

Chem 115 POGIL Worksheet - Week 2 - Solutions

Basic Atomic Structure

Key Questions, Exercises, and Problems

1. What is the Law of Definite Proportions?

A compound is always composed of the same elements in a fixed ratio by weight.

2. Why Does the Law of Definite Proportions suggest the postulates of Dalton's atomic theory?

If each of the elements in a compound is always present with a certain percentage by weight, regardless of the sample size, then it follows that there must be smallest entities of those elements (the atoms) that have weights in the same ratios to one another as the overall percentages in the sample.

3. Explain how Dalton's atomic theory predicts the Law of Multiple Proportions.

The Law of Multiple Proportions states that if two elements can form more than one compound, then the ratios of the weights of one element in the compounds to a fixed weight of the other element are small whole numbers. By Dalton's theory, atoms of each element have characteristic masses and combine as whole units in forming compounds. Therefore, the ratios among the masses of the elements in a sample of compound must be the same ratios as among the numbers of individual atoms of the elements in the compound.

4. Suppose elements X and Y can form two compounds. One compound has as many X atoms as Y atoms (formula XY), and the other compound has twice as many X atoms as Y atoms (formula X₂Y). What mass ratios would you compare between these compounds to demonstrate the Law of Multiple Proportions? What whole number ratio would be expected between these ratios?

We would calculate the ratios of the mass of element X to the mass of element Y in each compound. The ratio between the calculated value for the first compound to that for the second would be 1:2. For example, suppose for the compound XY we found $m_X/m_Y = 0.875$. Then, for X₂Y we would find the ratio $m_X/m_Y = 1.75$, because there is twice the mass of X per mass of Y in this compound. Now, if we take the ratio between these two ratios, we would get

$$\frac{(m_X/m_Y)_{X_2Y}}{(m_X/m_Y)_{XY}} = \frac{1.75}{0.875} = 2$$

This is the result predicted by the Law of Multiple Proportions.

5. A chemist prepared three different compounds that contain only iodine and fluorine and determined the mass of each element in each compound, as shown below. Calculate the mass of fluorine per gram of iodine in each compound, and explain how your results support atomic theory.

Comp.	m_I (g)	m_F (g)	m_F/m_I
1	4.75	3.56	0.749 ₄₇
2	7.64	3.43	0.448 ₉₅
3	9.41	9.86	1.04 ₇₈

In keeping with the Law of Multiple Proportions, we need to look at the ratios among the three m_F/m_I ratios shown above. The value for compound 2 is smallest, so we use that as the basis of comparison; i.e., we divide 0.448₉₅ into each of the three m_F/m_I values.

$$\frac{(m_F/m_I)_1}{(m_F/m_I)_2} = \frac{0.749_{47}}{0.448_{95}} = 1.67 = 5/3 \Rightarrow 5$$

$$\frac{(m_F/m_I)_3}{(m_F/m_I)_2} = \frac{1.04_{78}}{0.448_{95}} = 2.33 = 7/3 \Rightarrow 7$$

The calculation of the ratios among the m_F/m_I values does not initially yield integers, but we can see the decimal numbers as the fractions 5/3, 3/3, and 7/3, respectively. Therefore, the ratio among the m_F/m_I values is 5:3:7, in keeping with the Law of Multiple Proportions. We can go a step further in saying that the simplest whole-number formulas for the three compounds (their *empirical formulas*) are IF₅, IF₃, and IF₇, respectively.

6. What is the basis for defining the atomic number (Z) of an element?

The atomic number of an element is a count of the number of protons in its nucleus.

7. What is the basis for defining the mass number (A) of a nuclide?

The mass number is a count of both the protons and neutrons in the nucleus of a particular type of atom (a *nuclide*). Note that the mass number is not a statement of the mass of the nuclide.

8. Are Z and A exact or inexact numbers?

Both Z and A are exact numbers, because they are integer counts of fundamental particles.

9. How does an atom become a cation or anion?

An atom becomes a cation (positive ion) by losing one or more electrons, giving it a net positive charge (fewer electrons than protons). An atom becomes an anion (negative ion) by adding one or more electrons, giving it a net negative charge (more electrons than protons).

10. Does Z or A change in forming an ion? Why or why not?

Never! Ion formation always involves a change in the number of electrons relative to the net positive charge of the protons in the nucleus, which remain fixed.

11. In some nuclear reactions an atom's number of protons can change. Is it the same element after such a change?

No, because an atom's identity as that of a particular element is related to the number of protons in its nucleus, which determines the atomic number (Z).

12. On the periodic table attached, each block shows the atomic number of the element at the top, above the element's symbol. With the aid of the periodic table, give the standard nuclide notation for the following isotopes used in medicine: phosphorous-32, chromium-51, cobalt-60, iodine-131.



13. With the aid of the periodic table, fill in the blanks in the following table:

Charge	0	0	0	3+	2-
Symbol	${}^{56}\text{Fe}$	${}^{80}\text{Br}$	${}^{197}\text{Au}$	${}^{69}\text{Ga}^{3+}$	${}^{79}\text{Se}^{2-}$
Protons	26	35	79	31	34
Neutrons	30	45	118	38	45
Electrons	26	35	79	28	36
Mass no.	56	80	197	69	79

14. For all elements except fluorine, the atomic weight listed on the periodic table *does not* correspond to the mass of any nuclide? What does the atomic mass of most elements represent?

