Activity 1

Atoms, Isotopes, and Ions

Why?

Atoms are the fundamental building blocks of all substances. To begin to understand the properties of atoms and how they combine to form molecules, you must be familiar with their composition and structure.

Learning Objectives

- Understand the composition and structure of atoms, isotopes, and ions
- Understand how atomic symbols and names identify the number of particles composing an atom, isotope, or ion

Success Criteria

- Use atomic symbols to represent different isotopes and ions
- Given one or more of the following items, determine the others: name, atomic symbol, atomic number, mass number, neutron number, and electron number
- Calculate the percent of the atomic mass that is located in the nucleus of an atom
- Compare the size of an atom to the size of the atomic nucleus

Prerequisites

- Calculation of percent
- Unit conversion

Information

Matter, which is anything that has mass and occupies space, is composed of substances and mixtures of substances.

A *substance*, or more explicitly, a *pure substance*, is a variety of matter that has uniform and constant composition. For example, pure water is a substance.

Mixtures are composed of two or more substances. For example, salt water is a mixture, even though it is uniform, because the amount of salt in the water (the composition) can vary.

An *element* is a substance that cannot be decomposed into two or more other substances by chemical or physical means. In nuclear reactions, however, one element can be converted into one or more other elements. Only about 118 different elements are known to exist.

An *atom* is the smallest part of an element that can exist either alone or in combination with other atoms.

Isotopes are atoms that have the same number of protons but different numbers of neutrons.

An *ion* is an atom or molecule with a positive or negative charge.

A *cation* is an ion with a positive charge.

An *anion* is an ion with a negative charge.

Model: Sodium

The diagrams below show representations of sodium. Note that the diameter of an atom is about 10,000 times larger than the diameter of the atomic nucleus.

Table 1.1 Subatomic Particles

Particle	Mass (amu)*	Charge
Proton	1.0073	+1
Neutron	1.0087	0
Electron	0.0005	–1

* *Atomic mass unit* (amu) is a unit of mass equal to 1.66054×10^{-27} kg.

Atomic Symbol Notation

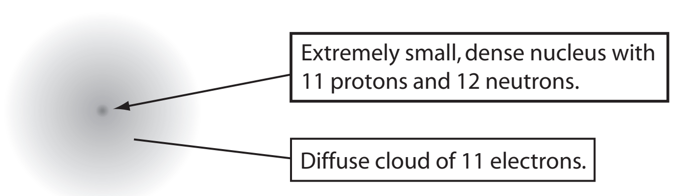
Figure 1.1

$${}^{A}_{Z}X^{+}$$

Mass Number Charge
Atomic Symbol
Atomic Number

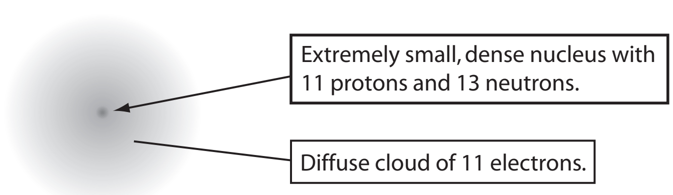
Sodium-23

$${}^{23}_{11}Na$$



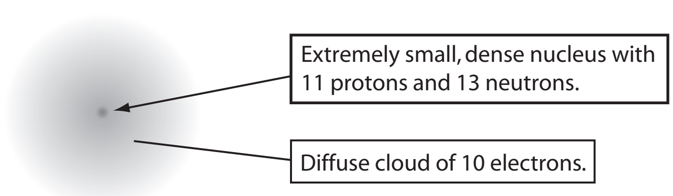
Sodium-24

$${}^{24}_{11}Na$$



Sodium-24 cation

$${}^{24}_{11}Na^{+}$$



KEY QUESTIONS

1. What are the three particles that comprise a sodium atom?

    Protons, neutrons and electrons

2. Which particles contribute most of the mass to the atom, and where are these particles located?

    Protons and neutrons, which are inside the nucleus at the center of the atom.

3. Which particles contribute most to the volume or size of the atom, and where are these particles located?

    Electrons, which are outside the nucleus.

4. What information is provided by the atomic number, Z, which is the subscript in the atomic symbol?

    The number of protons

5. What information is provided by the mass number, A, which is the superscript in the atomic symbol?

    The sum of the number of protons and number of neutrons.

6. What notation is used in the atomic symbol to indicate the charge of an atom or ion?

    Plus signs (positive) or minus signs (negative), with numbers to indicate multiple charges (>1) are used as superscripts on the right side of the symbol.

7. Given the definition of mass number and the information in Table 1.1 regarding the masses of protons, neutrons, and electrons, why is the mass number approximately, but not exactly equal to, the mass of an atom in amu?

    Protons and neutrons each have a mass very close to 1 amu, so counting the protons an neutrons gives the mass number, which therefore is very close to the mass of the atom in amu.

8. How is the charge of the atom or ion determined from the number of protons, neutrons, and electrons present?

    Charge equals number of protons minus number of electrons. The number of neutrons doesn't matter because they have no charge.

