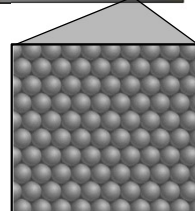
Physical Properties Can be measured without changing the identity of the substance



mass
volume
temperature
color
hardness

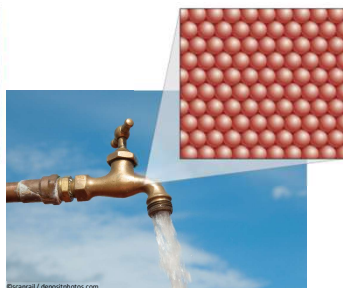
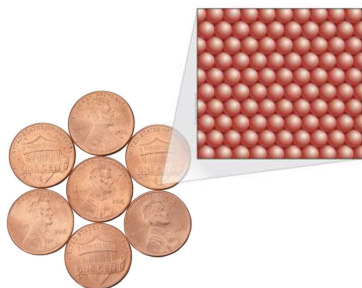
Physical Changes

Phase changes are physical changes.



Properties and Changes, Part 2

Physical Changes Don't change the identity of the substance



Properties and Changes

Chemical Properties: Can NOT be measured without changing the identity of the substance.

Chemical Changes: Change the identity of the substance - also called *chemical reactions*.



Elements combine to form compounds: a chemical change.



Properties and Changes

Chemical -
Change the identity of a substance.



Physical -
Do NOT change the identity of a substance



A change that forms new compounds: a chemical change.



Energy and Change

Energy: The ability to do work

Potential energy: Energy that is stored

Kinetic energy: The energy of motion



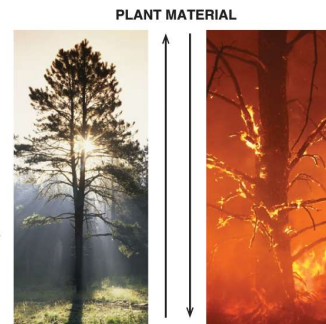
Heat Energy

Heat energy: involves the kinetic energy of the particles in a substance



Energy Changes

Energy stored
A tree grows by absorbing energy from the sun to convert carbon dioxide and water into plant material.



Energy released
Fire releases the stored potential energy as heat, converting the plant material back into carbon dioxide and water.

CARBON DIOXIDE + WATER

Revell, Introductory Chemistry, 2e, © 2021, W. H. Freeman and Company
Left and Right/Money Milbradt/Getty Images; Evgeny Dubinchuk/Shutterstock

Physical and chemical changes involve changes in energy.

Moving from higher energy to lower energy



Moving from lower energy to higher energy

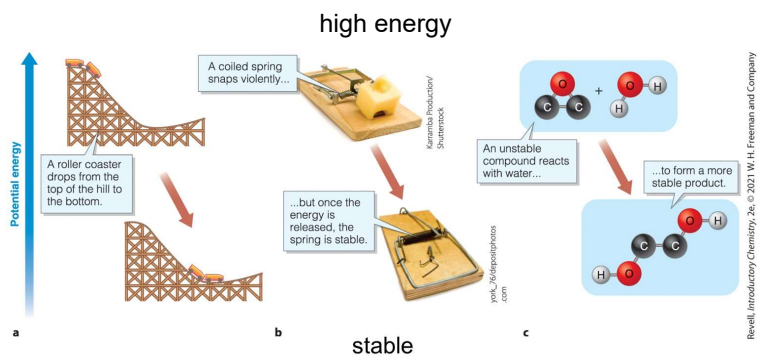


High Energy or Stable?

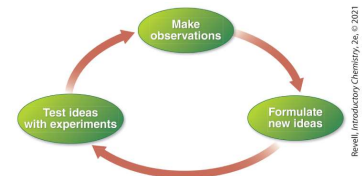


© D. Allen Photography/age-fotostock

Potential Energy



The Scientific Method



hypothesis: A tentative explanation that has not been tested.

theory: An idea supported by experimental evidence, or a *paradigm*, or way of thinking about a topic.

scientific law: A statement that describes observations that are true in widely varying circumstances.

Exothermic and Endothermic Change

Exothermic change: releases heat energy

Endothermic change: absorbs heat energy

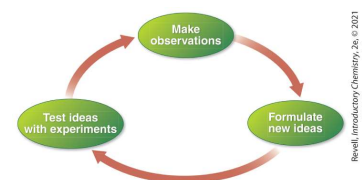
exothermic



endothermic



The Scientific Method, Continued



Theories

How or Why it happens

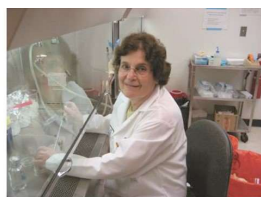
Laws

What happens

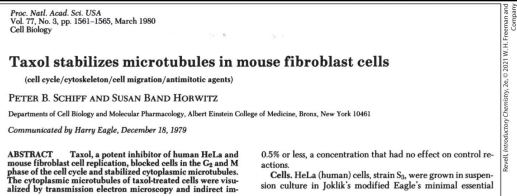
Scientific Communication



Scientists communicate findings through scientific papers.



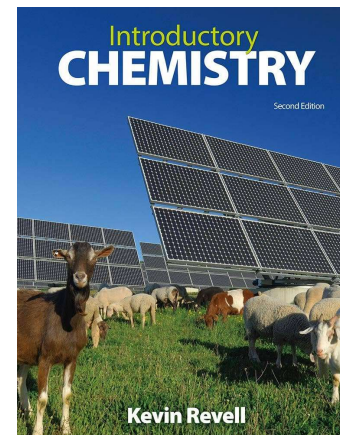
inga spence/Alamy age; Courtesy of Dr. Susan Band Horwitz



Introductory Chemistry Chem 103

Chapter 2 – Measurement

Lecture Slides



Scientists



Clockwise from upper left: Sovfoto/Getty Images; OLGA SHALYGIN/AP Images; Omar M. Yaghi Research group at University of California Berkeley; Dr. Adam Kiefer/Mercer University; Dr. Adam Kiefer/Mercer University; Dr. Lauren Richards Waugh; Yareli Jaisie, CHCPCrNH-H; Copyright E.I. Lilly and Company. All rights Reserved. Used with Permission; Copyright E.I. Lilly and Company. All rights Reserved. Used with Permission; Copyright 2016 Murray State University. All rights reserved.

Large and Small Measurements

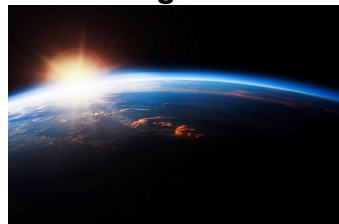


Photo credit: Tetra Images/Getty Images

Earth to the Sun:
149,600,000,000 meters

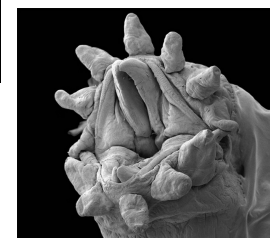


Photo credit: Philippe Grassle/FERREX/Shutterstock

Hydrothermal worm:
0.0005 m

Scientific Notation

$$2.14 \times 10^{-3}$$

coefficient (points to 2.14) *exponent* (points to -3) *multiplier* (points to 10)

Examples of Exponential Notation

$$5.1 \times 10^3 = 5100.$$

$$5.1 \times 10^2 = 510.$$

$$5.1 \times 10^1 = 51.$$

$$5.1 \times 10^0 = 5.1$$

$$5.1 \times 10^{-1} = 0.51$$

$$5.1 \times 10^{-2} = 0.051$$

$$5.1 \times 10^{-3} = 0.0051$$

Exponential Notation

$$\rightarrow 10^3 = 10 \times 10 \times 10 = 1,000.$$

$$\rightarrow 10^2 = 10 \times 10 = 100.$$

$$\rightarrow 10^1 = 10 = 10.$$

$$\rightarrow 10^0 = 1 = 1.$$

$$\rightarrow 10^{-1} = \frac{1}{10} = 0.1$$

$$\rightarrow 10^{-2} = \frac{1}{10 \times 10} = 0.01$$

$$\rightarrow 10^{-3} = \frac{1}{10 \times 10 \times 10} = 0.001$$

Going from Standard to Scientific Notation:

$$2,500,000 \text{ L} = 2.5 \times 10^6 \text{ L}$$

move 6 digits

$$137,000,000,000 \text{ J} = 1.37 \times 10^{11} \text{ J}$$

move 11 digits

$$0.000000142 \text{ g} = 1.42 \times 10^{-7} \text{ g}$$

move 7 digits (right)

$$0.000326 \text{ cm} = 3.26 \times 10^{-4} \text{ cm}$$

move 4 digits (right)

