CHAPTER 2: ATOMIC CONCEPTS

SECTION A

TO THE STUDENT: Study and know the book. Review the **bold words.**

ATOMIC MODELS

(Note: Names of the scientists do not have to be memorized.)

John Dalton stated that elements are made of atoms. Atoms of one element are alike; atoms of different elements are different.

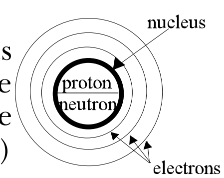
J.J. Thomson discovered electrons, particles with a negative charge. To him, the atom was a hard sphere of positive charge, with electrons in it.

Ernest Rutherford **bombarded gold foil** with **alpha particles** (nuclei of helium atoms). Most of the alpha **particles went** straight **through** the foil, **showing** that most of the **atom** is **empty space**. Alpha particles are positively charged. Some **alpha particles** that hit the gold foil **bounced back**. This **showed** that most of the mass of the atom is in the center, the **nucleus**, which is **positive**. Rutherford's model had electrons going around the nucleus.

Niels Bohr found that electrons are in different orbits around the nucleus.

THE ATOM

The **NUCLEUS** is in the center of the atom and has **protons** and **neutrons**.The **electrons** are around the nucleus. (Since protons, neutrons and electrons are inside the atom, they are called subatomic particles.) Most of the atom is **empty space**.



	PROTON	NEUTRON	ELECTRON
CHARGE	positive	none	negative
MASS	1 atomic mass unit	1 atomic mass unit	hardly any: 1/1836 atomic mass unit

Mass of one proton is one atomic mass unit (amu), therefore mass of ten protons equals ten atomic mass units (amu).

TABLE O lists the neutron, $^{1}_{0}n$; proton, $^{1}_{1}H$; and electron, $^{0}_{-1}e$. The top number is the mass. Mass of neutron = 1, mass of proton = 1, mass of electron = 0 (which means very, very little).

Table O
Symbols Used in Nuclear Chemistry

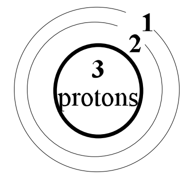
Name	Notation	Symbol
alpha particle	$^{4}_{2}He$ or $^{4}_{2}\alpha$	α
beta particle (electron)	$^{0}_{-1}e$ or $^{0}_{-1}\beta$	β^- β^-
neutron	$^{1}_{0}n$	n
proton	$^{1}_{1}H$ or $^{1}_{1}p$	p p

TABLE O

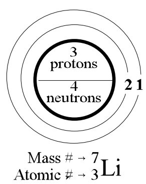
The **ATOMIC NUMBER** of any atom is equal to the number of **protons**, which is equal to the number of **electrons**.

SUMMARY:
Atomic Number = number of protons = number of electrons.

The atom lithium, Li, has an atomic number of 3. **Atomic number 3 = 3 protons** (3 positive charges) = **3 electrons** (3 negative charges). The **first** circle or **shell** can only hold **2 electrons**. Therefore, the **third electron** goes into the **next** circle or **shell**.



Lithium: $_3$Li
atomic number



The **MASS NUMBER** is equal to the total number of **protons and neutrons** in the nucleus. Lithium has a **mass number** of 7, which is **equal** to **3 protons** and **4 neutrons** in the nucleus. To find the **number of neutrons**, take the **mass number minus the atomic number**.

 # neutrons in Lithium = 7 (mass number) - 3 (atomic number) = 4 neutrons

As you see, lithium is written as $^{7}_{3}$Li. Li is the symbol for lithium; 3 is the atomic number, which is written at the bottom of the symbol of the element; and 7 is the mass number, which is written at the top of the symbol of the element

Question: Lithium has three protons.
1. What is the atomic number?
2. How many electrons does a lithium atom have?

Solution:
1. The atomic number equals the number of protons. Lithium has 3 protons, therefore the atomic number = 3.
2. In an atom, the number of electrons equals the number of protons. A lithium atom has 3 protons, therefore a lithium atom has 3 electrons.