9. What do all atoms and ions of sodium have in common?

    The same number of protons

10. In general, what feature of an atom identifies it as a particular element?

    The number of protons

11. In general, how do isotopes of the same element differ?

    Different isotopes have different numbers of neutrons.

12. How many isotopes of any particular element could there be? What might prevent all of these isotopes from occurring naturally?

From what we've seen in this activity, there could be an infinite number of isotopes because any number of neutrons could be added to the nucleus of an atom. Not all these isotopes occur naturally because not all of them are stable.

Note: An opportunity for student research projects is presented by this question. Have students identify the forces they think hold the nucleus together, and why a nucleus might become unstable once too many neutrons are present. They can also research isotopes in their textbooks or on the Internet and identify the characteristic neutron to proton ratios that lead to stable nuclides.

Exercises

1. Insert the missing information in the following table. The first row is completed for you to provide an example.

Table 1.2

Name	Symbol	Z	A	Number of Neutrons	Number of Electrons
boron-10	$^{10}_{5}B^{+}$	**5**	**10**	**5**	**4**
calcium-40	$^{40}_{20}Ca^{2+}$	*20*	*40*	*20*	**18**
oxygen-16	*$^{16}_{8}O$*	*8*	*16*	*8*	**8**
uranium-238	$^{238}_{92}U$	*92*	*238*	**146**	**92**
fluorine-19	*$^{19}_{9}F$*	**9**	**19**	*10*	**9**
chlorine-35	*$^{35}_{17}Cl^{-}$*	**17**	*35*	**18**	**18**
potassium-39	*$^{39}_{19}K$*	*19*	**39**	**20**	**19**

2. Show how to calculate the mass of a proton, neutron, and electron in kilograms using the data in Table 1 and the equality statement: **1 amu = 1.66054 × 10^{-27} kg**

proton: $$1.0073\ amu \times \frac{(1.66054 \times 10^{-27} kg)}{1\ amu} = 1.6727 \times 10^{-27} kg$$

neutron: $$1.0087\ amu \times \frac{(1.66054 \times 10^{-27} kg)}{1\ amu} = 1.6750 \times 10^{-27} kg$$

electron: $$0.0005\ amu \times \frac{(1.66054 \times 10^{-27} kg)}{1\ amu} = 8 \times 10^{-31} kg$$

PROBLEMS

1. The mass of a carbon-12 atom is 12 amu. What percent of the mass is located in the nucleus? Why is the value you calculated so close to 100%?

$$\text{percent mass in nucleus} = \frac{\text{mass of nucleus} \times 100}{\text{mass of atom}}$$

mass of nucleus = mass of atom – mass of electrons

$$\frac{[12\ amu - (6 \times 0.0005\ amu)] \times 100}{12\ amu} = 99.975\%$$

The value calculated is very close to 100% because the electrons not in the nucleus have a very small mass compared to the protons and neutrons.

Note 1: The students should now understand that almost 100% of the mass of an atom is in its nucleus.

Note 2: Students might calculate the percent mass located in the nucleus by adding the mass of six protons and six neutrons. Their answer then will be that 100.8% of the mass is located in the nucleus. This result presents the opportunity to emphasize the importance of validating answers.

Ask some questions. Is it possible for more than 100% mass to be in the nucleus? Is there another way to answer the question by considering the mass of the electrons? After they get the correct answer and realize it makes more sense, discuss with them the binding energy between protons and neutrons and the equivalence of mass and energy as expressed by Einstein's equation $E = mc^2$. The binding energy explains why the sum of the masses of the protons and neutrons in the nucleus is greater the mass of the nucleus.

Alternatively, students could be asked to research this issue and report to the class next session on why the sum of the masses of the protons and neutrons is larger than the mass of the nucleus.

2. The radius of a Cl nucleus is 4.0 fm, and the radius of a Cl atom is 100 pm. If the nucleus of the Cl atom were the size of a dime, which is 17 mm in diameter, determine whether the atom would be approximately (a) the size of a quarter, (b) the size of a car, (c) the size of a football stadium, or (d) the size of the earth, and explain how you made your decision. Show how to calculate the mass of a proton, neutron, and electron in kilograms using the data in Table 1.1 and the equality statement: **1 amu = 1.66054 × 10^{-27} kg**

Radius of a Cl nucleus is 4.0 fm, which is 4.0 × 10^{-15} m.

Radius of a Cl atom is 100 pm, which is 100 × 10^{-12} m.

Compare the ratios: $\frac{atom}{nucleus} = \frac{x}{dime}$

$$\frac{100 \times 10^{-12}}{4 \times 10^{-15}} = \frac{x}{17mm}$$

$$x = \frac{425 \times 10^{3} mm \times 1m}{1000mm} = 425\ m$$

Which of the items has a diameter of approximately 425 meters?

It is reasonable that a football stadium's size is 425 m. The other choices can be ruled out: The size of a quarter and a car are smaller than 425 m, and the size of the Earth is much larger.

Note: If students do not know where to begin, you can ask them to draw a sketch of the atom showing the nucleus, and a dime surrounded by one of the objects listed in the question. Then ask them if they see by looking at their sketch how they can compare the sizes. If more direction is needed, ask if taking ratios would be helpful.