Going from Scientific to Standard Notation:

$$\rightarrow 1.528 \times 10^5 \text{ kg} \quad \underline{1.52800} \quad = 152,800 \text{ kg}$$

$$\rightarrow 1.64 \times 10^7 \text{ L} \quad \underline{1.6400000} \quad = 16,400,000 \text{ L}$$

$$\rightarrow 1.35 \times 10^{-5} \text{ m} \quad \underline{00001.35} \quad = 0.0000135 \text{ m}$$

$$\rightarrow 8.28 \times 10^{-3} \text{ g} \quad \underline{008.28} \quad = 0.00828 \text{ g}$$

Calculations Involving Scientific Notation, Example 2

$$\begin{array}{c} \text{division} \\ \text{divide} \rightarrow \frac{8.4 \times 10^7}{2.0 \times 10^3} = 4.2 \times 10^4 \\ \text{coefficients} \quad \text{subtract} \\ \text{exponents} \end{array}$$

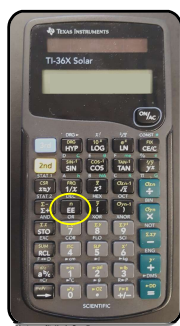
Calculations Involving Scientific Notation, Example 1

$$\begin{array}{c} \text{multiplication} \\ \text{add} \\ \text{exponents} \rightarrow 3.1 \times 10^4 \times 2.0 \times 10^2 = 6.2 \times 10^6 \\ \text{multiply} \\ \text{coefficients} \end{array}$$

Calculations Involving Scientific Notation, Example 3

$$\begin{array}{c} 2.5 \times 10^4 \times 6.0 \times 10^8 = 15 \times 10^{12} \\ \text{increase exponent} \\ \text{move 1 digit} \\ = 1.5 \times 10^{13} \end{array}$$

Using a Calculator For Scientific Notation:



EE E Exp

" $\times 10^{-}$ "

$$1.53 \times 10^{16}$$

1.53 EE 16

Measurement and Units, Continued

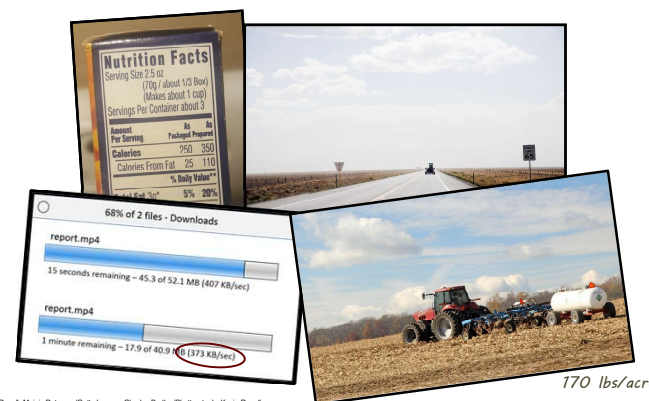


Photo credits clockwise from top left: Kevin Revelt; Maixie Paterson/Getty Images; Charles Brufag/Shutterstock; Kevin Revelt

Measurement and Units

units of measurement Quantities with accepted values that can be communicated between people.



Units

Common English and Metric Units

Measurement	Metric Unit	English Unit	Relationship
Length	meter (m)	foot (ft)	1 m = 3.280 ft
		mile (mi)	1 km = 0.621 mi
Mass or Weight	kilogram (kg)	pound (lb)	1 kg = 2.204 lb
Volume	liter (L)	gallon (gal)	1 liter = 0.264 gal

Units, Continued

Fundamental Units

Measurement	Unit
Mass	kilogram (kg)
Length	meter (m)
Time	second (s)
Temperature	kelvin (K)
Light Intensity	candela (cd)
Electric current	ampere (A)
Amount	mole (mol)

Derived Units

Measurement	Units
Volume	m ³
Velocity	m/s
Density	kg/m ³

Using Common Metric Prefixes

1. How many meters are in a kilometer?

$$1 \text{ km} = 1,000 \text{ m}$$

2. How many A are in a MA?

$$1 \text{ MA} = 1,000,000 \text{ A}$$

3. How many mg are in a g?

$$1 \text{ mg} = \frac{1}{1,000} \text{ g}$$

$$1,000 \text{ mg} = 1 \text{ g}$$

Table 2.5 Common Metric Prefixes

Prefix	Symbol	Meaning
Mega-	M	10 ⁶ 1,000,000
Kilo-	k	10 ³ 1,000
Milli-	m	10 ⁻³ $\frac{1}{1,000}$

Metric Prefixes

Table 2.5 Common Metric Prefixes

Prefix	Symbol	Meaning
Tera-	T	10 ¹² 1,000,000,000,000
Giga-	G	10 ⁹ 1,000,000,000
Mega-	M	10 ⁶ 1,000,000
Kilo-	k	10 ³ 1,000
Deci-	d	10 ⁻¹ $\frac{1}{10}$
Centi-	c	10 ⁻² $\frac{1}{100}$
Milli-	m	10 ⁻³ $\frac{1}{1,000}$
Micro-	μ	10 ⁻⁶ $\frac{1}{1,000,000}$
Nano-	n	10 ⁻⁹ $\frac{1}{1,000,000,000}$
Pico-	p	10 ⁻¹² $\frac{1}{1,000,000,000,000}$

160,000,000 bits

$$= 160 \text{ megabits}$$

0.0000032 grams

$$= 3.2 \times 10^{-6} \text{ grams}$$

$$= 3.2 \text{ micrograms}$$

Describing the Quality of Measurements



Photo credit: James A. Prince/Science Source

Precision and Accuracy

Accuracy

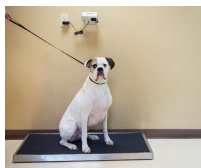
- How reliable are the measurements?
- Do they reflect the true value?



± 0.0001 g

Precision

- How finely are the measurements made?
- How closely are they grouped together?

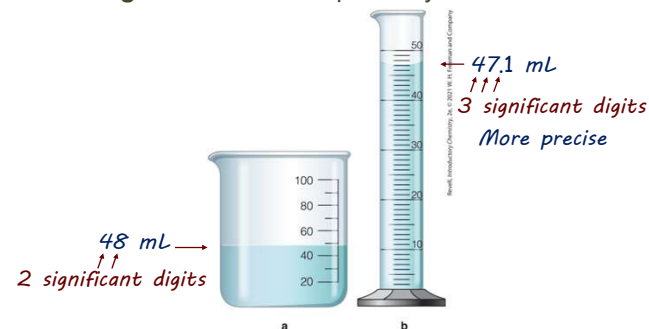


± 0.1 kg

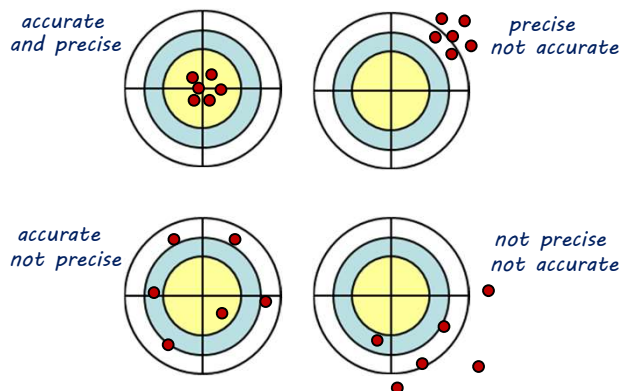
Significant Digits

We can estimate *one digit* between the marked values.

Significant digits: Indicate how precisely we know a measurement



Precision and Accuracy, Continued



Identifying Significant Digits, Part 1

1. All nonzero digits are significant, and all zeros between nonzero digits are significant.

1.2571 g
5 sig. digits

1.1052 cm
5 sig. digits

2. If a decimal point is present, zeros to the right of the last nonzero digit are significant.

5.07 g

5.00 g 3 sig. digits

4.99 g

Identifying Significant Digits, Part 2

3. Zeros to the left of the nonzero numbers are never significant.

000012 kg 0.0045 m
not significant *2 sig. digits* *not significant* *2 sig. digits*

How many significant digits are in 4.5 mm? 2

4.5 mm = 0.0045 m 2

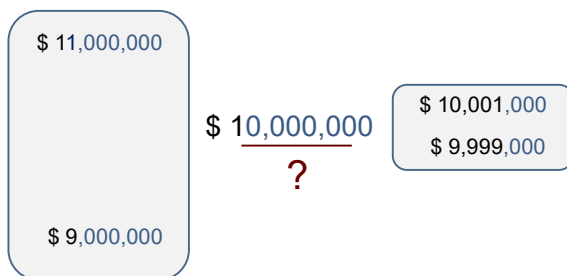
Place holders for the decimal

Defining Significant Digits for Large Numbers

10,000 kg $10,000 \pm 100 \text{ kg}$
3 sig. digits $1.00 \times 10^4 \text{ kg}$

Identifying Significant Digits, Part 3

4. If there is no decimal point present, zeros to the right of the last nonzero *may* or *may not* be significant.



Summary of Significant Digits

Significant digits show the precision of a measured quantity.