Question: Lithium has 3 protons and 4 neutrons.
A. What is the mass number?
B. What is the charge of the lithium nucleus?

Solution:
A. Mass number equals the sum of protons and neutrons. A lithium atom has 3 protons and 4 neutrons. Therefore, lithium has a mass number of 7.

B. The lithium nucleus has 3 protons (3 positive charges) and 4 neutrons (neutrons have zero charge); therefore, charge of the lithium nucleus is +3.

Question: An atom has a mass number of 9 and has 5 neutrons. How many protons does it have?

Solution:

Mass number = number of protons (p) + number of neutrons (n).

$$\begin{aligned} \text{Mass Number} &= p + n \\ 9 &= p + 5 \\ -5 &\quad\; -5 \\ \hline 4 &= p \end{aligned}$$

Answer: 4 protons.

Check: 4p + 5n = 9 mass number

Question: An atom has a mass number 11 and has 5 protons. How many neutrons does it have?

Solution:

mass number = number of protons (p) + number of neutrons (n).

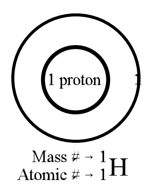
$$\begin{aligned} \text{Mass Number} &= p + n \\ 11 &= 5 + n \\ -5 &\quad -5 \\ \hline 6 &= \quad n \end{aligned}$$

Answer: 6 neutrons.

Check: 6n + 5p = 11 mass number

Now let's look at hydrogen. The element hydrogen, **H**, has an atomic number of 1 and a mass number of 1.

You do not have to memorize these numbers. If you know the element and want to know the atomic number, look at the Periodic Table, page Reference Tables 20-21. Hydrogen is written $^{1}_{1}H$. Below the symbol of the element is the atomic number; therefore, you can see that hydrogen has an atomic number of 1. Each element has its own atomic number. Each element with its atomic number is also given in Table S.



The atomic number is equal to the number of protons, which identifies the element (tells you what element it is). Atomic number 1 has 1 proton, and that tells you it is hydrogen (see drawing above).

Try Sample Questions #1-4, page 12, then do Homework Questions 1-10, pages 13-14, and #28, page 15.

ISOTOPES of the same element have the **same atomic number** but **different mass numbers**. There are three **isotopes** of hydrogen: **$^{1}_{1}H$, $^{2}_{1}H$, and $^{3}_{1}H$**. They all have the same atomic number, 1, which is the atomic number of hydrogen, but they have different top (mass) numbers. (These isotopes have different numbers of neutrons.)

Use this equation:

mass # - atomic # = number of neutrons

Therefore:

$^{1}_{1}H$: mass # - atomic # = number of neutrons; 1 - 1 = 0 neutrons

$^{2}_{1}H$: mass # - atomic # = number of neutrons; 2 - 1 = 1 neutrons

$^{3}_{1}H$: mass # - atomic # = number of neutrons; 3 - 1 = 2 neutrons

As you can see, isotopes differ in the number of neutrons.

You can **identify** (know) and describe which hydrogen **isotope** it is by the **mass number** (sum of protons and neutrons).

Isotope $^{3}_{1}H$ can be written as **^{3}H**, $^{3}_{1}$**H**, **Hydrogen-3** or **H-3**.

There are three isotopes of carbon, $^{12}_{6}C$, $^{13}_{6}C$, and $^{14}_{6}C$. Isotopes have the same atomic number, different mass number, and different number of neutrons. Again you can **identify** (know) and describe which carbon atom it is by the **mass number** (12, 13, or 14).

Isotope $^{14}_{6}C$ can be written as **^{14}C** (common notation), $^{14}_{6}$**C**, **carbon-14**, or **C-14**. Mass # is written after the dash: C-14.

One (1) atomic mass unit equals 1/12th the mass of ^{12}C.

1 amu (atomic mass unit) = 1.66 x 10^{-24}g.

The **ATOMIC MASS** of an element is the weighted average mass of the naturally occurring isotopes of that element. The average is weighted according to the proportions in which the isotopes occur.

