EXPERIMENT 0

Atoms and elements

A. Goal

The goal of this laboratory experiment is to practice unit conversions and carry out calculations with the correct number of significant figures.

B. Materials

☐ Display of different elements (Al, C, Cu, Fe, Mg, Ni, N, O, P, Si, S, Sn, Zn)

C. Background

The periodic table

The periodic table (see Figure 1) is a chart containing all known elements arranged in increasing number of electrons per atom in a way that elements with similar chemical and physical properties are located together. The periodic table contains all existing elements–some of them are synthetic others are natural–that form the matter arranged in columns and rows. Every element has a different name accompanied by a symbol that represents its name. The tabular arrangement of elements in the form of rows and columns allows further classification of the elements according to their properties. This section will cover the different features of the periodic table.

Elements and Symbols

Elements cannot be broken down into simpler substances. For example, aluminum is an element only made of aluminum atoms and if you analyze the composition of a piece of this metal you would only find aluminum atoms. Chemical symbols are one- or two-letter abbreviations that represent the names of the elements. Only the first letter is capitalized and if a second letter exists in the element's name, the second letter should be lowercase. For example, the chemical symbol for aluminum is Al, written as capital A and lowercase l.

Periods and groups

The periodic table (see Figure 1) contains all elements arranged in rows and columns. The horizontal rows are called *periods* and the vertical columns are called *groups or families*. For example, the first period contains hydrogen (H) and helium (He), whereas the second group contains Beryllium (Be), Magnesium (Mg), Calcium (Ca), Strontium (Sr), Barium (Ba) and Radium (Ra). There are seven periods (periods 1-7) and 18 groups. Some of the groups are labeled with an A (e.g. group 8A) whereas others are labeled with a B (e.g. group 8B). Group numbers can be found written with roman numbers and a letter (A or B) or with a more modern group numbering of 1-18 going across the periodic table. For example, group 2 (Mg-Ra) can also be called IIA, and group 13 (B-Ti) is also known as IIIA.

Properties in the periodic table

The physical and chemical properties of some elements of the table (see Figure 1) are similar, and these similarities led to the organization of the periodic table. Elements in the same group share properties and for example, oxygen and sulfur have similar properties: both are reactive elements. Differently, the properties across periods change going from metals to nonmetals. For example, the properties of Li and Ne are very different, and lithium is a reactive metal whereas neon is a nonreactive gas.

Metals, Nonmetals, and Metalloids

Overall, the elements of the periodic table (see Figure 1) can be classified as metals, nonmetals, and metalloids. Metals are those elements on the left of the table and nonmetals are the elements on the right of the table. The elements between metals and nonmetals are called metalloids and include only B, Si, Ge, As, Sb, Te, Po, and At. Metals are shiny solids and usually melt at higher temperatures. Some examples of metals are Gold (Au) or Iron (Fe). Nonmetals are often poor conductors of heat and electricity with low melting points. They also tend to be matt (non-shinny), malleable, or ductile. Some examples of nonmetals are Carbon (C) or Nitrogen (N). Metalloids are elements that share some properties with metals and others with nonmetals. For example, they are better conductors of heat and electricity than nonmetals, but not as good conductors as metals. Metalloids are semiconductors because they can act as both conductors and insulators under certain conditions. An example of metalloids is Silicon (Si) which should not be confused with silicone, a chemical employed in prosthetics.

Classification of elements in terms of groups

Some of the groups in the periodic table (see Figure 1) have specific names such as alkali metals, alkaline earth metals, transition metals, chalcogens, halogens, or noble gases. Alkali metals are the group 1A elements: lithium (Li), sodium (Na), potassium (K), rubidium (Rb), cesium (Cs), and francium (Fr). Alkali elements are soft and shiny metals, and they are also good conductors of heat and electricity, with low melting points. Alkali earth metals are group 2A (2) elements: beryllium (Be), magnesium (Mg), calcium (Ca), strontium (Sr), barium (Ba), and radium (Ra). Transition metals are the elements from groups 3 to 12 and they are located in the middle of the table. Chalcogens are group 6A (16) elements: oxygen (O), sulfur (S), selenium (Se), tellurium (Te), and polonium (Po). Halogens are group 7A (17) elements: fluorine (F), chlorine (Cl), bromine (Br), iodine (I), and astatine (At). Halogens are very reactive elements. Finally, noble gases are group 8A (18) elements: helium (He), neon (Ne), argon (Ar), krypton (Kr), xenon (Xe), and radon (Rn). They are inert and rarely combine with other elements in the periodic table, like a noble family: have you ever met a royal?