- Significant:
 - nonzeros 1.2571 g
 - zeros between nonzeros 1.1052 cm
 - zeros after the decimal point 1.100 mm
- Not Significant
 - zeros to the left of all nonzeros 000023 L
 - zeros to the right of nonzeros with no decimal 0.0031 mg
- May be Significant
 - zeros to the right of nonzeros with no decimal 47,000,000 kg

Exact Numbers

Values for which there is no uncertainty

- Counted Values



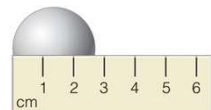
Exactly 7 pennies

- Defined Values

1,000 mg = 1 g

3 feet = 1 yard

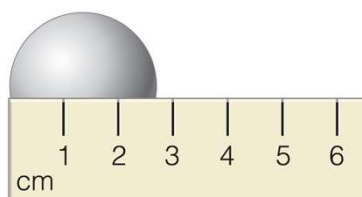
Example: What is the circumference of the ball?



Circumference = πd

Diameter	Calculated Circumference	
2.6 cm	8.16814090 cm	
2.7 cm	8.48230016 cm	8.5 cm
2.8 cm	8.79645943 cm	

Calculations with Significant Digits



2.6 cm
 2.7 cm
 2.8 cm
estimated

Multiplication and Division with Significant Digits

- When multiplying or dividing, report the same number of digits as are in the least precise starting measurement.

A vehicle travels 315.3 miles in the span of 5.2 hours.
 What is its average speed, in miles per hour?

$$\frac{315.3 \text{ miles}}{5.2 \text{ hours}} = 60.63461538$$

4 sig. digits
 2 sig. digits
 = 61 miles/hour

Addition and Subtraction with Significant Digits

2. When adding or subtracting, round to the last decimal place of the least precise starting measurement.

While training for a triathlon, you swim 0.432 miles, then bike 18.1 miles. What was your total distance traveled?

$$\begin{array}{r} \text{Swim } 0.432 \text{ mi.} \\ + \text{ Bike } 18.1 \text{ mi.} \\ \hline = 18.532 \text{ mi.} \\ = 18.5 \text{ mi.} \end{array}$$

Example with Significant Digits

A chemist measures the mass of chloride in three water samples, as shown in the table. Together, the three samples have a volume of 2.31 liters. What is the average mass of chloride per liter of water? Answer to significant digits.

Sample	Mass of Chloride
A	15.21 mg
B	9.33 mg
C	11.329 mg

total mass chloride:

$$\begin{array}{r} 15.21 \text{ mg} \\ 9.33 \text{ mg} \\ 11.329 \text{ mg} \\ \hline 35.869 \text{ mg} \end{array}$$

$$= 35.87 \text{ mg}$$

4 sig. digits

total mass
volume

$$= \frac{35.869 \text{ mg}}{2.31 \text{ L}}$$

$$= 15.52770563$$

$$= 15.5 \text{ mg/L}$$

Use unrounded mass

4 sig. digits

3 sig. digits

Rounding Calculations with Significant Digits

If a calculation involves multiple steps, wait until the end to round to significant digits.

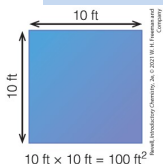
Unit Conversions



Photo credit clockwise from top: rikichen/Shutterstock, eye35 / Alamy

Unit Conversions: Dimensional Analysis, Example 1

Whatever we do to the number, we also do to the units.



$$10 \text{ ft} \times 10 \text{ ft} = 100 \text{ ft}^2$$

multiply number
multiply units



$$15.0 \text{ mL} \times \frac{1.02 \text{ mg}}{1 \text{ mL}} = 15.3 \text{ mg}$$

Unit Conversions: Dimensional Analysis, Example 3

How many inches are in 326 cm?

$$2.54 \text{ cm} = 1 \text{ inch}$$

$$\frac{2.54 \text{ cm}}{1 \text{ inch}} \quad \text{or} \quad \frac{1 \text{ inch}}{2.54 \text{ cm}}$$

starting unit (cm) \times conversion factor = ending unit (inches)

$$326 \text{ cm} \times \frac{1 \text{ inch}}{2.54 \text{ cm}} = 128 \text{ inches}$$

$$326 \text{ cm} \times \frac{2.54 \text{ cm}}{1 \text{ inch}} = 828 \frac{\text{cm}^2}{\text{inch}} \quad \text{X} \quad \text{wrong units}$$

Unit Conversions: Dimensional Analysis, Example 2

A copper pellet has a mass of 0.281 kg. What is this mass in grams?

$$1 \text{ kg} = 1,000 \text{ g}$$

$$\frac{1 \text{ kg}}{1,000 \text{ g}} = 1 \quad \text{or} \quad \frac{1,000 \text{ g}}{1 \text{ kg}} = 1$$

conversion factors

$$0.281 \text{ kg} \times \frac{1,000 \text{ g}}{1 \text{ kg}} = 281 \text{ g}$$

starting unit (kg) conversion factor ending unit (g)

Unit Conversions: Dimensional Analysis, Example 4

The speed of light in a vacuum is $3.00 \times 10^8 \text{ m/s}$. What is this speed in miles per hour?

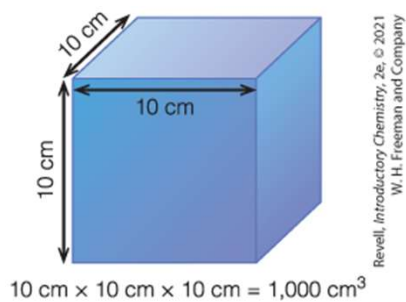
$$1 \text{ mile} = 1609.3 \text{ meters}$$

$$1 \text{ hour} = 3600 \text{ seconds}$$

$$3.00 \times 10^8 \frac{\text{m}}{\text{s}} \times \frac{1 \text{ mi}}{1609.3 \text{ m}} \times \frac{3600 \text{ s}}{1 \text{ hr}} = 6.71 \times 10^8 \frac{\text{mi}}{\text{hr}}$$

meters to miles seconds to hours

Units of Volume



Volume Sizes, Continued

liter (L):
1 L = 1 dm³



milliliter (mL)
1 milliliter = 1 cubic centimeter
1 mL = 1 cm³



Volume Sizes

m³



dm³



cm³

Cubic Decimeters and Cubic Meters

How many cubic decimeters are in one cubic meter?

$$1 \text{ m} = 10 \text{ dm}$$

$$(1 \text{ m})^3 = (10 \text{ dm})^3$$

$$1 \text{ m}^3 = 1,000 \text{ dm}^3$$

Cubic Centimeters and Cubic Meters

How many cubic centimeters are in one cubic meter?

$$1 \text{ m} = 100 \text{ cm}$$

$$(1 \text{ m})^3 = (100 \text{ cm})^3$$

$$1 \text{ m}^3 = 1,000,000 \text{ cm}^3$$

Relating mass and volume: density



Example, Multiple Unit Conversions

A hospital administers an IV fluid at a rate of 95.0 cm^3 per hour.
How many liters of this fluid does the patient receive per day?