It is the average of the masses of the isotopes of which it is composed, weighted according to atomic abundance.

15. The atomic weight listed for fluorine on the periodic table (18.998403 u) *does* correspond to the mass of a particular nuclide. What does that imply about the isotopic composition of naturally occurring fluorine?

Fluorine has only one naturally occurring isotope, ^{19}F .

16. Boron consists of 19.78% ^{10}B with atomic mass 10.0129 u and 80.22% ^{11}B with atomic mass 11.00931 u. Calculate the atomic weight of naturally occurring boron.

$$\text{at. wt.} = (0.1978)(10.0129 \text{ u}) + (0.8022)(11.0093 \text{ u}) = 1.980_{55} \text{ u} + 8.831_{67} \text{ u}$$

$$= 10.812 \text{ u}$$

Note that the two multiplications in this calculation limit their results to 4 sig. figs, which have 3 decimal places in both cases. Adding these two together, we retain 3 decimal places. But the sum is greater than 10, so the final answer has 3 decimal places and 5 sig. figs.

17. By definition, the mass of a $^{12}_6\text{C}$ atom is exactly 12 u. What is the sum of the masses of the particles comprising a $^{12}_6\text{C}$ atom? Why is the sum not 12 u?

$$(6)m_p + (6)m_n + (6)m_e = (6)(1.007277 \text{ u}) + (6)(1.008665 \text{ u}) + (6)(0.0005486 \text{ u})$$

$$= 12.098943_6 \text{ u}$$

The extra mass of 0.098943_6 u represents the mass converted into energy when the fundamental particles combine in forming the atom. This energy, called the *binding energy*, can be calculated with Einstein's equation, $E = mc^2$, where m is the mass converted into energy, and c is the speed of light in a vacuum.

18. What information about an element is provided in the box for that element in the periodic table?

Its atomic number, its symbol, and the atomic weight of naturally occurring sample of the element are listed. For elements that do not occur naturally, the mass number of the longest-lived isotope is indicated, usually surrounded with parentheses or brackets.

19. What determines the sequence of elements from the first to the last?

The ordering in the periodic table is by atomic number, Z .

20. What is the difference between a group and a period?

A group is composed of elements listed in a column of the periodic table. A period is a row of elements in the periodic table.

21. Where are the metals, nonmetals, and metalloids located?

Metals occupy the left and center of the periodic table. Non-metals occupy the upper right corner of the periodic table. Metalloids fall along the border between the metals and non-metals.

22. Are the majority of elements metals, nonmetals, or metalloids?

The majority of elements are metals, followed by non-metals, and then metalloids.

23. Does hydrogen belong to group 1? Why or why not?

Hydrogen is a nonmetallic gas, existing naturally as molecules composed of two atoms, H_2 . The group 1 elements are all reactive metals, completely unlike hydrogen in their character.

24. Write the name, symbol, atomic number and average mass for each of the following, and indicate whether the element is metal, nonmetal, or metalloid:

- a. The group 2 element in period 3
magnesium, Mg, $Z = 12$, at. wt. = 24.305
- b. The group 16 element in period 2
oxygen, O, $Z = 8$, at. wt. = 15.9994
- c. The group 15 element in period 4
arsenic, As, $Z = 33$, at. wt. = 74.9216

25. Write the name and symbol of the element that has 48 electrons.

cadmium, Cd

26. Name the elements with properties similar to chlorine, Cl.

The other group 17 elements: fluorine (F), bromine (Br), iodine (I), and astatine (At).

27. Give the symbols and names of elements 57 and 72 in the period 6. Why are they adjacent to each other in the periodic table?

$Z = 57$ is lanthanum, and $Z = 72$ is hafnium. The intervening elements in the sequence of atomic numbers comprise the lanthanides, which appear at the bottom of the periodic table.

28. Chlorine consists of ^{35}Cl with a mass of 34.96885 u and ^{37}Cl with a mass of 36.96590 u. The atomic weight of chlorine is 35.453 u. What is the percent abundance of each isotope?

We know that the atomic weight is the sum of the two nuclide masses, each multiplied by the decimal fraction for their abundance in the isotopic mixture. Furthermore, the sum of the two fractions must equal 1. If we let x be the fraction of ^{35}Cl , then $1 - x$ is the fraction of ^{37}Cl . From this we can write the following algebraic expression and solve it for x :

$$35.453 = 34.96885x + 36.96590(1 - x) = 34.96885x + 36.96590 - 36.96590x$$

$$35.453 - 36.96590 = (34.96885 - 36.96590)x$$

$$1.512_{90} = 1.99705x$$

$$x = 1.512_{90}/1.99705 = 0.7575_{67} \quad \text{and} \quad 1 - x = 0.2424_{33}$$

Therefore, naturally occurring chlorine contains 75.76% ^{35}Cl and 24.24% ^{37}Cl .