# Atomic Theory

- concept of atom has been around for over 2000 yrs.
- Greek philosophers argued that matter could be subdivided into tiny indivisible particles called atomos - meaning cannot be cut or indivisible
- In 1808 John Dalton proposed a theory to Explain the observations of matter

## Dalton's Atomic Theory

- all matter is made up of tiny, indivisible particles called atoms.
- all atoms of an element are identical
- atoms of different elements are different
- atoms are rearranged to form new substances in chemical reactions, but they are never created or destroyed

An atom is the smallest part of an element

Dalton's Theory did not explain how thing aquire an electrical charge.

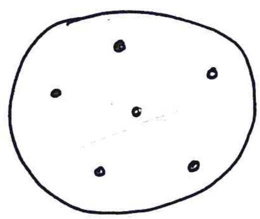
J.J. Thomson used a cathode ray tube to discover a new particle – the electron in 1897.

An electron is a negatively charged particle in an atom or ion

He proposed that an electron is a negatively charged, extremely small part of an atom.

The new model

Plum pudding model



the electrons – the negative charged particles were evenly spaced in a positively charged sphere

1909 Ernest Rutherford tests Thomsons theory

He aimed tiny positive alpha particles at a thin sheet of gold foil.

An alpha particle has 2 protons and 2 neutrons.

He measured how much the gold foil deflected the particles by using a flouresent screen.

this prediction (hypothesis)

if the electrons were equally distributed throughout the atom, the positively charged alpha particles should pass straight through the atoms of the foil.

After many trials, he observed most of the alpha particles did pass through the gold foil unaffected. However, some deflected at large angles.

From this he reasoned that each atom contained a small, dense, positively charged central nucleus

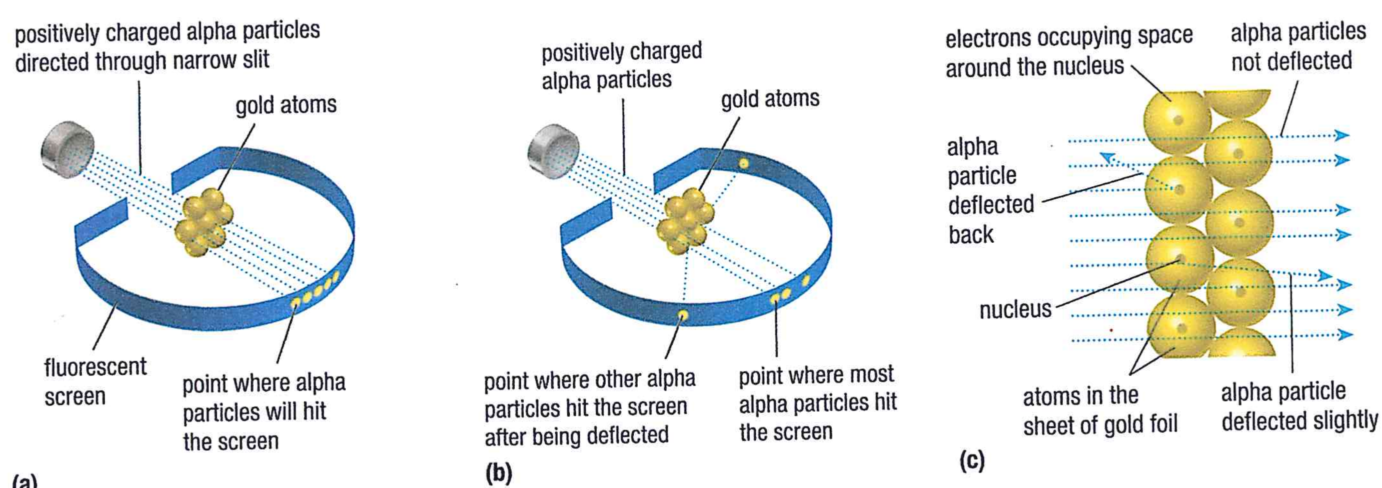



**Figure 6** (a) Rutherford's prediction: if Thomson's model were correct, the alpha particles would pass through the gold atoms unaffected (b) Rutherford's observation: a small portion of the alpha particles were deflected by the gold atoms (c) Rutherford's explanation: each atom has a dense, positively charged nucleus that deflects alpha particles

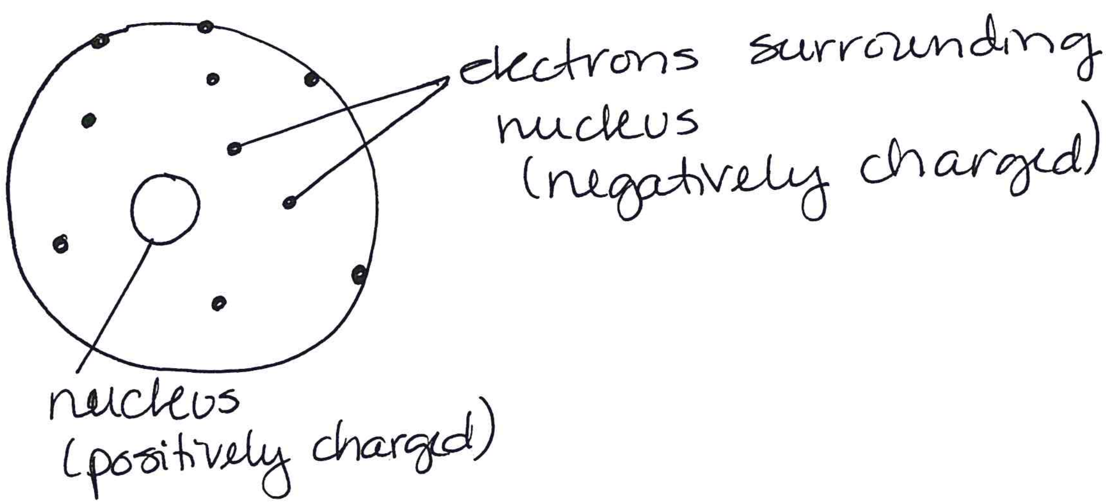
pg 12

Rutherford also proposed that the nucleus is made up of positively charged particles - each one called a <u>proton</u>

<u>A proton</u> is a positively charged particle in the atom's nucleus.

James Chadwick confirmed through experiments that the nucleus also contains <u>neutral</u> particles as well as protons.
These neutral particles in a nucleus are called <u>neutrons</u>.

## Rutherford's Model of the Atom

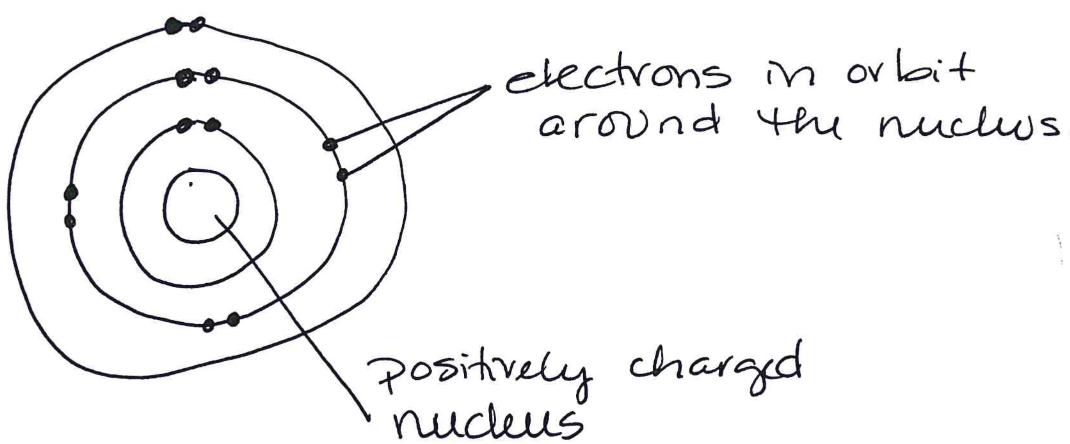


# Bohr's Proposal of Energy Levels

Through experiments Bohr realized hydrogen had a unique atomic spectrum - a pattern of colored lines that no other element can produce. The hydrogen atoms emitted light when they were "excited" - hit with energy.