Volume

Time

$$1 \text{ cm}^3 = 1 \text{ mL}$$

$$24 \text{ hr} = 1 \text{ day}$$

$$1,000 \text{ mL} = 1 \text{ L}$$

$$1,000 \text{ cm}^3 = 1 \text{ L}$$

$$95.0 \frac{\text{cm}^3}{\text{hr}} \times \frac{1 \text{ L}}{1000 \text{ cm}^3} \times \frac{24 \text{ hr}}{1 \text{ day}} = 2.28 \frac{\text{L}}{\text{day}}$$

cm^3
to liters
hours
to days

Density

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

$$d = \frac{m}{V}$$

Density Examples



Density, Example 2

An antifreeze mixture has a density of 1.06 g/mL. If you measure out 600.0 g of this solution, what volume will it occupy?

$$d = \frac{m}{V}$$

$$V = \frac{m}{d}$$

$$V = \frac{600.0 \cancel{\text{g}}}{1.06 \frac{\cancel{\text{g}}}{\text{mL}}} = 566 \text{ mL}$$

Density, Example 1

A saltwater solution has a mass of 11.29 g, and a volume of 10.4 mL. What is the density of this solution?

$$d = \frac{m}{V} = \frac{11.29 \text{ g}}{10.4 \text{ mL}} = 1.09 \text{ g/mL}$$

Density, Example 3

Aluminum has a density of 2.70 g/cm³. What is the mass of a block of aluminum with a volume of 1.32 L?

$$d = \frac{m}{V}$$

$$1 \text{ cm}^3 = 1 \text{ mL}$$

$$1,000 \text{ cm}^3 = 1 \text{ L}$$

$$m = dV$$

$$1.32 \cancel{\text{L}} \times \frac{1000 \text{ cm}^3}{1 \cancel{\text{L}}} = 1320 \text{ cm}^3$$

$$m = (2.70 \frac{\text{g}}{\cancel{\text{cm}^3}})(1320 \cancel{\text{cm}^3})$$

$$m = 3,560 \text{ g}$$

Densities of Common Materials

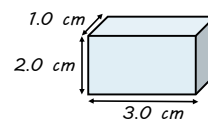
Table 2.6 Densities of Common Materials

Material	Density (g/cm ³)
Aluminum	2.70
Titanium	4.51
Iron	7.87
Copper	8.96
Lead	11.34
Gold	19.31
Water*	1.00
Seawater*	1.02
Air*	0.001

*At 25°C and standard atmospheric pressure

Density, Example 4

A rectangular object measures 3.0 cm x 2.0 cm x 1.0 cm and has a mass of 7.2 g. What is the density of this object? Will it float in water?



$$V = \text{length} \times \text{width} \times \text{height}$$

$$= 3.0 \text{ cm} \times 2.0 \text{ cm} \times 1.0 \text{ cm}$$

$$= 6.0 \text{ cm}^3$$

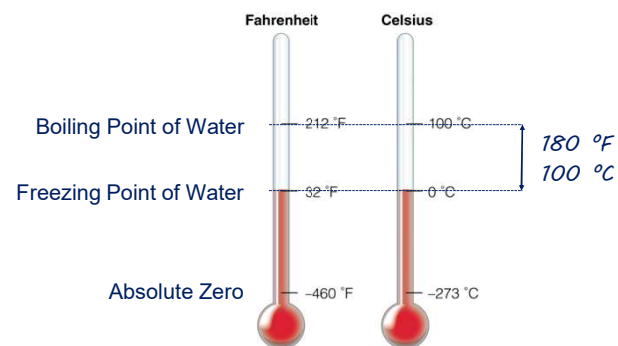
$$d = \frac{m}{V} = \frac{7.2 \text{ g}}{6.0 \text{ cm}^3} = 1.2 \text{ g/cm}^3$$

more dense than water - will not float

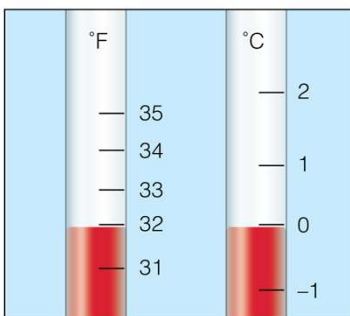
Will it Float or Sink?



Converting Between Temperature Units



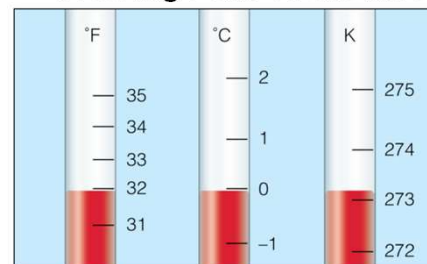
Fahrenheit and Celsius



$$^{\circ}\text{F} = \frac{9}{5}^{\circ}\text{C} + 32$$

$$^{\circ}\text{C} = \frac{5}{9}(^{\circ}\text{F} - 32)$$

Freezing Point on the Three Temperature Scales



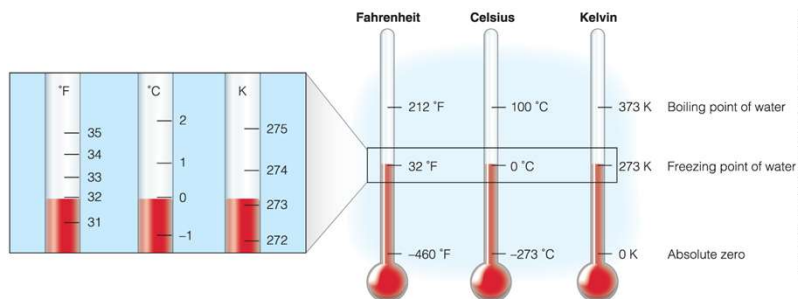
$$\text{K} = ^{\circ}\text{C} + 273.15$$

"32 degrees Fahrenheit"

"0 degrees Celsius"

"273 kelvins"

The Three Temperature Scales



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Temperature Calculation

*A refrigerator maintains an inside temperature of 42 °F.
Express this temperature in Celsius and in kelvins.*

$$^{\circ}\text{C} = \frac{5}{9}(^{\circ}\text{F} - 32)$$

$$^{\circ}\text{C} = \frac{5}{9}(42 - 32) = 5.6^{\circ}\text{C}$$

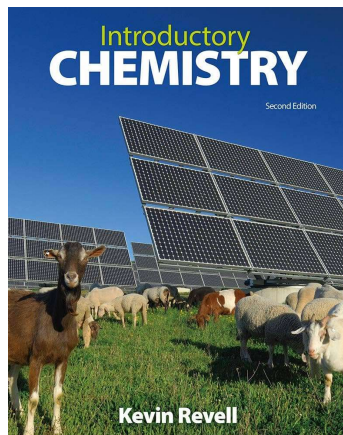
$$\text{K} = ^{\circ}\text{C} + 273.15$$

$$\text{K} = 5.6 + 273.15 = 278.75 \text{ K} = 278.8 \text{ K}$$

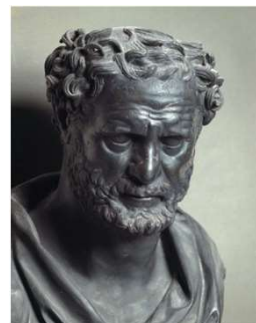
Introductory Chemistry
Chem 103

Chapter 3 – Atoms

Lecture Slides

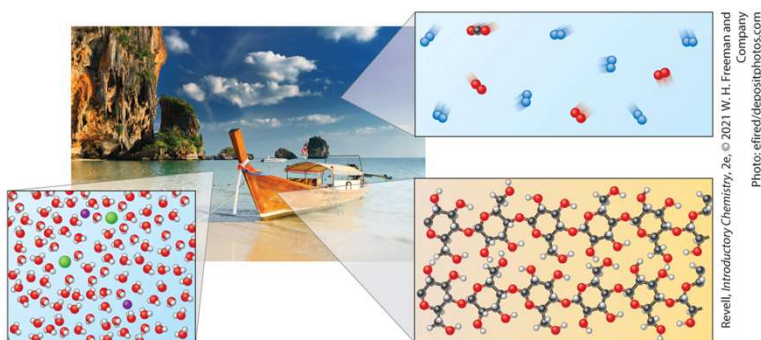


400 B.C.E. - Democritus



atomos – “indivisible”

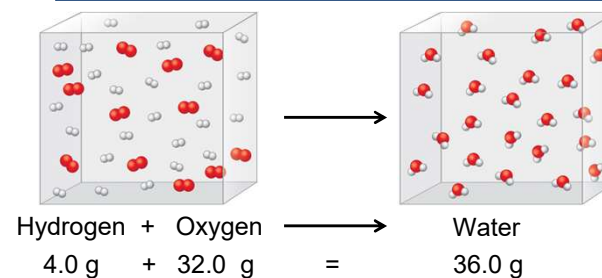
Atoms



Law of Conservation of Mass

Antoine Lavoisier (1743-1794)

In chemical reactions,
matter is neither created or destroyed.



Example of the Law of Conservation of Mass

If 16.0 grams of methane react with 64.0 grams of oxygen, 36.0 grams of water are produced. How many grams of carbon dioxide are produced in this reaction?