35.453
Cl
17

There are two isotopes of chlorine, $^{35}_{17}Cl$ and $^{37}_{17}Cl$. They have the same atomic number but different mass numbers. Look at the box for the element $_{17}Cl$ from the Periodic Table. The atomic mass of $_{17}Cl$ is 35.5, which is the average weight of all the isotopes. Atomic mass is given in atomic mass units (amu); atomic mass of $^{35.5}_{17}Cl$ is 35.5 atomic mass units. Since the atomic mass, average weight 35.5 amu, is closer to atomic mass 35 (of $^{35}_{17}Cl$) than to atomic mass 37 (of $^{37}_{17}Cl$), there is more of the isotope $^{35}_{17}Cl$ and it is the most abundant isotope.

Question: There is 25% of the naturally occurring isotope $^{37}_{17}Cl$ and 75% of the naturally occurring $^{35}_{17}Cl$. What is the atomic mass of the element?

Solution: Method 1 (Can be used when percent is easily changed to a fraction): 25% or one quarter of chlorine has an atomic mass of 37. 75% or 3/4 of chlorine has a mass of 35. Take the average of the masses in the proportion which they are.

37 1/4 or 1 out of 4
35 }
35 } 3/4 or 3 out of 4
35 }
4) 142
35.5 = Atomic mass
Average

Atomic mass = 35.5 amu

Method 2: Take the percentage of each isotope times its mass; add the numbers.

Isotope	Percentage		Times	Mass		
$^{37}_{17}$Cl Take 25%:	$\frac{25}{100}$	or .25	X	37	=	9.25
$^{35}_{17}$Cl Take 75%:	$\frac{75}{100}$	or .75	X	35	=	26.25
					Add:	35.50
						Atomic mass

Atomic mass = 35.50 amu

Question: Carbon-14 differs from hydrogen-3 in that carbon-14 has

(1) 6 more neutrons (2) 6 more protons
(3) 6 more electrons (4) 2 more neutrons

Solution: Carbon-14 means the mass number is 14. Carbon has an atomic number of 6. See Periodic Table. $_6$C

Number of neutrons = mass # - atomic # = 14 - 6 = **8 neutrons**.

Hydrogen-3 means mass # is 3. Hydrogen has an atomic number of 1. See Periodic Table. $_1$H

\# of neutrons = mass # - atomic # = 3-1 = **2 neutrons**.

Answer 1. Carbon-14 has 6 more neutrons than hydrogen-3.

Try Sample Questions #5-6, page 12, then do Homework Questions, #11-14, page 14, and #29, page 15.

CHANGES IN ATOMIC MODELS

THOMSON MODEL OF THE ATOM: HARD SPHERE MODEL. The atom is a hard sphere of positive charge with electrons (negative charges) in it.

RUTHERFORD MODEL OF THE ATOM. Most of the mass of the atom is in the center, the nucleus, which is positive. Protons are in the nucleus. Most of the atom is empty space. Electrons go around the nucleus.

BOHR MODEL OF THE ATOM. Protons are in the nucleus, which is positive. Electrons revolve (go around) the nucleus in concentric circular orbits.

MODERN MODEL: WAVE MECHANICAL MODEL (ELECTRON CLOUD). Protons are in the nucleus. The electron cloud model (based on the work done by many scientists over a very long time) shows that an electron is in **an orbital**, (which is not the exact location of the electron, but) which is the most probable place (location) where the electron is. It shows the electron as a diffuse (spread out) cloud of negative charge. The thickest (most dense) part of the cloud is the most probable place to find the electron. The thinnest part of the cloud is the least likely place to find the electron. When an electron goes from an orbital which has more energy to an orbital which has less energy, a spectrum (colors, energy) is given off.

PRINCIPAL ENERGY LEVELS

PRINCIPAL ENERGY LEVELS (SHELLS or PRINCIPAL QUANTUM NUMBERS) can be shown as 1, 2, 3, 4:

⊖)1)2)3)4

Principal energy level shows how far the electron is from the nucleus. The first energy level (Shell #1) is closest to the nucleus, while other energy levels are further away from the nucleus. Electrons in the first energy level have the lowest energy. Those in the 2nd energy level have more energy; those in the 3rd have still more energy, etc.