From this he proposed that electrons orbit the nucleus of the atom in definite energy levels.

# Bohr's Planetary Model of the Atom



# Bohr-Rutherford Diagrams

These diagrams show the number of subatomic particles in an atom and represent the arrangement of electrons around the nucleus.

**The Valence Shell**: Most reactions involve only the electrons in the valence shell.

**The valence shell** is the outer most energy level

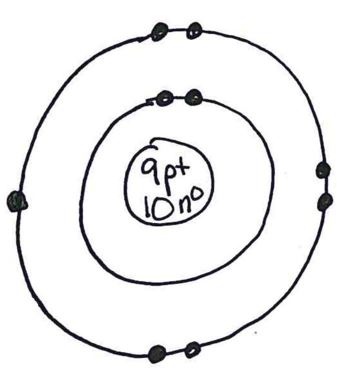
**Valence Electrons**: Electrons located in the valence shell.

**Example**

Fluorine, $^{9}_{19}F$

9 is the number of protons And the number of electrons

19 is the number of protons plus the number of neutrons.



# Energy levels

In Bohr's model, the electrons can only exist in certain allowed orbits. Each orbit has a specific quantity of energy associated with it. Electron orbits are also called Energy Levels.

Electrons can "jump" from 1 Energy level to another. As they go from a higher to lower energy level they emit light. As they go from a lower to higher energy level they absorb light.

In Bohr's model the maximum number of electrons in each level is

1st level ⇒ 2

2nd level ⇒ 8

3rd level ⇒ 18

omit

## A Summary of Subatomic Particles

**Table 1** summarizes the subatomic particles and their characteristics.

**Table 1** Subatomic Particles

| Subatomic particle | Symbol | Location in the atom | Charge | Approximate mass (kg) |
|---|---|---|---|---|
| electron | $e^-$ | in energy levels outside the nucleus | –1 | $9.11 \times 10^{-31}$ |
| proton | $p^+$ | in the nucleus | +1 | $1.67 \times 10^{-27}$ |
| neutron | $n^0$ | in the nucleus | 0 | $1.67 \times 10^{-27}$ |

## Atomic Number And Mass Number

6
C
carbon
12.01

Atomic Number (Z) is the unique number of protons in one atom of an element.

In a neutral atom the number of protons equals the number of electrons.

Mass Number (A) is the sum of the protons And neutrons in the nucleus of an atom

\# of neutrons = mass number – atomic number

6 ← Atomic number – # protons, # electrons
C
12.01 ← Mass number –

\# protons = 6
\# electrons = 6
\# neutrons = 6

\# neutrons = Mass # – atomic #

The atom can be represented in 3 different ways:

for Carbon

$^{6}_{12}C$ , C-12 , carbon-12

At times it is written $^{12}_{6}C$ ← atomic mass, ← atomic #

We will use $^{6}_{12}C$. Your periodic chart in the book has atomic # on top and atomic mass on bottom.

## Mass of An Atom

The unit to measure the mass of an atom is the atomic mass unit, u.

Atomic Mass Unit is defined as $\frac{1}{12}$ the mass of a carbon-12 atom

F-19 has a mass that is $\frac{19}{12}$ times that of C-12. So F-19 has a mass of 19u.

$1u = 1.660\,540\,2 \times 10^{-27}$ kg

# Octet Rule

Elements with full valence shells have a special stability.

In the 1st 18 elements, a full valence shell (except the first shell) contains 8 electrons.

Noble gases have 8 electrons in their valence shell. They are <u>extremely stable</u>. They do not usually react to form compounds.

<u>Full or Stable Octet</u>: an electron arrangement where the valence shell is filled with 8 valence electrons. (2 for H and He).

Only the Noble Gases have full octets. All other atoms combine with other atoms to attain this arrangement.

This is the <u>Octet Rule</u>: a generalization stating that when atoms combine, they tend to achieve 8 valence electrons.

**Valence**: the charge of an ion. The combining capacity of an atom determined by the number of electrons that it will lose, gain or share.

**Example**

Sodium loses 1 valence electron to become $Na^+$, sodium cation.

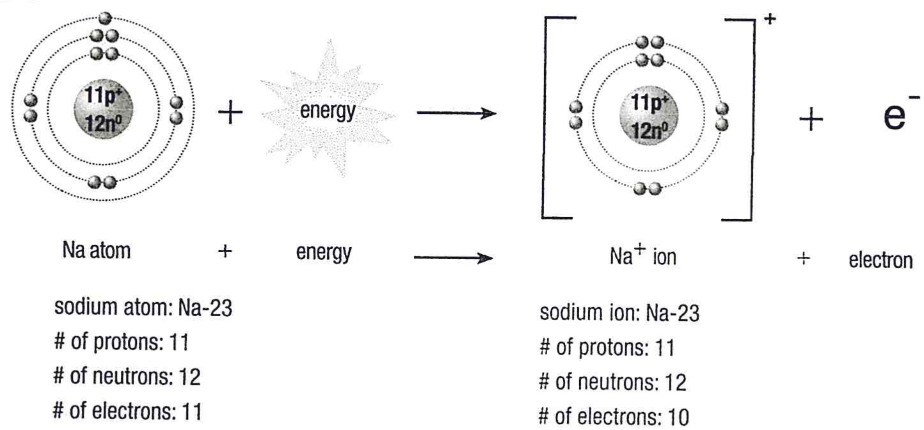



**Figure 3** A sodium atom loses its one valence electron to become a sodium cation, $Na^+$.

**Negative Ions: Anions**

Non-metals, elements on the right side of the periodic table, tend to gain electrons to fill their almost-complete valence shell.

They gain electrons and become negatively charged anions.

It does this by <u>sharing</u>, <u>losing</u> or <u>gaining</u> electrons.

When an atom gains or loses an electron it forms an <u>ion</u>.

<u>Ion</u>: a charged entity formed when an atom gains or loses one or more electrons.

## <u>Positive Ions: Cations</u>

Metals are located to the left of the zigzag staircase line on the periodic table. In the 1st few groups on the left side, metals have just a few electrons in their valence shell.

They lose electrons to acheive a stable arrangement.

They lose and become positively charged.

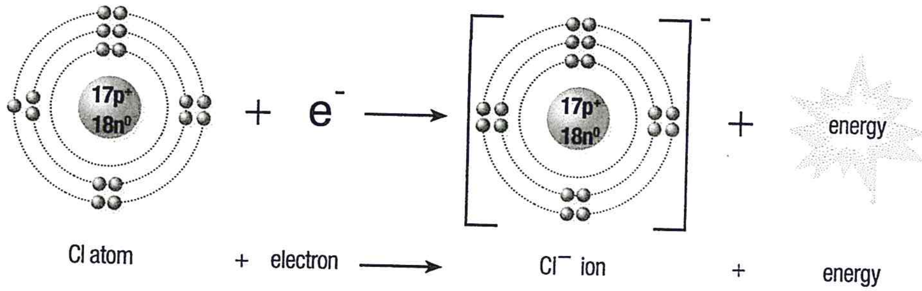
<u>Cation</u> - a positively charged ion formed by the removal of one or more electrons from the valence shell of a neutral atom.