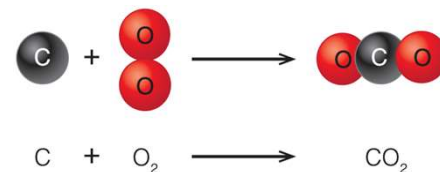
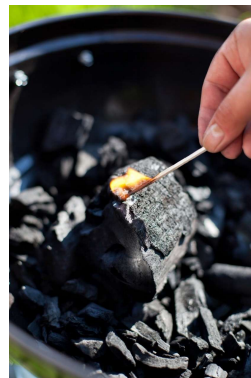
methane + oxygen \longrightarrow carbon dioxide + water

$$16.0\text{ g} + 64.0\text{ g} = \underline{44.0\text{ g}} + 36.0\text{ g}$$



Cherko Danil Vlasovich/Shutterstock

Understanding Atomic Theory

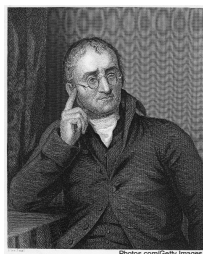


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Origins of Atomic Theory

John Dalton (1766-1844)

- Elements are made of tiny, indivisible particles called atoms
- The atoms of each element are unique.
- Atoms can join together in whole-number ratios to form compounds.
- Atoms are unchanged in chemical reactions.

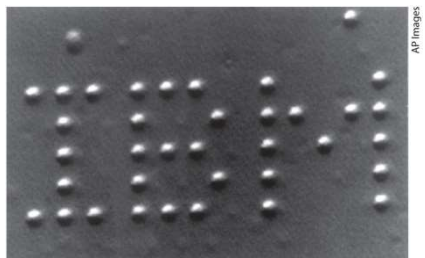


Photos.com/Getty Images

Three Foundational Ideas

1. All matter is composed of atoms.
2. The atoms of each element have unique characteristics and properties.
3. In chemical reactions, atoms are not changed, but combine in whole-number ratios to form compounds.

Can we see atoms?



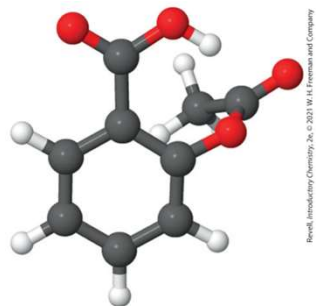
Periodic Table of the Elements



Mendeleev

9 F 19.00	17 Cl 35.45	35 Br 79.90	53 I 126.90
------------------------	--------------------------	--------------------------	--------------------------

Scientists use X-ray crystallography to visualize the arrangement of atoms



PDB ID: 1GZX
Paoli et al, 2002

Periodic Table of the Elements, Continued

1A																	8A																	
1 H 1.01	2A																	16A																
3 Li 6.94	4 Be 9.01																	17A																
5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 18.99	10 Ne 20.18																	18A												
11 Na 22.99	12 Mg 24.31	13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.06	17 Cl 35.45	18 Ar 39.95																	19A										
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.88	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.38	31 Ga 69.72	32 Ge 72.64	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80																	20A
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc 98.91	44 Ru 101.07	45 Rh 101.07	46 Pd 106.42	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.60	53 I 126.90	54 Xe 131.29																	21A
55 Cs 132.91	56 Ba 137.33	57 La 138.91	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm 144.91	62 Sm 150.36	63 Eu 151.96	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.05	71 Lu 174.97																	22A	
87 Fr (223)	88 Ra (226)	89 Ac (227)	90 Th (232)	91 Pa (231)	92 U (238)	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)																	23A	

Lanthanide series

58	59	60	61	62	63	64	65	66	67	68	69	70	71
Ce	La	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb
140.12	138.91	144.24	144.91	(145)	150.36	151.96	157.25	158.93	162.50	164.93	167.26	168.93	173.05

Actinide series

92	93	94	95	96	97	98	99	100	101	102	103	
Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No
232.04	231.04	238.03	237.05	244.04	243.04	247.04	247.04	251.04	252.04	257.04	258.04	259.04

The Meaning of Periodic

A calendar is periodic...

Sun	Mon	Tue	Wed	Thu	Fri	Sat
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

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Abbreviations for the Elements

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Name	Symbol	Name	Symbol	Latin Name
carbon	C	sodium	Na	<i>natrrium</i>
hydrogen	H	iron	Fe	<i>ferrum</i>
magnesium	Mg	copper	Cu	<i>cuprum</i>
calcium	Ca	lead	Pb	<i>plumbum</i>

Groups and Periods

Groups (Families)

Periods

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Blocks of Elements

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Metals

Lie to the left on the periodic table

Lie to the left on the periodic table

Metals

transition metals

1A 2A 3A 4A 5A 6A 7A 8A

1 2 13 14 15 16 17 18

2 3 4 5 6 7 8 9 10 11 12

3 Na Mg 13 Al 14 Si 15 P 16 S 17 Cl 18 Ar

4 K Ca 19 Sc 20 Ti 21 V 22 Cr 23 Mn 24 Fe 25 Co 26 Ni 27 Cu 28 Zn 29 Ga 30 Ge 31 As 32 Se 33 Br 34 Kr

5 Rb Sr 35 Y 36 Zr 37 Nb 38 Mo 39 Tc 40 Ru 41 Rh 42 Pd 43 Ag 44 Cd 45 In 46 Sn 47 Sb 48 Te 49 I 50 Xe

6 Cs Ba 51 La 52 Ce 53 Pr 54 Nd 55 Pm 56 Sm 57 Eu 58 Gd 59 Tb 60 Dy 61 Ho 62 Er 63 Tm 64 Yb 65 Lu

7 Fr Ra Ac 71 Sc 72 Ti 73 V 74 Cr 75 Mn 76 Fe 77 Co 78 Ni 79 Cu 80 Zn 81 Ga 82 Ge 83 As 84 Se 85 Br 86 Kr 87 Rb 88 Sr 89 Y 90 Zr 91 Nb 92 Mo 93 Tc 94 Ru 95 Rh 96 Pd 97 Ag 98 Cd 99 In 100 Sn 101 Sb 102 Te 103 I 104 Xe 105 Cs 106 Ba 107 La 108 Ce 109 Pr 110 Nd 111 Pm 112 Sm 113 Eu 114 Gd 115 Tb 116 Dy 117 Ho 118 Er 119 Tm 120 Yb 121 Lu