First principal energy level can only hold **2** electrons.
Second principal energy level can only hold **8** electrons.
Third principal energy level can only hold **18** electrons.
Fourth principal energy level can only hold **32** electrons.

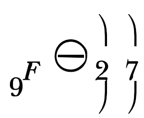
Maximum Number of Electrons in Each Principal Energy Level

⊖ NUCLEUS	)1	)2	)3	)4
Maximum # of electrons	**2**	8	18	32

Try Sample Question #7, page 12, then do Homework Questions #15-18, page 14, and #30, page 15.

ELECTRON CONFIGURATION

Electron configuration shows how many electrons are in each principal energy level.

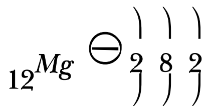


Fluorine

Fluorine ($^{19}_{9}F$) has an atomic number of 9, therefore fluorine has 9 electrons.

1. You put 2 electrons in principal energy level 1. Principal energy level 1 can only hold 2 electrons.
2. The next 7 electrons are in principal energy level 2.

The **electron configuration** to describe the electrons in **fluorine** is **2-7**: 2 electrons in the first principal energy level, 7 electrons in the second principal energy level.

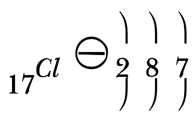


Magnesium

Magnesium ($^{24}_{12}$Mg) has an atomic number of 12; therefore, it has 12 electrons:

1. You put 2 electrons in principal energy level 1. Principal energy level 1 can only hold 2 electrons.
2. The next 8 electrons are in principal energy level 2. The second principal energy level only holds 8 electrons.
3. The next two electrons are in principal energy level 3.

The **electron configuration** to describe the electrons in **magnesium** is **2-8-2** : 2 electrons in the first energy level, 8 in the second energy level, and 2 electrons in the third energy level.



Chlorine

Chlorine ($^{35}_{17}$Cl) has an atomic number of 17; therefore, it has 17 electrons.

(1) You put 2 electrons in principal energy level 1. Principal energy level 1 can only hold 2 electrons.

(2) The next 8 electrons are in principal energy level 2. Principal energy level 2 can only hold 8 electrons.

(3) The next 7 electrons then are in principal energy level 3.

The **electron configuration** of **chlorine** is **2-8-7**; 2 electrons in the first energy level, 8 in the second energy level, and 7 electrons in the third energy level.

USE THE *PERIODIC TABLE* FOR ELECTRON CONFIGURATIONS

On the Regents, you will be given the Periodic Table, on Page Reference Tables 20-21. Look at the element C at the top of the Periodic Table. In the lower left hand corner of that box, it says "electron configuration." This is the electron configuration of C. Similarly, for each of the elements, the electron configuration is in the lower left hand corner of the box in the table. Look at $_{17}$Cl on the Periodic Table. The electron configuration is given as 2-8-7, just like you figured out in the example above. By looking at the electron configuration in the Periodic Table, you see chlorine has 3 principal energy levels (2 electrons in the first, 8 electrons in the second, and 7 electrons in the third energy level).

Do Homework Questions #19-21, page 14.

PERIODIC TABLE

GROUND AND EXCITED STATES

An atom is in the **GROUND STATE** when the electrons are filling the atom in order: 2-8-18-32, like it is written in the Periodic Table. The Periodic Table shows the ground state electron configurations.

An atom is **excited** when the electrons have absorbed energy or gotten more energy. The **electrons jump ahead** to a higher energy level, leaving one of the inner principal energy levels partly empty.

Question: Which is the electron configuration of an atom in the excited state?

(1) 2-8-2 (2) 2-8-1 (3) 2-7-1 (4) 2-8-3

Solution: Answer 3. The first energy level can hold 2 electrons. The second energy level can hold 8 electrons. In choice 3, there are only 7 electrons in the second principal energy level, because one electron jumped ahead to the third principal energy level. The second principal energy level is now partially empty (only 7 electrons in the second principal energy level), therefore the atom is excited.