How to classify Hydrogen

At first sight, hydrogen (H) may seem to be put in the wrong spot on the periodic table (see Figure 1). Although it is located at the top of Group 1A (1), it is not an alkali metal, as it has very different properties. Thus hydrogen does not belong to the alkali metals, being nonmetal.

Sample Problem 1

Answer the following questions: (a) Give the group and period of the following elements, and give the name: Ca, Ir, and C. (b) Classify as alkali metal, alkali earth metal, transition metal, halogen or noble gas, and give the name: Mg, Li, Co, He, F. (c) Classify as metal, nonmetal or metalloid, and give the name: Ba, N, Si.

SOLUTION

(a)The period and group of Ca (Calcium) is 2 (2A) and 4, respectively. The period and group of Ir (Iridium) is 9 (8B) and 6, respectively. The period and group of C (Carbon) is 14 (IVA) and 2, respectively. (b) Mg (Magnesium) is an alkali earth metal, whereas Li (Lithium) is a alkali metal. Co (Cobalt) is a transition metal. He (Helium) is a noble gas. F (Fluorine) is an halogen. (c) Ba (Barium) is a metal. N (Nitrogen) is a nonmetal. Si (Sillicon) is a metalloid.

STUDY CHECK

Answer the following questions: (a) Give the group and period of the following elements, and give the name: Cl. (b) Classify as alkali metal, alkali earth metal, transition metal, halogen or noble gas, and give the name: Ne. (c) Classify as metal, nonmetal or metalloid, and give the name: W.

▶Answer: (a) Chlorine: G 17 (VIIA) P3; (b) Neon Noble gas ; (c) Tungsten metal.

The atom

Atoms are the smallest piece of an element that retains their characteristics. They are the building blocks of matter. This section covers the structure of the atom. You will learn how to calculate the number of subatomic particles that made an atom and how to differentiate atoms of an element–all atoms of an element are not equal.