Lanthanide series

Actinide series

116 Po 117 At 118 Oganesson

119 Uue 120 Uub 121 Uut 122 Uuq 123 Uuq 124 Uuq 125 Uuq 126 Uuq 127 Uuq 128 Uuq 129 Uuq 130 Uuq 131 Uuq 132 Uuq 133 Uuq 134 Uuq 135 Uuq 136 Uuq 137 Uuq 138 Uuq 139 Uuq 140 Uuq 141 Uuq 142 Uuq 143 Uuq 144 Uuq 145 Uuq 146 Uuq 147 Uuq 148 Uuq 149 Uuq 150 Uuq 151 Uuq 152 Uuq 153 Uuq 154 Uuq 155 Uuq 156 Uuq 157 Uuq 158 Uuq 159 Uuq 160 Uuq 161 Uuq 162 Uuq 163 Uuq 164 Uuq 165 Uuq 166 Uuq 167 Uuq 168 Uuq 169 Uuq 170 Uuq 171 Uuq 172 Uuq 173 Uuq 174 Uuq 175 Uuq 176 Uuq 177 Uuq 178 Uuq 179 Uuq 180 Uuq 181 Uuq 182 Uuq 183 Uuq 184 Uuq 185 Uuq 186 Uuq 187 Uuq 188 Uuq 189 Uuq 190 Uuq 191 Uuq 192 Uuq 193 Uuq 194 Uuq 195 Uuq 196 Uuq 197 Uuq 198 Uuq 199 Uuq 200 Uuq 201 Uuq 202 Uuq 203 Uuq 204 Uuq 205 Uuq 206 Uuq 207 Uuq 208 Uuq 209 Uuq 210 Uuq 211 Uuq 212 Uuq 213 Uuq 214 Uuq 215 Uuq 216 Uuq 217 Uuq 218 Uuq 219 Uuq 220 Uuq 221 Uuq 222 Uuq 223 Uuq 224 Uuq 225 Uuq 226 Uuq 227 Uuq 228 Uuq 229 Uuq 230 Uuq 231 Uuq 232 Uuq 233 Uuq 234 Uuq 235 Uuq 236 Uuq 237 Uuq 238 Uuq 239 Uuq 240 Uuq 241 Uuq 242 Uuq 243 Uuq 244 Uuq 245 Uuq 246 Uuq 247 Uuq 248 Uuq 249 Uuq 250 Uuq 251 Uuq 252 Uuq 253 Uuq 254 Uuq 255 Uuq 256 Uuq 257 Uuq 258 Uuq 259 Uuq 260 Uuq 261 Uuq 262 Uuq 263 Uuq 264 Uuq 265 Uuq 266 Uuq 267 Uuq 268 Uuq 269 Uuq 270 Uuq 271 Uuq 272 Uuq 273 Uuq 274 Uuq 275 Uuq 276 Uuq 277 Uuq 278 Uuq 279 Uuq 280 Uuq 281 Uuq 282 Uuq 283 Uuq 284 Uuq 285 Uuq 286 Uuq 287 Uuq 288 Uuq 289 Uuq 290 Uuq 291 Uuq 292 Uuq 293 Uuq 294 Uuq 295 Uuq 296 Uuq 297 Uuq 298 Uuq 299 Uuq 300 Uuq 301 Uuq 302 Uuq 303 Uuq 304 Uuq 305 Uuq 306 Uuq 307 Uuq 308 Uuq 309 Uuq 310 Uuq 311 Uuq 312 Uuq 313 Uuq 314 Uuq 315 Uuq 316 Uuq 317 Uuq 318 Uuq 319 Uuq 320 Uuq 321 Uuq 322 Uuq 323 Uuq 324 Uuq 325 Uuq 326 Uuq 327 Uuq 328 Uuq 329 Uuq 330 Uuq 331 Uuq 332 Uuq 333 Uuq 334 Uuq 335 Uuq 336 Uuq 337 Uuq 338 Uuq 339 Uuq 340 Uuq 341 Uuq 342 Uuq 343 Uuq 344 Uuq 345 Uuq 346 Uuq 347 Uuq 348 Uuq 349 Uuq 350 Uuq 351 Uuq 352 Uuq 353 Uuq 354 Uuq 355 Uuq 356 Uuq 357 Uuq 358 Uuq 359 Uuq 360 Uuq 361 Uuq 362 Uuq 363 Uuq 364 Uuq 365 Uuq 366 Uuq 367 Uuq 368 Uuq 369 Uuq 370 Uuq 371 Uuq 372 Uuq 373 Uuq 374 Uuq 375 Uuq 376 Uuq 377 Uuq 378 Uuq 379 Uuq 380 Uuq 381 Uuq 382 Uuq 383 Uuq 384 Uuq 385 Uuq 386 Uuq 387 Uuq 388 Uuq 389 Uuq 390 Uuq 391 Uuq 392 Uuq 393 Uuq 394 Uuq 395 Uuq 396 Uuq 397 Uuq 398 Uuq 399 Uuq 400 Uuq 401 Uuq 402 Uuq 403 Uuq 404 Uuq 405 Uuq 406 Uuq 407 Uuq 408 Uuq 409 Uuq 410 Uuq 411 Uuq 412 Uuq 413 Uuq 414 Uuq 415 Uuq 416 Uuq 417 Uuq 418 Uuq 419 Uuq 420 Uuq 421 Uuq 422 Uuq 423 Uuq 424 Uuq 425 Uuq 426 Uuq 427 Uuq 428 Uuq 429 Uuq 430 Uuq 431 Uuq 432 Uuq 433 Uuq 434 Uuq 435 Uuq 436 Uuq 437 Uuq 438 Uuq 439 Uuq 440 Uuq 441 Uuq 442 Uuq 443 Uuq 444 Uuq 445 Uuq 446 Uuq 447 Uuq 448 Uuq 449 Uuq 450 Uuq 451 Uuq 452 Uuq 453 Uuq 454 Uuq 455 Uuq 456 Uuq 457 Uuq 458 Uuq 459 Uuq 460 Uuq 461 Uuq 462 Uuq 463 Uuq 464 Uuq 465 Uuq 466 Uuq 467 Uuq 468 Uuq 469 Uuq 470 Uuq 471 Uuq 472 Uuq 473 Uuq 474 Uuq 475 Uuq 476 Uuq 477 Uuq 478 Uuq 479 Uuq 480 Uuq 481 Uuq 482 Uuq 483 Uuq 484 Uuq 485 Uuq 486 Uuq 487 Uuq 488 Uuq 489 Uuq 490 Uuq 491 Uuq 492 Uuq 493 Uuq 494 Uuq 495 Uuq 496 Uuq 497 Uuq 498 Uuq 499 Uuq 500 Uuq 501 Uuq 502 Uuq 503 Uuq 504 Uuq 505 Uuq 506 Uuq 507 Uuq 508 Uuq 509 Uuq 510 Uuq 511 Uuq 512 Uuq 513 Uuq 514 Uuq 515 Uuq 516 Uuq 517 Uuq 518 Uuq 519 Uuq 520 Uuq 521 Uuq 522 Uuq 523 Uuq 524 Uuq 525 Uuq 526 Uuq 527 Uuq 528 Uuq 529 Uuq 530 Uuq 531 Uuq 532 Uuq 533 Uuq 534 Uuq 535 Uuq 536 Uuq 537 Uuq 538 Uuq 539 Uuq 540 Uuq 541 Uuq 542 Uuq 543 Uuq 544 Uuq 545 Uuq 546 Uuq 547 Uuq 548 Uuq 549 Uuq 550 Uuq 551 Uuq 552 Uuq 553 Uuq 554 Uuq 555 Uuq 556 Uuq 557 Uuq 558 Uuq 559 Uuq 560 Uuq 561 Uuq 562 Uuq 563 Uuq 564 Uuq 565 Uuq 566 Uuq 567 Uuq 568 Uuq 569 Uuq 570 Uuq 571 Uuq 572 Uuq 573 Uuq 574 Uuq 575 Uuq 576 Uuq 577 Uuq 578 Uuq 579 Uuq 580 Uuq 581 Uuq 582 Uuq 583 Uuq 584 Uuq 585 Uuq 586 Uuq 587 Uuq 588 Uuq 589 Uuq 590 Uuq 591 Uuq 592 Uuq 593 Uuq 594 Uuq 595 Uuq 596 Uuq 597 Uuq 598 Uuq 599 Uuq 600 Uuq 601 Uuq 602 Uuq 603 Uuq 604 Uuq 605 Uuq 606 Uuq 607 Uuq 608 Uuq 609 Uuq 610 Uuq 611 Uuq 612 U

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Metalloids

Located between metals and nonmetals

Located between metals and nonmetals

Nonmetals

Located in the upper-right side of the periodic table

[illegible]

Photo credits left to right: (c) Richard Megna / Fundamental Photographs; sciencephotos / Alamy

Group 1A: Alkali Metals

[illegible]

- Soft metals
- React violently with water

Group 2A: Alkaline Earth Metals

1A	2A	3A	4A	5A	6A	7A	8A
1	2						
2	Be						
3	Mg						
4	Ca						
5	Sr						
6	Ba						
7	Ra						



4	Be
	9.01
12	Mg
	24.31
20	Ca
	40.08

- Less reactive than group 1A
- burn brightly

Group 8A: Noble Gases

1A	2A	3A	4A	5A	6A	7A	8A
1	2						
2							He
3							Ne
4							Ar
5							Kr
6							Xe
7							Rn

2	He
	4.00
10	Ne
	20.18
18	Ar
	39.95
36	Kr
	83.80

- generally do not form compounds
- gases at room temperature

Group 7A: Halogens



3A	4A	5A	6A	7A	8A
13	14	15	16	17	18
				F	
				Cl	
				Br	
				I	
				At	
				Ts	

9	F
	19.00
17	Cl
	35.45
35	Br
	79.90
53	I
	126.90

- diatomic molecules in elemental form
- Form many different compounds

Uncovering Atomic Structure



- The atoms of each element are unique.
- Atoms combine in whole-number ratios to form compounds.
- Atoms are not created or destroyed in chemical reactions.

subatomic particles particles that make up atoms

Describing particles

Mass

atomic mass unit (u)

$$1 \text{ u} = 1.66 \times 10^{-27} \text{ kg}$$

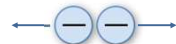
hydrogen atom:
mass = 1.0 u

Charge

opposite charges attract



like charges repel



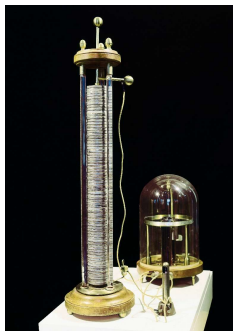
Separating Elements from Molecules



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Charles D. Winters/Science Source