You can also use the Periodic Table, page Reference Tables 20-21, to realize that the atom 2-7-1 is excited. Look at the **electron configuration** of sodium, $_{11}$Na, **2-8-1**, or any element after it on the Periodic Table. You realize that the first principal energy level must have 2 electrons before electrons can go into the second energy level. The second principal energy level must have 8 electrons before electrons go into the third energy level. In the example, **2-7-1**, you notice that the **eighth electron is missing** in the second principal energy level, therefore the atom is **excited**.

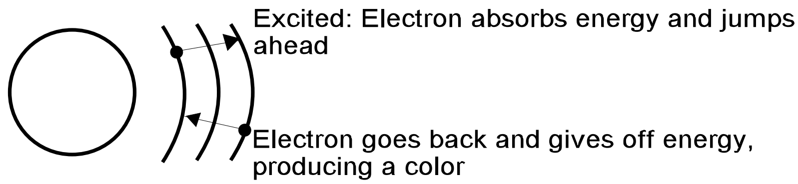
Question: Which electron configuration represents an atom in the excited state?

(1) 1-2 (2) 2-1 (3) 2-3 (4) 2-7

Solution: Answer 1. The first energy level is missing an electron, therefore the atom is excited. (The first energy level can hold 2 electrons.)

Or, look in the Periodic Table at the electron configuration of sodium, $_{11}$Na, 2-8-1. The first energy level has 2 electrons. In this example, 1-2, an electron is missing from the first principal energy level; therefore, the atom is excited.

When the **excited electrons** (the electrons that jumped ahead) **go back to lower energy levels**, they give off energy (in specific amounts called **QUANTA**), which produces a **spectrum** of colors, or **BRIGHT LINE SPECTRUM.**



For example, in a sodium atom, $^{23}_{11}$Na, when an **excited electron** goes back to a **lower energy level**, it gives off energy, which **produces** a **color** (colored light)**.**

Note: When the colored light from an element (example sodium) goes through a prism, it produces a spectrum.

Excited electrons from **different atoms** of the **same element** (example, different atoms of Na) return to different energy levels. In some sodium atoms, the excited electrons go back from energy level 3 to energy level 2, while in other sodium atoms the excited electrons go back from energy level 3 to energy level 1 (called energy transitions), producing a **spectrum of color** or **bright-line spectrum.**

A **flame test helps** to **identify** an **element**. In a flame test, different metal ions are heated in a flame, and each element (metal ion) produces its own color. (Colors are produced because electrons jump back and give off energy). Lithium always produces a crimson (red) color (red light) when heated in a flame. If you heat an element (metal ion) in a flame and you get a red color (red light), you know it is lithium.

A **bright-line spectrum** also **helps** to **identify** an **element** (figure out which element it is). The (bright-line) spectrum of lithium looks like this:

blue green orange red
| | | |
SPECTRUM OF LITHIUM

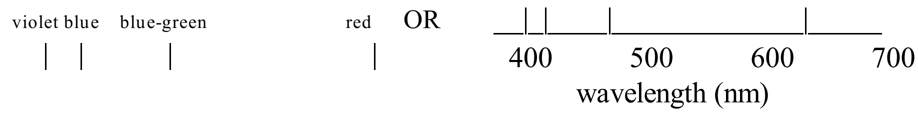
Each element has its own bright-line spectrum, different from any other element. If you have an element and you want to see if it is lithium, **compare the bright-line spectrum** of the sample that you have with the bright line spectrum of lithium. If you have lithium, your sample's bright-line spectrum and lithium's spectrum will be the same. If you do not have lithium, your sample's spectrum and lithium's spectrum will be different.

BRIGHT-LINE SPECTRA

```
Lithium      |   |           |   |
Sample 1     |   |           |   |
Sample 2        |        |   |         |
```

Sample 1 is lithium; Sample 2 is not lithium.