The charge is often called the valence.

**Anion**: a negatively charged ion formed by the addition of one or more electrons to a neutral atom.

**Example**

An atom of Chlorine gains an electron to become a chloride anion, $Cl^-$




chlorine atom: Cl-35
\# of protons: 17
\# of neutrons: 18
\# of electrons: 17

chlorine ion: Cl-35 −
\# of protons: 17
\# of neutrons: 18
\# of electrons: 18

**Figure 4** An atom of chlorine gains an electron to become a chloride anion, $Cl^-$.

## Naming Cations And Anions

Cations: Have the same name as their element plus ion.

$Na^+$ is a sodium ion

Anions: Replace the end of the element's name with the suffix -ide plus ion.

$Cl^-$ is a chloride ion

# Common Valences for some Elements

The common valences are located in top right corner.

| Period | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 H hydrogen 1+ 1− | | | | | | | | | | | | | | | | | 2 He helium |
| 2 | 3 Li lithium 1+ | 4 Be beryllium 2+ | | | | | | | | | | | 5 B boron | 6 C carbon | 7 N nitrogen 3− | 8 O oxygen 2− | 9 F fluorine 1− | 10 Ne neon |
| 3 | 11 Na sodium 1+ | 12 Mg magnesium 2+ | | | | | | | | | | | 13 Al aluminum 3+ | 14 Si silicon | 15 P phosphorus 3− | 16 S sulfur 2− | 17 Cl chlorine 1− | 18 Ar argon |
| 4 | 19 K potassium 1+ | 20 Ca calcium 2+ | 21 Sc scandium | 22 Ti titanium | 23 V vanadium | 24 Cr chromium 2+ 3+ | 25 Mn manganese | 26 Fe iron 2+ 3+ | 27 Co cobalt | 28 Ni nickel | 29 Cu copper 1+ 2+ | 30 Zn zinc 2+ | 31 Ga gallium | 32 Ge germanium | 33 As arsenic | 34 Se selenium | 35 Br bromine 1− | 36 Kr krypton |
| 5 | 37 Rb rubidium 1+ | 38 Sr strontium 2+ | 39 Y yttrium | 40 Zr zirconium | 41 Nb niobium | 42 Mo molybdenum | 43 Tc technetium | 44 Ru ruthenium | 45 Rh rhodium | 46 Pd palladium | 47 Ag silver 1+ | 48 Cd cadmium | 49 In indium | 50 Sn tin 2+ 4+ | 51 Sb antimony | 52 Te tellurium | 53 I iodine 1− | 54 Xe xenon |
| 6 | 55 Cs cesium 1+ | 56 Ba barium 2+ | 57 La lanthanum | 72 Hf hafnium | 73 Ta tantalum | 74 W tungsten | 75 Re rhenium | 76 Os osmium | 77 Ir iridium | 78 Pt platinum | 79 Au gold | 80 Hg mercury | 81 Tl thallium | 82 Pb lead 2+ 4+ | 83 Bi bismuth | 84 Po polonium | 85 At astatine 1− | 86 Rn radon |
| 7 | 87 Fr francium 1+ | 88 Ra radium 2+ | 89 Ac actinium | 104 Rf rutherfordium | 105 Db dubnium | 106 Sg seaborgium | 107 Bh bohrium | 108 Hs hassium | 109 Mt meitnerium | 110 Ds darmstadtium | 111 Rg roentgenium | 112 Cn copernicium | 113 Uut ununtrium | 114 Uuq ununquadium | 115 Uup ununpentium | 116 Uuh ununhexium | 117 Uus ununseptium | 118 Uuo ununoctium |

**Figure 5** This periodic table shows the common valences for various elements on the periodic table. Look in the top right corner of each cell. Where an element has more than one valence, the most common valence is indicated in bold type. Do you notice any patterns?

Some elements have multiple ionic charges.

<u>Multivalent</u>: the property of having more than one possible valence.

A multivalent element is one that can form 2 or more different stable ions.

Most of the transition metals, those in the middle of the periodic table, can form more than one type of ion.

# Naming multivalent elements

- Use the Latin name and the suffix
  - -ous for the lower valence
  - -ic for the higher valence

- Use the IUPAC system
  - A Roman numeral in the name indicates the charge of the ion.

## Some Examples

**Table 1** Examples of Multivalent Metals

| Metal | Ions | Classical names | IUPAC names |
|---|---|---|---|
| copper, Cu | $Cu^{+}$<br>$Cu^{2+}$ | cuprous<br>cupric | copper(I)<br>copper(II) |
| iron, Fe | $Fe^{2+}$<br>$Fe^{3+}$ | ferrous<br>ferric | iron(II)<br>iron(III) |
| tin, Sn | $Sn^{2+}$<br>$Sn^{4+}$ | stannous<br>stannic | tin(II)<br>tin(IV) |
| lead, Pb | $Pb^{2+}$<br>$Pb^{4+}$ | plumbous<br>plumbic | lead(II)<br>lead(IV) |
| manganese, Mn | $Mn^{2+}$<br>$Mn^{3+}$<br>$Mn^{4+}$<br>$Mn^{6+}$<br>$Mn^{7+}$ | n/a | manganese(II)<br>manganese(III)<br>manganese(IV)<br>manganese(VI)<br>manganese(VII) |

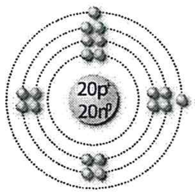
# Polyatomic Ions

Polyatomic ions: an ion made up of more than one atom, that acts as a single entity.

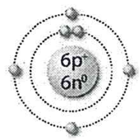
## Section 1.2: Atomic Structure

### Section 1.2 Questions, page 16

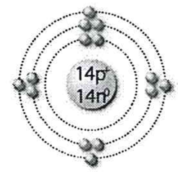
**1. (a)** **(b)** **(c)**




Ca




C

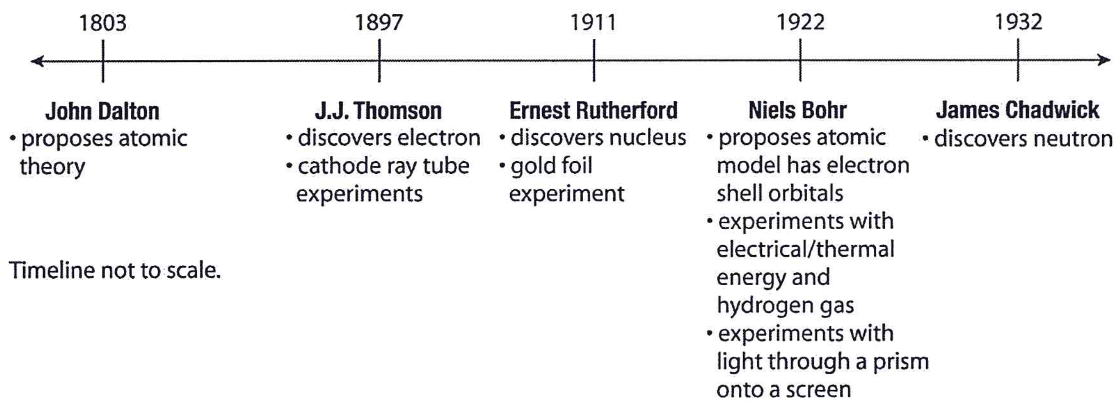



Si

**2.** In Ca there are 2 valence electrons. In C there are 4 valence electrons. In Si there are 4 valence electrons

**3.** Students' timelines should include the following scientists/experiments/discoveries in chronological order, with a brief description or diagram of each experiment.