Volta

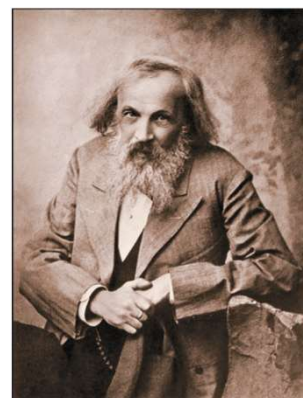
1800: The year that changed chemistry



BeBa/berfoto/The Image Works

Volta invents electrochemical cell (battery)

Mendeleev's Periodic Table

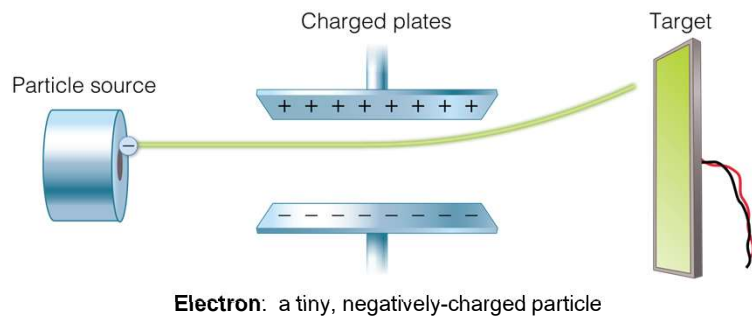


Stock Montage/Getty Images

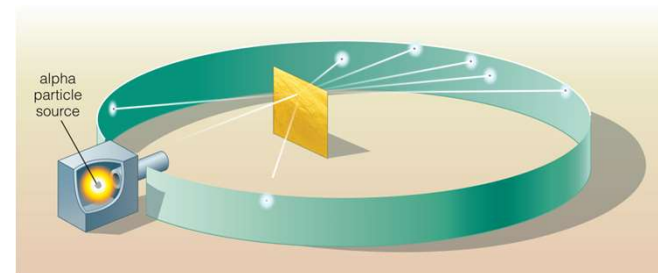
ПЕРИОДИЧЕСКАЯ СИСТЕМА ЭЛЕМЕНТОВ															
I II III IV V VI VII VIII IX X XI XII															
1	H													He	
2	Li	Be	B	C	N	O	F	Ne							
3	Na	Mg	Al	Si	P	S	Cl	Ar							
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Pb
6	Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Po	At
7	Fr	Ra	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Mn

Sorfoto/Getty Images

Identification of Charged Particles



Ernest Rutherford



Plum Pudding Model

atoms
 {
 negative positive
 electrons ?

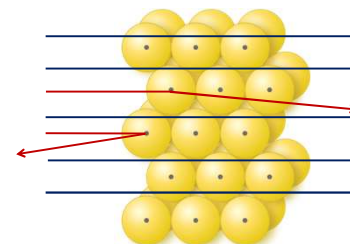


Plum pudding model

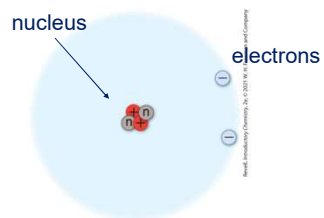
envisioned negative electrons spread throughout a positively-charged material.

Rutherford's Conclusions

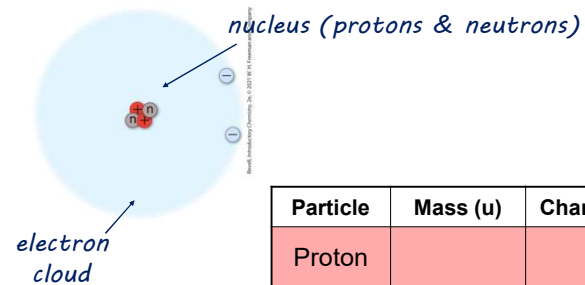
The atom is mostly empty space, with a dense nucleus at the center.



Model of an Atom

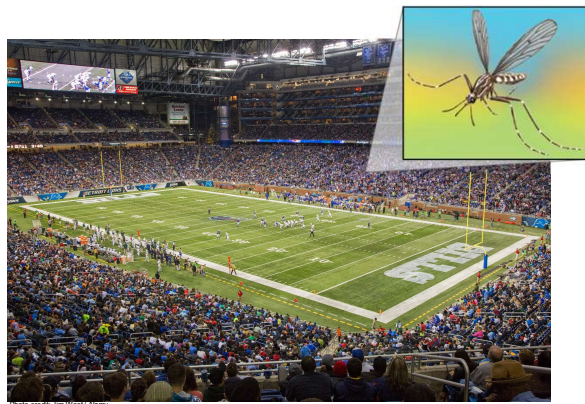


Atomic Particles

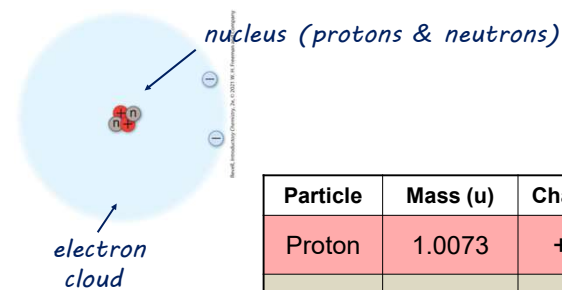


Particle	Mass (u)	Charge
Proton		
Neutron		
Electron		

The Volume of an Atom



Atomic Particles, Continued



Particle	Mass (u)	Charge
Proton	1.0073	+1
Neutron	1.0087	--
Electron	0.0005	-1

Atomic Identity

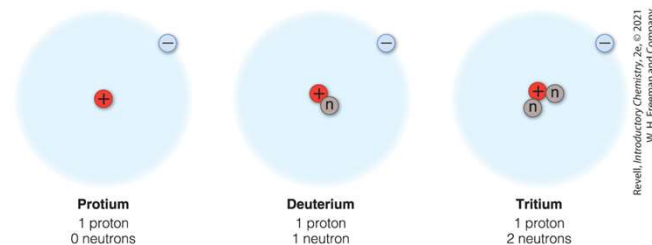
The number of protons determines the identity of the atom.

- 1 proton – hydrogen
- 2 protons – helium
- 3 protons – lithium
- 4 protons – beryllium

Isotopes

Have the same atomic number, but different mass number

Three isotopes of hydrogen:



Atomic Number and Mass Number

Atomic number

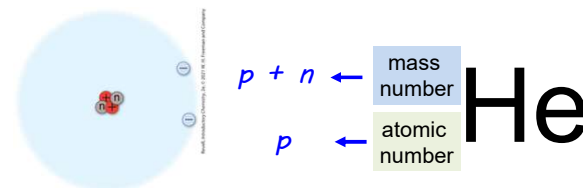
The number of protons in an atom
Also the number of electrons in a neutral atom

Mass number

The number of protons + neutrons

→ 1	H	1.01
→ 3	Li	6.94
→ 11	Na	22.99
→ 19	K	39.10

Writing Atomic Symbols



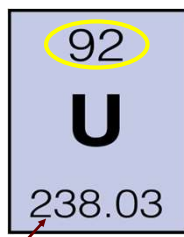
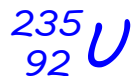
Helium:
2 protons
2 neutrons

${}^4_2\text{He}$

Example of Writing Atomic Symbols

An important isotope of uranium has 92 protons and 143 neutrons. Write the symbol with the atomic and mass numbers.

$$92 + 143 = 235$$



average atomic mass

Example of Weighted Average

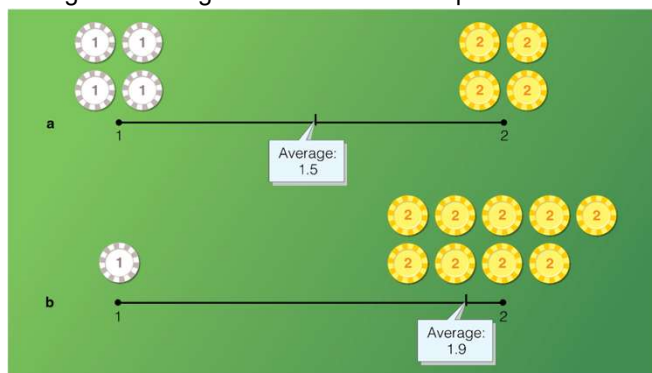
We have a large number of poker chips. 10% of the chips are \$1 chips, and 90% are \$2 chips. What is the average value of the chips?

$$\text{average value} = (\text{value A} \times \text{fraction A}) + (\text{value B} \times \text{fraction B})$$

$$\begin{aligned} \text{average value of chips} &= (\$1 \times 0.10) + (\$2 \times 0.90) \\ &= \$1.9 \end{aligned}$$

Average Atomic Mass

A weighted average of the different isotopes of an element.