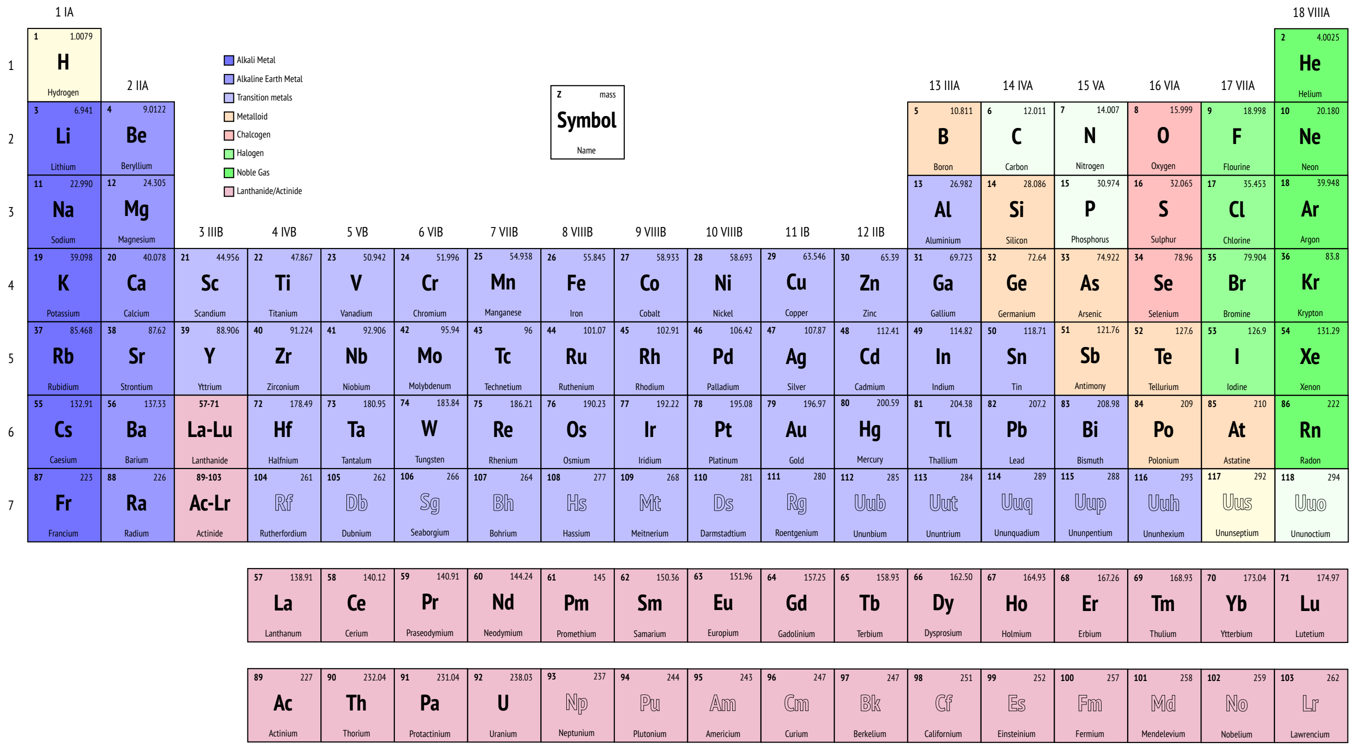


Figure 1 The periodic table of the elements

Atomic Structure

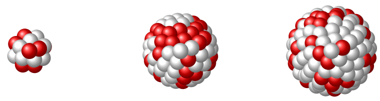
An atom is an electrically neutral, spherical entity made of a nucleus surrounded by negatively charged electrons. Atoms contain three atomic particles: the proton, neutron, and electron. Protons have a positive charge (+), whereas electrons carry a negative charge (–). Both electrons and protons have the same charge in magnitude but with opposite signs. Neutrons on the other hand are neutral, and they have no electrical charge. Protons and neutrons are located in the core of the atom, which is called the nucleus, and account for the mass of the atom. The only exception is the hydrogen atom, the smallest element, with just one proton in the nucleus. Electrons are delocalized in the exterior part of the atoms. They are not necessarily located in a specific spot and their existence spreads in the area next to the nucleus. Electrons move rapidly and are spread and held by nuclear attraction. Atoms are neutral without a charge as the number of electrons and protons are the same. Some atoms have a positive charge, resulting in removing electrons, and we call these cations. Others–called anions–can have a negative charge as a result of accepting a negatively charged electron. The mass of a proton or neutron is 2000 times larger than the mass of an electron and the atom's diameter is more than 10000 times the diameter of its nucleus. The nucleus is very dense being 99% of an atom's mass while occupying a small volume.

Atomic and mass number

Elements are made of atoms, and each atom of an element is characterized by an atomic number (Z) and a mass number (A). The atomic number (Z) of an element indicates the number of protons in an atom. This number can be easily located in the periodic table (see Figure 1). All atoms of an element have the same atomic number, whereas the atomic number of different elements differ. For example, Carbon has an atomic number of Z=6, whereas Oxygen has an atomic number of Z=8. The mass number (A) of an element indicates the combined number of protons and neutrons. Mass numbers can not be found in the periodic table. More importantly, different atoms of the same element can have different mass numbers. For example, a Carbon atom made of 6 neutrons and 6 protons has a mass number of A=12. Both A and Z for an atom X are indicated in the following form called isotope notation:

$$^{\mathrm{A}}_{\mathrm{Z}}\mathrm{X}$$

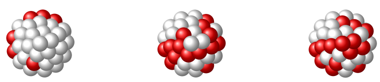
As an example, the notation $^{24}_{12}\mathrm{Mg}$ means that the atomic number of Mg is Z=12 and the mass number is A=24. Using the isotope notation, one can quickly identify the number of protons, neutrons, and electrons in an atom. As the atomic number is always indicated on the bottom part (e.g. Mg has 12 electrons). At the same time, the number of electrons and protons in a neutral atom is the same–neutral means an atom without a charge. The number of neutrons of an isotope can be computed by subtracting the atomic number from the mass number. Below you can find three different atoms, an atom of Carbon with 12 protons and neutrons, a larger atom of Calcium with 44 protons and neutrons, and an even larger atom of Gold with 197 protons and neutrons.



$^{12}_{6}\mathrm{C}$ $^{44}_{20}\mathrm{Ca}$ $^{197}_{79}\mathrm{Au}$

Isotopes

All atoms of an element have the same atomic number but may differ in terms of mass number. Isotopes are atoms of the same element with different numbers of neutrons and therefore with different mass numbers but with the same atomic number. For example: $^{24}_{12}\mathrm{Mg}$, $^{25}_{12}\mathrm{Mg}$ and $^{26}_{12}\mathrm{Mg}$ are three isotopes of Mg. $^{27}_{12}\mathrm{Mg}$ is heavier than $^{24}_{12}\mathrm{Mg}$ as it contains more neutrons and protons in the nucleus. Most elements occur in nature in a particular isotopic composition, and each of the isotopes has a specific proportional abundance. For example, the abundance of $^{24}_{12}\mathrm{Mg}$ is 79%, and the abundance of $^{25}_{12}\mathrm{Mg}$ and $^{26}_{12}\mathrm{Mg}$ is 10% and 11%, respectively. This means, $^{24}_{12}\mathrm{Mg}$ is more abundant than for example $^{26}_{12}\mathrm{Mg}$.



$^{24}_{12}\mathrm{Mg}$ $^{25}_{12}\mathrm{Mg}$ $^{26}_{12}\mathrm{Mg}$

Another example of isotopes can be found in Carbon, with two naturally occurring isotopes. In the case of charged atoms, we have the cations have fewer electrons than their corresponding atom, whereas anions have more electrons, both based on their charge. The mass of an atom is measured relative to the mass of an atomic standard, the Carbon-12 atom, whose mass is defined as 12 atomic units of mass, amu. For example, the mass of $^{1}\mathrm{H}$ is 1.008 amus. The term atomic unit of mass has been renamed to dalton (Da). Therefore, the mass of $^{1}\mathrm{H}$ is 1.008 amus or 1.008 Da. The atomic mass is a relative unit of mass equivalent to 1.66054×10^{24}g.

Average atomic mass

As atoms are made of numerous isotopes–this means different atoms of the same element but with a different number of neutrons and hence different weights. The average atomic mass (also called atomic weight) represents the mass of the atoms of an element and results from all existing isotopes taking into account their abundance. It is the average of the masses of the naturally occurring isotope weighted according to their abundance expressed in atomic mass units or daltons. We can think of % *relative abundance*, and for example, the % relative abundance of $^{1}\mathrm{H}$ is 99%. But we can also think of *fractional abundance*, that in the case of $^{1}\mathrm{H}$ would be 0.99. For an element with n isotopes each with different masses (A_1, A_2, ..., A_n) and different fractional abundances (f_1, f_2, .., f_n), the atomic mass is given by

$$\text{Atomic mass} = \sum_{i=1}^{n} A_i \cdot f_i = A_1 \cdot f_1 + A_2 \cdot f_2 + \cdots + A_n \cdot f_n$$

Note that when adding the fractional abundances of all isotopes, one should obtain a value of one:

$$\sum_{i=1}^{n} f_i = f_1 + f_2 + \cdots + f_n = 1$$

Atomic masses can be simply found in any periodic table (see Figure 1) for each element. For example, the atomic mass of oxygen (O) is 15.999 amu and the atomic mass of nitrogen (N) is 14.007 amu. The atomic mass found in the periodic table is an average that results from including the mass of the different isotopes and their abundance. Table **??** lists the relative abundance of a series of common isotopes.