**Formation of the Atomic Theory**




**4.** Dalton's atomic theory proposed the following:

• All matter is made up of tiny, indivisible particles called atoms. This proposal was no longer valid after Rutherford determined that there are subatomic particles (protons and electrons).

• All atoms of an element are identical. The proposal is still valid for atoms of an element under stable conditions.

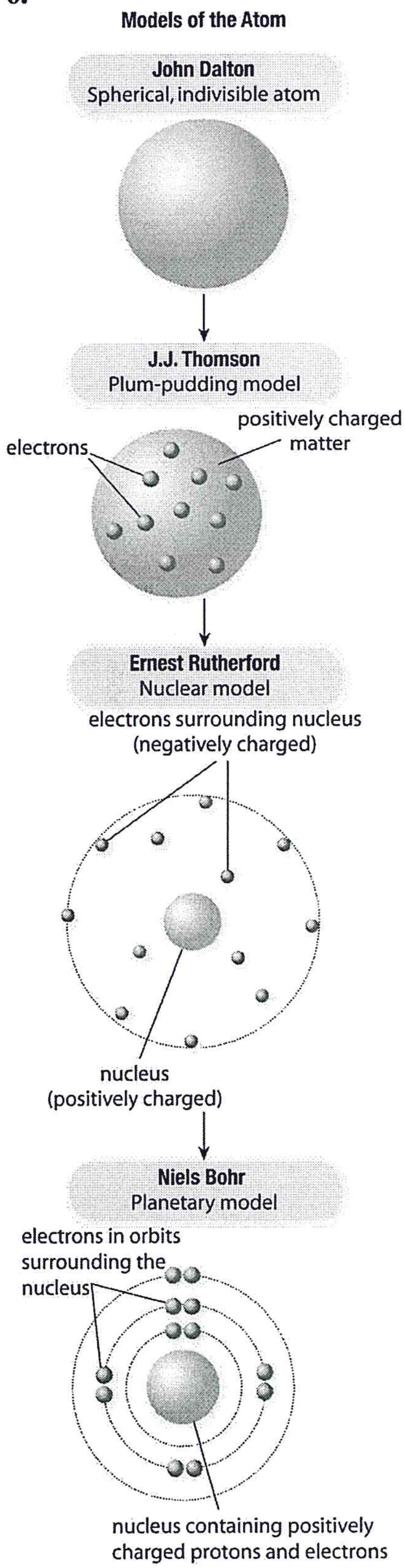
• Atoms of different elements are different. This is correct.

• Atoms are rearranged to form new substances in chemical reactions, but they are never created or destroyed. This is correct.

**5. Table 2** Atoms of Selected Elements

| Name of element | Symbol | Atomic number | Mass number | Number of protons | Number of neutrons | Number of electrons |
|---|---|---|---|---|---|---|
| uranium | U | 92 | 235 | 92 | 143 | 92 |
| magnesium | Mg | 12 | 25 | 12 | 13 | 12 |
| iodine | I | 53 | 131 | 53 | 78 | 53 |
| carbon | C | 6 | 14 | 6 | 8 | 6 |
| technetium | Tc | 43 | 99 | 43 | 56 | 43 |

**6.**


Models of the Atom
John Dalton
Spherical, indivisible atom
J.J. Thomson
Plum-pudding model
electrons
positively charged
matter
Ernest Rutherford
Nuclear model
electrons surrounding nucleus
(negatively charged)
nucleus
(positively charged)
Niels Bohr
Planetary model
electrons in orbits
surrounding the
nucleus
nucleus containing positively
charged protons and electrons

**7.** Answers may vary. Sample answer: We learn atomic theory to help us make predictions about the behaviour of matter. The models we study are probably incorrect in some ways, but they offer the best explanation that we are able to make at the present time. We learn about the progression of ideas to understand the scientific process of discovery.
**8.** Answers may vary. The scale model will have the length of the athletic field representing the radius of the atom and the average distance between the nucleus and an electron. The nucleus would then be about the size of a marble. Some students may also indicate that an electron is approximately 1000 times smaller than the nucleus. Sample sketch:


**9.** A star's atomic spectrum would be a combination of the atomic spectra for hydrogen and helium.
**10.** There are 119 protons, 119 electrons, and 183 neutrons in each atom of this element.
**11.** Answers may vary. Students will likely find information on the Standard Model (a theoretical framework describing all the currently known elementary particles). Students' answers will likely mention how neutrons and protons are composed of quarks and describe the six flavours of quarks (up, down, charm, strange, top, and bottom) and some properties of quarks (such as electric charge, colour charge, spin, and mass).

# Section 1.3: Ions and the Octet Rule

## Mini Investigation: Using Flame Tests, page 20

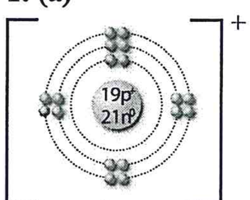
**A.** Answers may vary. Each sample should give a different result; however, some students may have difficulty distinguishing between two similar colours.
**B.** The flame colour was different for each sample because each element emits a unique spectrum.
**C.** The mystery substance being tested in Figure 6(c) could be copper(II) chloride, because none of the other solutions had a blue-green flame.
**D.** A real-life application in which flame tests would be used to identify ions is in analyzing unknown solutions for metal ions.

## Research This: Tattoo Ink — Decorative Body Art or Toxic Mixture?, page 22

**A. & B.** Answers may vary. Sample arguments for "tattoos are safe": People have used tattoos safely for 4000 years. Tattoo parlours in Ontario are regulated and must meet health and safety standards. You can choose a facility with a good reputation for safety. Sample arguments for "tattoos are not safe": Used or unsterilized tattooing equipment can transmit viral infections, such as hepatitis B and C, HIV/AIDS, herpes, toxic shock syndrome, skin tuberculosis, inoculation leprosy, as well as several bacterial skin infections. Some people are allergic to tattoo pigments. Malignant melanoma has also been linked to tattooing.

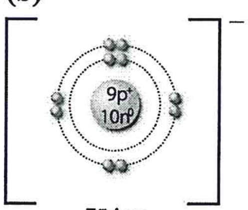
## Section 1.3 Questions, page 22

**1. (a)**



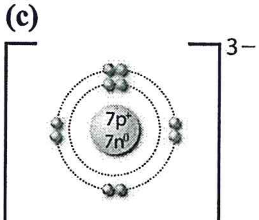

$K^+$ ion

**(b)**



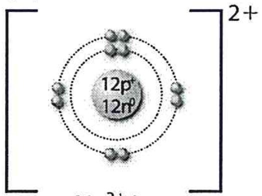

$F^-$ ion

**(c)**




$N^{3-}$ ion

**(d)**




**2.** **(a)** argon
**(b)** neon
**(c)** neon
**(d)** neon

**3.** The octet rule is a generalization stating that when atoms combine, they tend to achieve 8 valence electrons.

**4.** **(a)** oxide
**(b)** copper(I)
**(c)** tin(IV)
**(d)** sulfate
**(e)** hydroxide
**(f)** ammonium

**5.** We can communicate which ion is present in a compound by using the IUPAC system, in which a Roman numeral in the ion's name indicates the charge of the ion. For example, the $Mn^{2+}$ ion is manganese(II) and the $Mn^{4+}$ ion is manganese(IV). If manganese(IV) forms a compound with oxygen, for example, the compound is manganese(IV) oxide.

**6.** **(a)** $NO_3^-$
**(b)** $CO_3^{2-}$
**(c)** $C_2H_3O_2^-$
**(d)** $MnO_4^-$

**7.** In calcium carbonate, $CaCO^3$, the cation is $Ca^{2+}$ and the anion is $CO_3^{2-}$.

**8.** Ne, $Na^+$, $Al^{3+}$, and $O^{2-}$ have the same electron arrangement.

**9.** Two experimental techniques that might help to identify the presence of metal ions are a flame test with identity key and a conductivity test.