Example of Average Atomic Mass of Carbon

Carbon atoms exist primarily as two isotopes:

$${}^{12}\text{C}: \text{mass} = 12.0000 \text{ u} \quad (98.93\%)$$

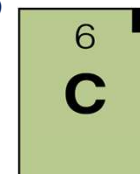
$${}^{13}\text{C}: \text{mass} = 13.0034 \text{ u} \quad (1.07\%)$$

What is the average atomic mass for carbon?

Average mass of carbon

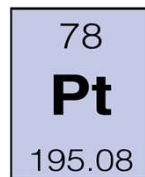
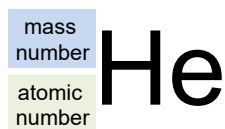
$$= (12.0000 \text{ u})(0.9893) + (13.0034 \text{ u})(0.0107)$$

$$= 12.01 \text{ u}$$




Summary of Atoms and Elements

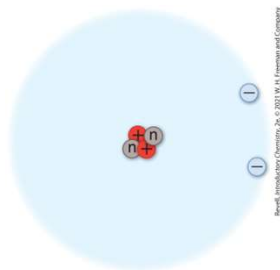
- The protons determine the identity of the atoms
- **atomic number:** protons
- **mass number:** protons + neutrons
- **isotopes:** same number of protons, different neutrons
- The periodic table: atomic number and the average atomic mass.






History of the Atom, Part 1

Model	Year		Key Ideas
Dalton's Atomic Theory	1808		Atoms are indivisible particles.



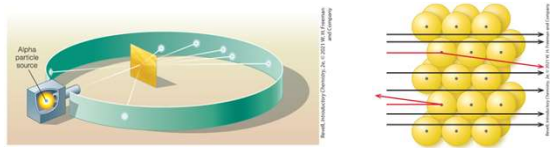
Electrons – A Preview



History of the Atom, Part 2

Model	Year		Key Ideas
Dalton's Atomic Theory	1808		Atoms are indivisible particles.
Plum Pudding Model	1904	 	Negative electrons are spread through a positive matrix.

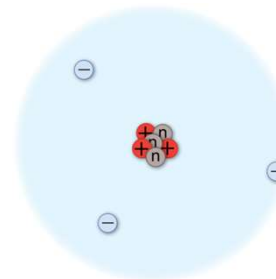
History of the Atom, Part 3

Model	Year		Key Ideas
Dalton's Atomic Theory	1808		Atoms are indivisible particles.
Plum Pudding Model	1904		Negative electrons are spread through a positive matrix.
			





Ions, Part 1

Atoms gain or lose electrons to form *ions*.

Ion: An atom or group of atoms with an overall charge.



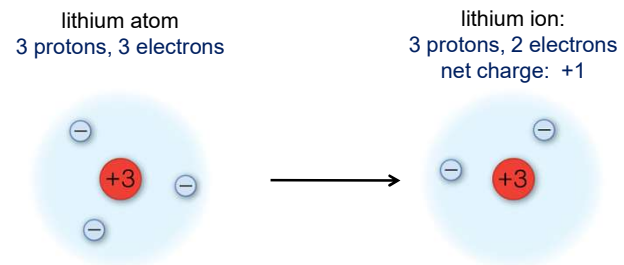
History of the Atom, Part 4

Model	Year		Key Ideas
Dalton's Atomic Theory	1808		Atoms are indivisible particles.
Plum Pudding Model	1904		Negative electrons are spread through a positive matrix.
Bohr Model	1913		Electrons orbit the nucleus like planets orbit the sun.
Quantum Model	1920s		Electrons behave both as particles and as waves.

Ions, Part 2

Atoms gain or lose electrons to form *ions*.

Ion: An atom or group of atoms with an overall charge.

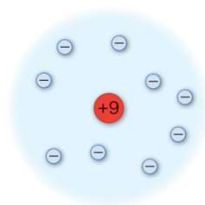


Ions, Part 3

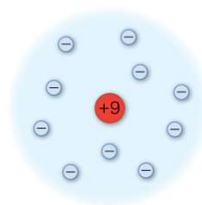
Atoms gain or lose electrons to form *ions*.

Ion: An atom or group of atoms with an overall charge.

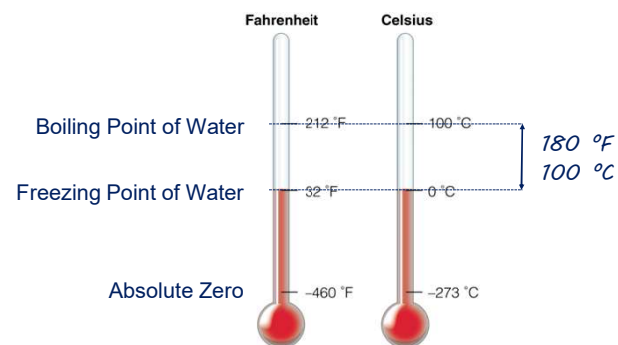
fluorine atom
9 protons, 9 electrons



fluoride ion:
9 protons, 10 electrons
net charge: -1



Converting Between Temperature Units



Example of Ions

Sulfur is atomic number 16. Sulfur atoms commonly form sulfide ions, which have a charge of -2 . How many electrons are in the electron cloud of a sulfide ion?

sulfur atom:

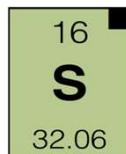
16 protons

16 electrons

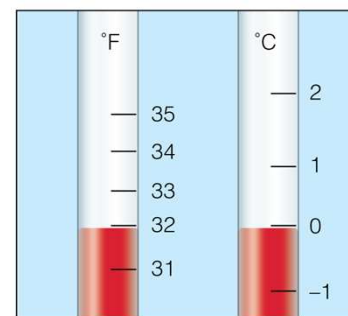
sulfide ion: (-2)

16 protons

18 electrons



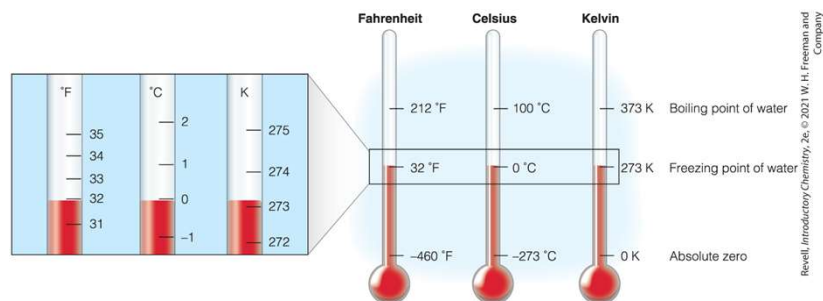
Fahrenheit and Celsius



$$^{\circ}\text{F} = \frac{9}{5}^{\circ}\text{C} + 32$$

$$^{\circ}\text{C} = \frac{5}{9}(^{\circ}\text{F} - 32)$$

The Three Temperature Scales



Temperature Calculation

A refrigerator maintains an inside temperature of 42 °F.
Express this temperature in Celsius and in kelvins.

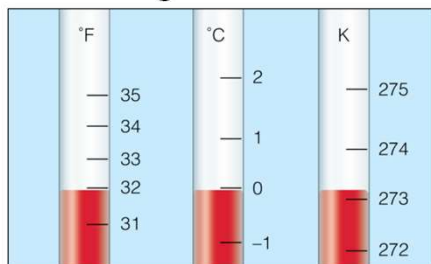
$$^{\circ}\text{C} = \frac{5}{9} (^{\circ}\text{F} - 32)$$

$$^{\circ}\text{C} = \frac{5}{9} (42 - 32) = 5.6 ^{\circ}\text{C}$$

$$\text{K} = ^{\circ}\text{C} + 273.15$$

$$\text{K} = 5.6 + 273.15 = 278.75 \text{ K} = 278.8 \text{ K}$$

Freezing Point on the Three Temperature Scales



$$\text{K} = ^{\circ}\text{C} + 273.15$$

"32 degrees Fahrenheit"

"0 degrees Celsius"

"273 kelvins"