Sample Problem 2

Calculate the number of protons, neutrons and electrons of the following atoms:

(a) $^{27}_{12}Mg$ (b) $^{22}_{10}Ne$ (c) $^{20}_{10}Ne$

SOLUTION

(a) $^{27}_{12}Mg$ has 12 electrons (Z=12) and 12 protons as well (the number of electrons and protons are the same if the atom is neutral), and 15 neutrons, as 27-12=15. (b) $^{22}_{10}Ne$ has 10 electrons and 10 protons, and 12 neutrons. (c) $^{20}_{10}Ne$ has10 electrons and 10 protons, and 10 neutrons as well.

STUDY CHECK

Calculate the number of protons, neutrons and electrons of the following atoms: (a) $^{32}_{16}S$ (b) $^{34}_{16}S$ (c) $^{36}_{16}S$

Answer: (a) 16p, 16e and 16n; (b) 16p, 16e and 18n; (a) 16p, 16e and 20n.

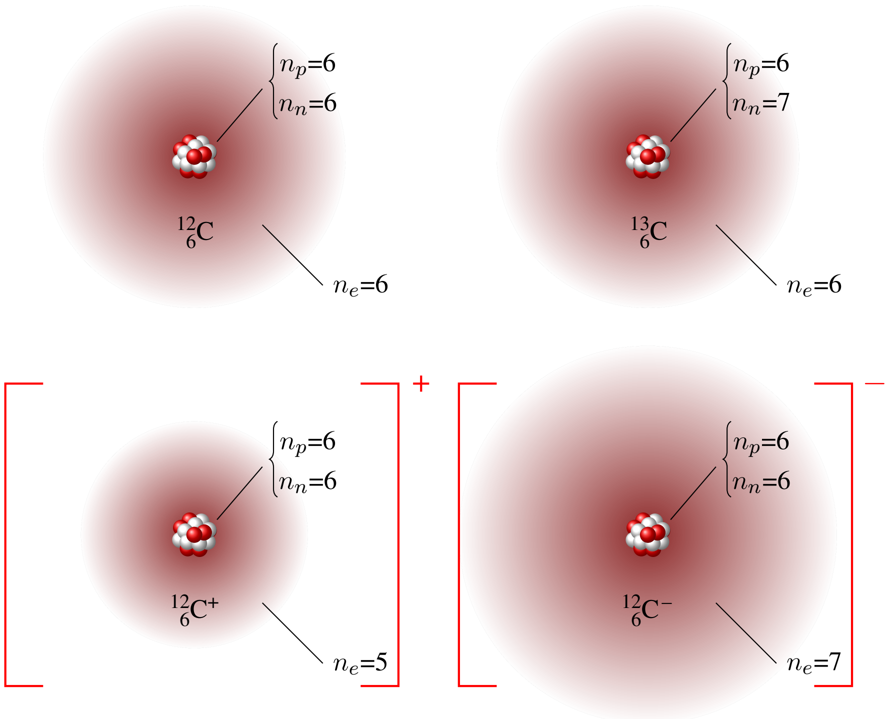


Figure 2 Representations of four different atoms, two neutral atoms on top and two ions on the bottom.

D. Procedure

Appearance of some chemical elements

Step 1: – Write the chemical symbol and describe the color of the elements listed below.

Step 2: – Describe the luster of the elements listed below (shiny/dull).

Step 3: – Based on your observations, describe the elements as metals, nonmetals or metalloids.

Good Lab Practice

✍ Be gentle when handling the display of chemical elemens.

The atom and its composition

Step 1: – Fill the table below indicating the number of electrons, protons and neutrons of the following neutral isotopes.