**10.** Answers may vary. Sample answer: Iron deficiency anemia is caused by insufficient intake of iron. Iron is an essential part of hemoglobin and decreased levels of iron result in insufficient levels of red blood cells. Common symptoms include weakness, fatigue, and pale skin. Iron-rich foods that can help alleviate anemia include red meats, nuts, beans, and lentils. Iron supplements can be used as well.

Some polyatomic ions are good:

Calcium phosphate is a major constituent of bones and teeth

hydrogen carbonate helps to regulate blood pH.

Some have negative effects:

phosphates can cause algae blooms in lakes or ponds.

Nitrites can form cancer-causing agents when reacting with substances in the digestive system.

Most polyatomic ions are composed of C, O, N, P, S, Cl.

Most are anions. Each ion gains one or more electrons to reach a stable arrangement.

A polyatomic ion behaves just like an ion made of only one atom.

## Ions in the Body

~99% of your body is made up of 6 elements

O, C, H, N, Ca, P

Many exist as ions dissolved in $H_2O$

There are smaller quantities of
S, Cl, Na, Mg, I

Need a delicate balance for good health.

$Na^+$: nerve impluse transmission
muscle contraction
$H_2O$ balance

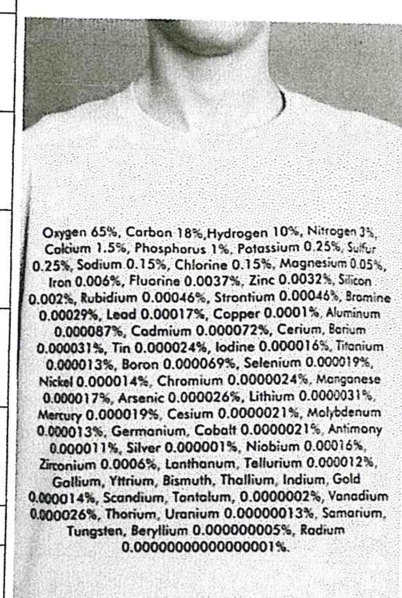
if too low: death can occur
if too high: hypertension, ↑ risk of heart disease

**Table 2** IUPAC Names and Formulas for Some Common Polyatomic Ions

| Name | Formula |
|---|---|
| acetate | $C_2H_3O_2^-$ |
| bromate | $BrO_3^-$ |
| carbonate | $CO_3^{2-}$ |
| hydrogen carbonate | $HCO_3^-$ |
| hypochlorite | $ClO^-$ |
| chlorite | $ClO_2^-$ |
| chlorate | $ClO_3^-$ |
| perchlorate | $ClO_4^-$ |
| chromate | $CrO_4^{2-}$ |
| dichromate | $Cr_2O_7^{2-}$ |
| cyanide | $CN^-$ |
| hydroxide | $OH^-$ |
| iodate | $IO_3^-$ |
| permanganate | $MnO_4^-$ |
| nitrite | $NO_2^-$ |
| nitrate | $NO_3^-$ |
| phosphate | $PO_4^{3-}$ |
| hydrogen phosphite | $HPO_3^{2-}$ |
| hydrogen phosphate | $HPO_4^{2-}$ |
| dihydrogen phosphite | $H_2PO_3^-$ |
| dihydrogen phosphate | $H_2PO_4^-$ |
| sulfite | $SO_3^{2-}$ |
| sulfate | $SO_4^{2-}$ |
| hydrogen sulfide | $HS^-$ |
| hydrogen sulfite | $HSO_3^-$ |
| hydrogen sulfate | $HSO_4^-$ |
| thiosulfate | $S_2O_3^{2-}$ |
| ammonium | $NH_4^+$ |

**Table 3** Some Important Ions in the Human Body

| Ion | Role | Source |
|---|---|---|
| $Na^+$ | important for body fluid control | salt<br>cheese<br>preservatives |
| $K^+$ | important for body fluid control and cell functions | bananas<br>milk<br>potatoes |
| $Ca^{2+}$ | a key component of bone and teeth | milk<br>cheese<br>spinach |
| $Fe^{3+}$ | important in muscle function; an essential part of hemoglobin in blood | kidney beans<br>asparagus<br>pine nuts |
| $Mg^{2+}$ | crucial for muscle and nerve functions | green plants<br>nuts<br>grains |
| $Cl^-$ | important for body fluid control | salt |
| $I^-$ | helps regulate the body's metabolic rate | fish<br>dairy products<br>iodized salt |



# Isotopes

Isotope: a form of an element in which the atoms have the same number of protons as all other forms of that element, but a different number of neutrons.

By using the mass number - the total number of protons and neutrons in the nucleus - you can distinguish between different isotopes for a given element.

## Example

C-12 and C-14 are different isotopes of C.

| | ${}^{6}_{12}C$ | and ${}^{6}_{14}C$ |
|---|---|---|
| $p^+$ | 6 | 6 |
| $e^-$ | 6 | 6 |
| $n^0$ | 6 | 8 |

same # $p^{\oplus}$

same # $e^{\ominus}$

<u>different</u> # $n^0$

Different elements have different #'s of isotopes. They also exist in different relative abundances.

Isotopic Abundance: the percentage of a given isotope in a sample of an element.

Mass Spectrometer: a measuring instrument used to determine the mass and abundance of isotopes.

A simple type of mass spectrometer is composed of three main sections: the ion source, the analyzer, and the detector (**Figure 6**). The sample is injected into the spectrometer and vaporized by heat. The sample is then ionized and accelerated by an electric field. The fast-moving ions next pass through a magnetic field, where they are deflected. The magnetic field deflects smaller isotopes more than larger isotopes. A detector plate senses the relative abundance of each isotope and a computer determines the mass and abundance of each isotope.

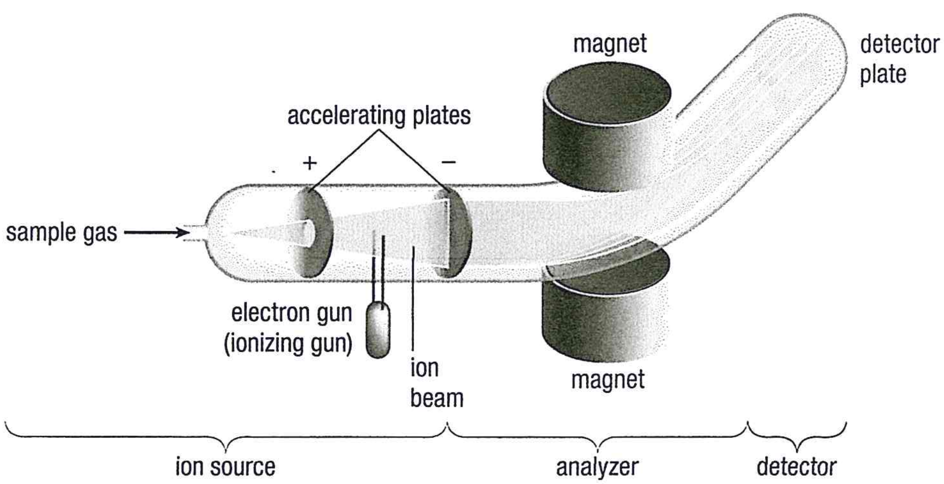



**Figure 6** A mass spectrometer

# Radiation And Radioisotopes

**Radioactive decay**: the spontaneous disintegration of unstable isotopes

Some isotopes emit nuclear radiation when they decay.