The spectrum of any element (examples lithium, hydrogen) has lines showing colors (see lithium spectrum above) or lines showing wavelength. The spectrum of hydrogen can be drawn either way:



Question: The excited atom has an electron configuration of 1-6. What atom is this?

Solution: To find the number of electrons an atom has, add the number of electrons in each principal energy level. You know that the number of electrons equals the atomic number. In this case, 1 + 6 = 7 **electrons** = **atomic number** 7, which is nitrogen**.** In Table S, on page Reference Tables 23-24, you see that **atomic number** 7 (**first column**) is **nitrogen**. Or, look at the **Periodic Table** to the right or on page Reference Tables 20-21. In the box in the Periodic Table with **atomic** number 7 is N; **N** is **nitrogen**.

$_{6}C$	$_{7}N$	$_{8}O$
↑atomic number	↑atomic number	↑atomic number

ELECTRON DOT METHOD

If you want to show how many electrons are in the last principal energy level (valence electrons), you can use the Lewis electron dot structures. Electrons in the last principal energy level or valence electrons affect the chemical properties of the element. If an atom has 1 or 2 electrons in the last principal energy level that atom is very active, which means the atom easily unites(reacts) with other atoms to form compounds.If an atom has 8 electrons in the last principal energy level, the atom does not react or reacts very little with other atoms.

Look at the electron configuration of magnesium, $_{12}Mg$, on the Periodic Table.

↓ last principal energy level

The electron configuration is 2-8-2.

There are 2 electrons in the last principal energy level, 2 valence electrons. All the other electrons in the atom are non-valence electrons (not in the last principal energy level). Mg has (2 + 8 =) 10 non-valence electrons.

LEWIS ELECTRON DOT METHOD: Look at the electron configuration for the element in the Periodic Table on page Reference Tables 20-21. Find the number of **electrons in the last principal energy level**. If there are **three electrons** in the **last** principal **energy level**, put **three dots** around the symbol of the element, X (X means any element).

How to Write Lewis Electron Dot Structures

There can only be 2 electrons on each side of the symbol of the element.

1. Put the 1st and 2nd valence electrons on one side of the symbol of the element. You can put the 1 or 2 electrons on any side of X.

   X· X:

2. For the 3rd, 4th, and 5th electrons, put each electron on a different side of the symbol. Ẋ: ·Ẋ: ·Ẋ: (with a dot below)

3. For the 6th, 7th and 8th electrons, add the electron to any side with 1 electron. ·Ẍ: (with a dot below) :Ẍ: (with a dot below) :Ẍ: (with two dots below)

Element	Valence Electrons	Placement of Dots	Electron Dot
$_{1}H$ *Hydrogen*	1	1 dot on one side	H·
$_{2}He$ *Helium*	2	2 dots on one side	He:
$_{3}Li$ *Lithium*	1	1 dot on one side	Li·
$_{4}Be$ *Beryllium*	2	2 dots on one side	Be:
$_{5}B$ *Boron*	3	2 dots on one side, 1 dot on another side	Ḃ:
$_{6}C$ *Carbon*	4	2 dots on one side, 1 dot on a second side, 1 dot on a third side	·Ċ:
$_{7}N$ *Nitrogen*	5	2 dots on one side, 1 dot on each of the other three sides	·Ṅ: (with a dot below)
$_{8}O$ *Oxygen*	6	2 dots on each of two sides, 1 dot on each of the other two sides	·Ö: (with a dot below)
$_{9}F$ *Fluorine*	7	2 dots on each of three sides, 1 dot on the fourth side	:F̈: (with a dot below)
$_{10}Ne$ *Neon*	8	2 dots on each side	:N̈e: (with two dots below)
$_{16}S$ *Sulfur*	6	2 dots on each of two sides, 1 dot on each of the other two sides	·S̈: (with a dot below)

PERIODIC TABLE

Try Sample Question #8, page 12, then do Homework Questions #22-27, page 15, and #31-32, page 15.

REMEMBER: When you answer Regents questions on ATOMIC CONCEPTS, use the Periodic Table, Table O and Table S.