Neutral isotopes

Step 1: – Fill the table below indicating the number of electrons, protons and neutrons of the following neutral isotopes.

Charged isotopes

Step 1: – Fill the table below indicating the number of electrons, protons and neutrons of the following charged isotopes.

Average atomic masses

Step 1: – For the element below calculate the average atomic mass by multiplying the mass of the different isotopes by its abundance and adding the contributions.

Atomic spectrum

Step 1: – Your instructor will show you the light spectra for a set of elements and compounds.

Step 2: – Describe the light color for each.

STUDENT INFO

Name: ______________________ Date: ______

Pre-lab Questions

Atoms and elements

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1. The mass number of an atom is equal to the number of: (a) electrons (b) neutrons (c) neutrons plus protons (d) protons

2. Consider a neutral atom with 30 protons and 34 neutrons. The mass number of the element is: (a) 30 (b) 32 (c) 34 (d) 64 (e) 94

3. Consider a neutral atom with 30 protons and 34 neutrons. The atomic number of the element is: (a) 30 (b) 32 (c) 34 (d) 64 (e) 94

4. In an atom, the nucleus contains: (a) an equal number of protons and electrons. (b) all the protons and neutrons (c) all the protons and electrons (d) only neutrons (e) only protons

Results
EXPERIMENT

STUDENT INFO	
Name: ______________________	Date: ______

Atoms and elements

Appearance of some chemical elements

Element	Symbol	Atomic number	Luster Shinny/dull	Metallic Character Metal/Nonmetal/ Metalloid
Aluminium	___________	___________	___________	___________
Carbon	___________	___________	___________	___________
Copper	___________	___________	___________	___________
Iron	___________	___________	___________	___________
Magnesium	___________	___________	___________	___________
Nickel	___________	___________	___________	___________
Nitrogen	___________	___________	___________	___________
Oxygen *	___________	___________	___________	___________
Phosphorus	___________	___________	___________	___________
Silicon	___________	___________	___________	___________
Silver*	___________	___________	___________	___________
Gold *	___________	___________	___________	___________
Sulfur	___________	___________	___________	___________
Tin	___________	___________	___________	___________
Zinc	___________	___________	___________	___________
Calcium	___________	___________	___________	___________

* Not given

The atom and its composition

Name	Symbol	Atomic number, Z	Mass number, A	Protons	Neutrons	Electrons
	Fe				30	
			134			55
					32	28
Fluorine			18			
	C		12			

Neutral isotopes

Isotope	Protons	Neutrons	Electrons
$^{27}_{12}Mg$			
$^{64}_{29}Cu$			
$^{79}_{34}Se$			
$^{103}_{46}Pd$			

Charged isotopes

Isotope	Protons	Neutrons	Electrons
$^{27}_{12}Mg^{2+}$			
$^{64}_{29}Cu^{+}$			
$^{18}_{8}O^{2-}$			
$^{15}_{7}N^{3-}$			

Average atomic masses

Isotope	Isotopic mass (m)	Abundance (%)	Fractional Abundance (f)	$m \times f$
$^{32}_{16}S$	31.97207	95.0		
$^{33}_{16}S$	32.97146	0.76		
$^{34}_{16}S$	33.96786	4.22		
Average mass (amu)				

Atomic spectrum

Nitrogen

Oxygen

Helium

Neon

Argon

STUDENT INFO

Name: ______________________ Date: ______

Post-lab Questions

Atoms and elements

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1. The atomic mass of Ga is 69.72 amu. There are only two naturally occurring isotopes of gallium: 69Ga, with a mass of 69.0 amu, and 71Ga, with a mass of 71.0 amu. Calculate the natural abundance of the 69Ga isotope.

2. Magnesium contains three different isotopes: magnesium-24 with an abundance of 79% and a mass of 23.9850423 amu, magnesium-25 with an abundance of 10% and a mass of 24.9858374 amu, and magnesium-26 with a mass of 25.9825937 amu. Calculate the abundance of magnesium-26 and the average atomic mass of a sample of magnesium.