**Nuclear radiation**: energy or very small particles emitted from the nucleus of a radioisotope as it decays.

**There are 3 types**

alpha particle, $\alpha$: a positively charged particle with the same structure as the nucleus of the He-4 atom.
2 protons and 2 neutrons.

beta particle, $\beta$: a negatively charged particle identical to an electron

gamma ray, $\gamma$: a form of high-energy electromagnetic radiation. Have no mass.

These particles have different penetrating abilities.

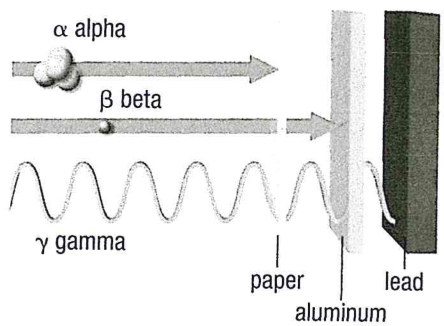



Figure 7 The three types of radiation have different penetrating abilities.

A <u>radioisotope</u> is an isotope that spontaneously decay to produce 2 or more smaller nuclei and radiation.

All radioisotopes are radioactive, meaning they emit radiation as they decay.

<u>Atomic Mass</u>

The atomic mass is the weighted average of the masses of all the naturally occurring isotopes of an element.

This considers the values <u>and</u> the relative abundance.

## **Sample Problem 1:** Calculating Atomic Mass For 3 Isotopes

Calculate the atomic mass of magnesium. Magnesium-24, magnesium-25, and magnesium-26 have isotopic abundances of 78.7 %, 10.1 %, and 11.2 % respectively.

**Given:** atomic mass and abundance of the 3 isotopes of magnesium

**Required:** atomic mass of magnesium

**Analysis:**

atomic mass = % abundance of isotope 1 (mass of isotope 1) +
% abundance of isotope 2 (mass of isotope 2) + ...

**Solution:**

atomic mass = 78.7 % (24 u) + 10.1 % (25 u) + 11.2 % (26 u)
= 24.3 u

Think about the answer obtained. Confirm that the answer makes sense. Round it to the appropriate number of digits.

**Statement:** The atomic mass of magnesium is 24.3 u.

## **Sample Problem 2:** Calculating Atomic Mass For 5 Isotopes

Germanium has the following isotopic composition. Calculate the atomic mass of germanium.

| | |
|---|---|
| 20.5 % | Ge-70 |
| 27.4 % | Ge-72 |
| 7.8 % | Ge-73 |
| 36.5 % | Ge-74 |
| 7.8 % | Ge-76 |

**Given:** atomic mass and abundance of the 5 isotopes of germanium

**Required:** atomic mass of germanium

**Analysis:**

atomic mass = % abundance of isotope 1 (mass of isotope 1) +
% abundance of isotope 2 (mass of isotope 2) + ...

**Solution:**

atomic mass = 20.5 % (70 u) + 27.4 % (72 u) + 7.8 % (73 u) + 36.5 % (74 u) + 7.8 % (76 u)

= 14.35 + 19.73 + 5.69 + 27.01 + 5.93 [extra digits carried]

= 72.71 u

Think about the answer obtained. Confirm that the answer makes sense. Round it to the appropriate number of digits.

**Statement:** The atomic mass of germanium is 73 u.

## Practice

1. Calculate the atomic mass of each of the following elements, given these naturally occurring isotopes and abundances:
   (a) Neon: Ne-20 (90.5 %), Ne-21 (0.3 %), Ne-22 (9.2 %) [ans: 20 u]
   (b) Titanium: Ti-46 (7.9 %), Ti-47 (7.3 %), Ti-48 (73.9 %), Ti-49 (5.5 %), Ti-50 (5.4 %) [ans: 48 u]

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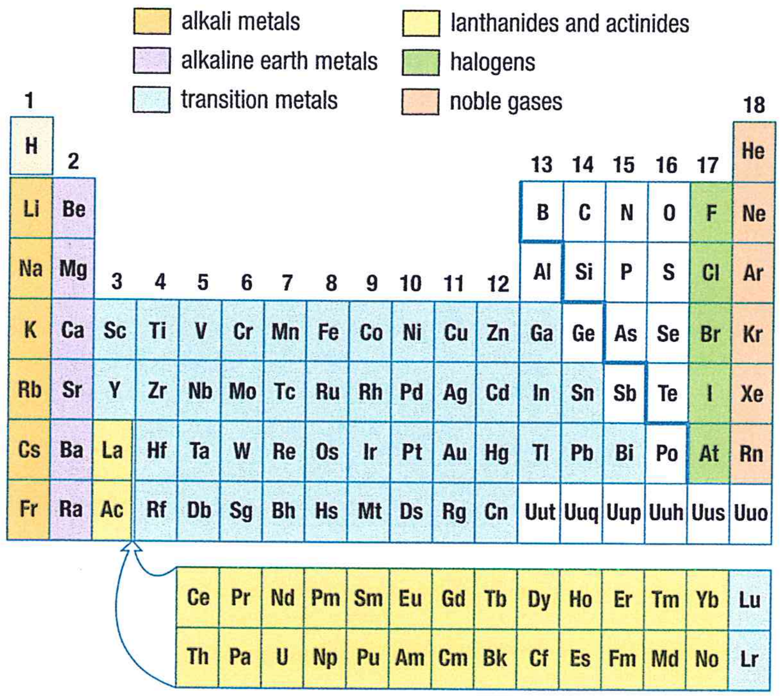
The Periodic Table

## Organization of the Periodic Table

The modern periodic table has many important features and characteristics. Elements are organized in order of increasing atomic number, yet spaced so that elements with similar physical and chemical properties are aligned in columns (**Figure 1**).




**hydrogen:** a unique element with many physical properties of non-metals but chemical properties of metals

**alkali metals:** soft, silver-coloured elements; solids at room temperature; exhibit metallic properties; react violently with water to liberate hydrogen gas; react with halogens to form compounds such as sodium chloride, NaCl(s); stored under oil or in a vacuum to prevent reaction with air

**alkaline earth metals:** light, very reactive metals; solids at room temperature; exhibit metallic properties; react with oxygen to form oxides with the general chemical formula, MO(s); all except beryllium will react with hydrogen to form hydrides; react with water to release hydrogen

**transition metals:** exhibit a range of chemical and physical properties; strong, hard metals with high melting points; good conductors of electricity; variable reactivity; form multivalent ions; many react with oxygen to form oxides; some react with acids to release hydrogen gas

**lanthanides:** elements with atomic numbers 57 to 70

**actinides:** elements with atomic numbers 89 to 102

**transuranic elements:** synthetic (not naturally occurring) elements with atomic number 93 or greater (beyond uranium)

**noble gases:** gases at room temperature; low melting and boiling points; extremely unreactive, making them especially interesting to chemists; krypton, xenon, and radon reluctantly form compounds with fluorine; radon is radioactive

**halogens:** may be solids, liquids, or gases at room temperature; exhibit non-metallic properties—not lustrous and non-conductors of electricity; extremely reactive, especially fluorine; react readily with hydrogen and metals

**representative elements:** both metals and non-metals from Groups 1, 2, and 13 to 18; may be solids, liquids, or gases at room temperature; many form colourful compounds

**Figure 1** Characteristic properties of elements in the periodic table

Group 1 - alkali metals - very reactive
Group 2 - alkaline earth metals - not quite as reactive as alkali metals
Group 3-12 - transition metals
Group 17 - halogens - very reactive
Group 18 - noble gases

# Bohr-Rutherford diagrams help explain properties.

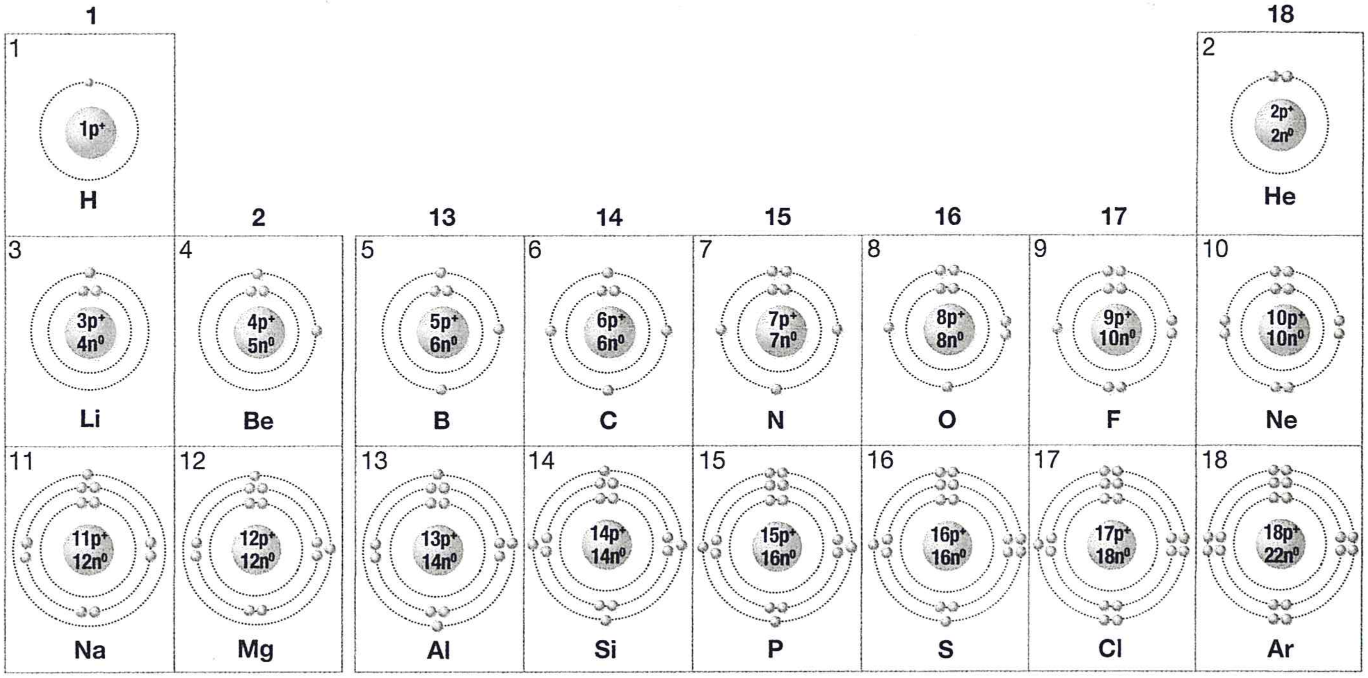


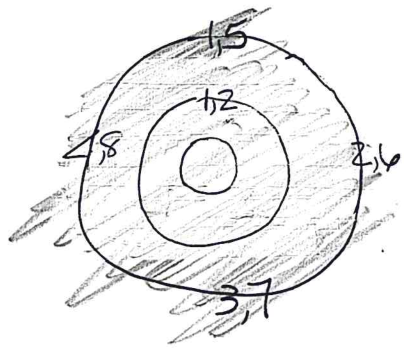

**Figure 3** Bohr–Rutherford diagrams of the first 18 elements. Note that the transition metals are omitted to save space.

Notice that, in the Bohr–Rutherford diagrams for the alkali metals, each atom has a single valence electron. The alkaline earth metals each have 2 valence electrons. The halogens each have 7 valence electrons and the noble gases each have 8 valence electrons or a full orbit. We can connect the number of valence electrons with the chemical properties of elements in a family. As we move across a period from left to right, we observe trends in reactivity. Specifically, we see that elements in Group 1 are highly reactive, then reactivity decreases as we move to the right. Reactivity starts to increase again after Group 14, rising as we reach the halogens and then dropping rapidly at the noble gases. We can use these trends to predict elements' properties.

## Lewis Symbols

A representation of an element consisting of the chemical symbol and dots to represent the valence electrons. Also called electron dot diagrams.

To draw a Lewis Symbol place 1 electron at the top, then on the right, then at the bottom, and then on the left. Then make pairs the same way.




## Examples

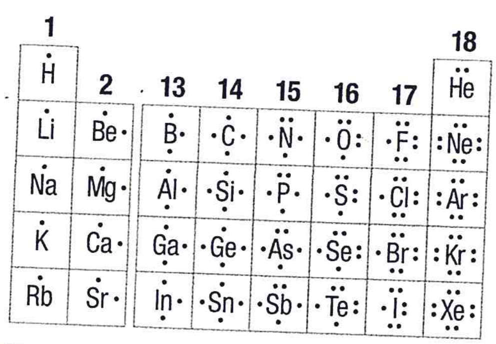



**Figure 4** Lewis symbols for the representative elements

# Periodic Trends in Atomic Properties

**Atomic Radius**: the distance from the nucleus to just beyond the outermost electrons - or the valence electrons.

in diatomic molecules ($O_2$, $N_2$) the atomic radius is the distance between the 2 nuclei, divided by 2.

**Effective Nuclear Charge**: the net force experienced by an electron in an atom due to the positively charged nucleus.

As you more left to right across the table

- the atomic radii decreases
- each element has one more proton and one more electron
- electrons are being added to the same energy level (no shielding occurs)
- As nuclear charge increases, the attraction for the electrons increases
- this attraction pulls electrons closer and radii decreases

As you move down a group (top to bottom)

- the atomic radii increases
- another energy level is added as you progress from one period to another.
- each level is a greater distance from the nucleus.
- the electrons on the outer energy level are shielded from the nucleus by the inner electrons.
- the outer electrons are not as attracted to the nucleus.
- the radius increases.

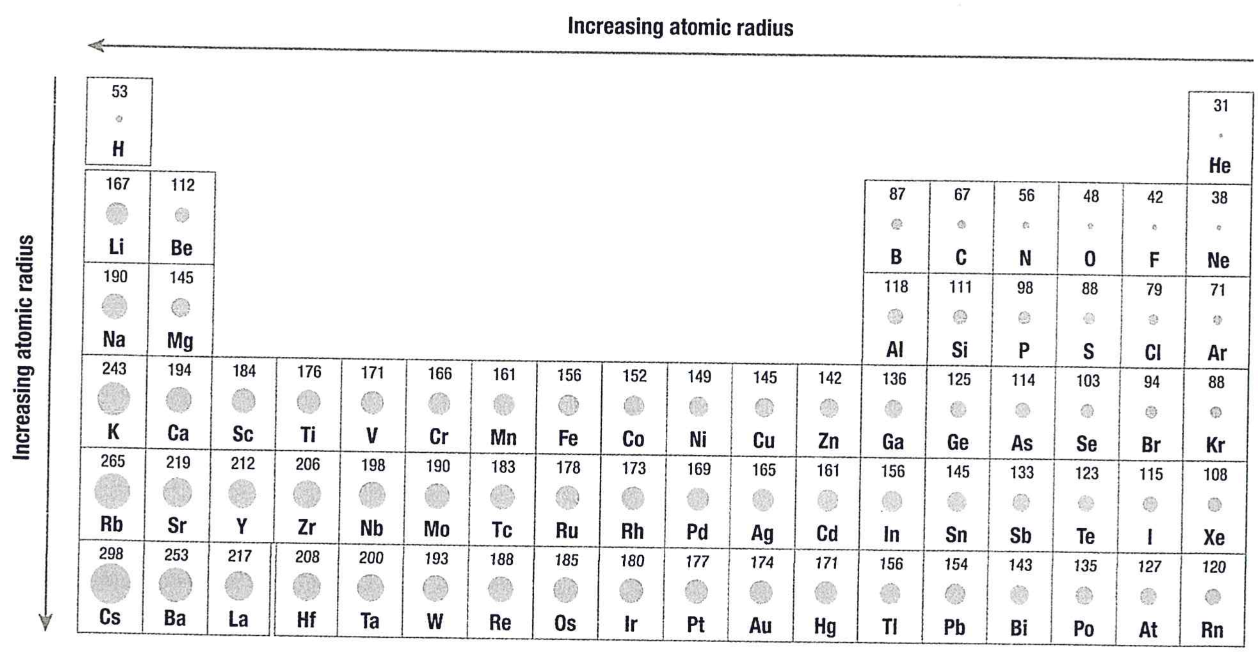



**Figure 2** Atomic radius is a periodic trend. What trends can you observe and explain in the first six periods?

# Ionic Radius

A measurement of the size of an ion. The distance from the centre of an ion to the outermost electrons. Usually measured in pm (picometers)

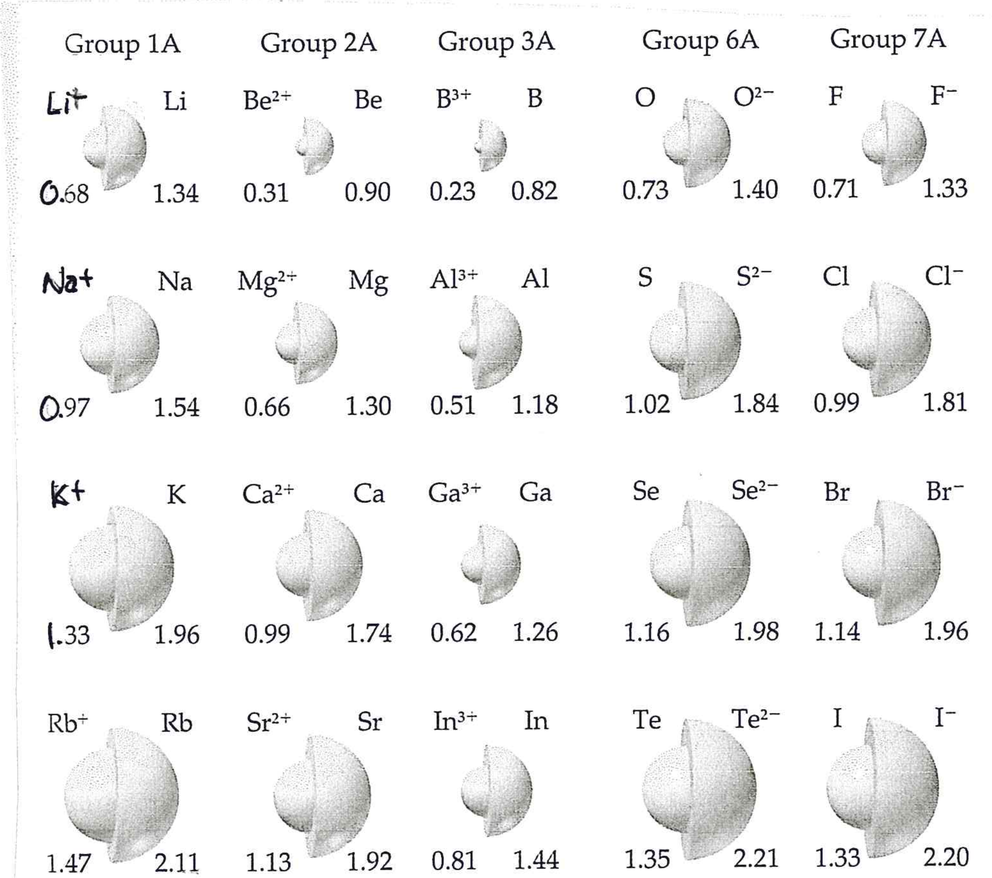
When you remove a valence electron, the cation __always__ becomes smaller than the neutral atom.

- This is because the force of attraction by the nucleus has less electrons to act upon.
- Each electron now has a stronger force upon it.
- The nucleus pulls each electron closer.
- The cation is smaller

When you add a valence electron, the anion is __always__ bigger than the neutral atom.

- gaining an electron results in a greater repulsion among the electrons

- the nuclear charge remains the same.
- the effective nuclear charge is shared among more electrons.
- the radii is bigger because not pulled tight.




◀ **Figure 8.5** Comparisons of the radii, in Å, of neutral atoms and ions for several of the groups of representative elements. Neutral atoms are shown in gray, cations in red, and anions in blue.

(note: radii in Å not pm)

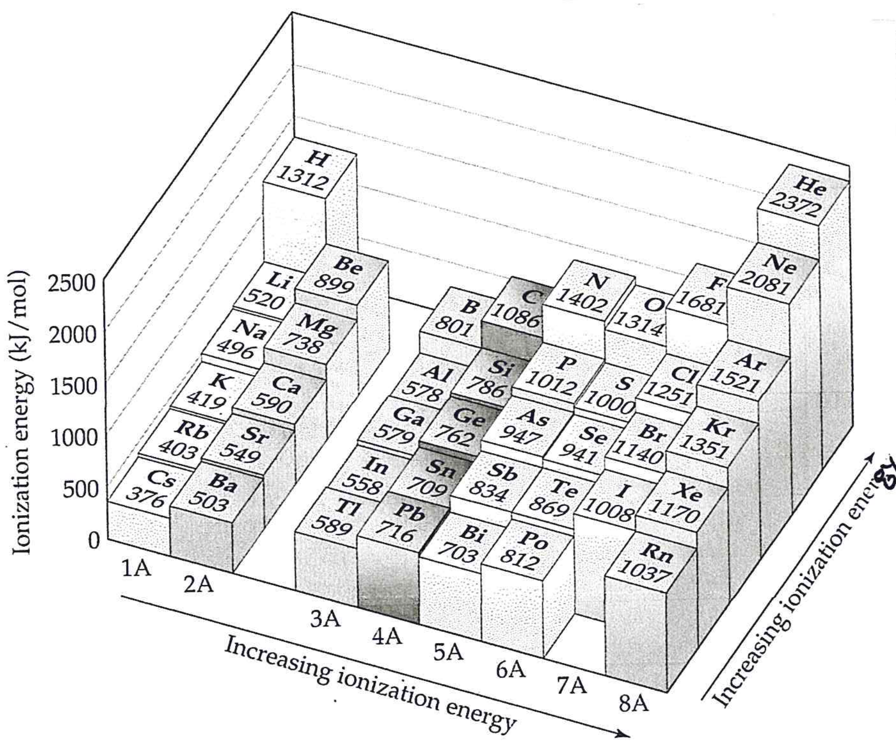
## Ionization Energy

the quantity of energy required to remove an electron from an atom or an ion in the gaseous state.

$Li_{(g)} + 520\ kJ/mole \rightarrow Li^{+}_{(g)} + e^{-}$

the unit for ionization energy is kJ/mole

if there is more than one electron that can be removed, specify which electron — 1st, 2nd ... ionization energy.




▶ **Figure 7.7** First ionization energies for the representative elements in the first six periods. The ionization energy generally increases from left to right and decreases from top to bottom. The ionization energy of astatine has not been determined.

As you go down a group the IE decrease

- the farther away an electron is from the nucleus the easier it is to remove.

As you go left to right, IE tends to increase

- as atomic radii decreases, the pull on the electron is greater so it is harder to remove.