7.2 Bohr's Theory of the Atom

Have you ever seen the light given off by a neon sign? It is a vibrant, orange-red colour. If the tubes of a sign are filled with a gas other than neon, the colour is different. When atoms absorb electrical or heat energy, they can re-emit the energy as light. Each element emits a very specific pattern of wavelengths, or colours, of light. This pattern is called the **emission spectrum** of the element (Figure 1). You can see the emission spectrum of an element in the light given off when the element is heated in a flame. Rutherford's former student and colleague, Niels Bohr, used this property of elements, as well as discoveries by other scientists of the time, to solve the problems with Rutherford's model of the atom. 7A *Investigation*

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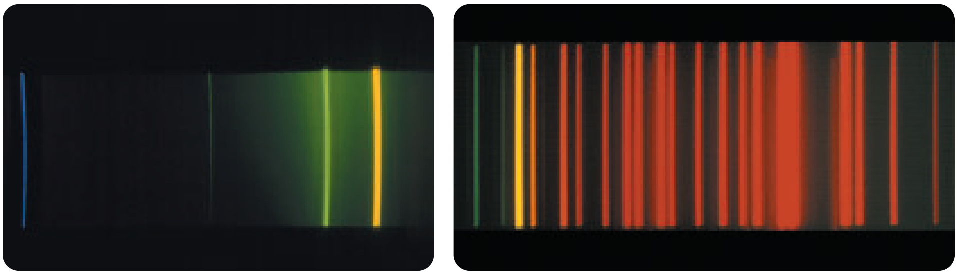
Flame Colours

To perform this investigation, turn to page 224.

In this investigation, you will observe different flame colours from different elements, and then identify an element from its flame colour.



(a) (b)

Figure 1 The light emission spectrum of mercury (a) is different than that of neon (b).

Bohr's Contribution to the Atomic Theory

Albert Einstein had shown that atoms can only absorb or emit light energy in specific amounts. Bohr used this observation to explain why the electrons orbiting the nucleus do not continuously give off energy. He proposed a theory of the atom in which the electrons are restricted to specific "allowed" orbits, or **shells** as they are now called, around the nucleus (Figure 2), much like the planets have specific orbits around the Sun. The amount of energy an electron has is related to how far it is from the nucleus. Each element has a unique pattern of light emission because it has a unique separation of its allowed electron shells (orbits).

While within a single shell, an electron does not emit energy. Atoms only emit or absorb light energy when their electrons "jump" between shells. Bohr's ideas about the structure of the atom are listed below:

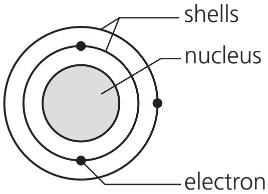
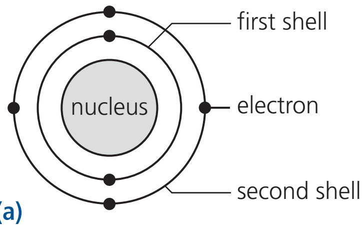


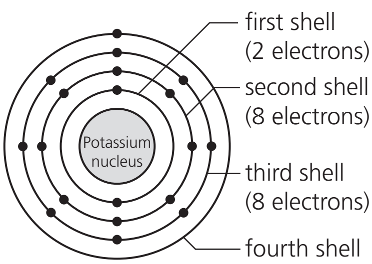
Figure 2 Bohr's model of the atom restricts electrons to specific shells around the nucleus.

Bohr's Revisions to the Atomic Theory: Electrons in Specific Orbits

- Electrons are located in defined shells, which are located certain distances from the nucleus.
- Electrons cannot exist between the defined shells.
- Electrons can gain energy to move up to a higher shell, or they can lose energy to move down to a lower shell.
- Electrons are more stable (have less energy) when they are closer to the nucleus.



(a)



(b)

Figure 3 The number of shells (orbits) in an atom depends on the number of electrons in the atom

If you would like to learn more about the atomic theory of matter, go to **www.science.nelson.com** GO

The Atomic Theory of Matter

The development of the atomic theory required new technologies and discoveries to be made in order for it to advance. In the 1920s and later, the atomic theory was again modified as more discoveries were made about the behaviour of electrons in atoms. There are a maximum number of electrons that can occupy any one shell. The first shell can only contain a maximum of two electrons, and the second shell can contain a maximum of eight. The electrons fill the shells starting with the first or innermost shell and work outward. For example, an element with six electrons has two electrons in the first shell and four electrons in the second (Figure 3(a)).

The Number of Shells for an Element

The number of shells that an element will need is related to which row of the Periodic Table it is found in. First-row elements have electrons in the first shell. Second-row elements have electrons in the first and second shells. Third-row elements have electrons in the first, second, and third shells, and so on. For the first 20 elements, the third shell can only contain a maximum of eight electrons. Therefore potassium, in the fourth row, has one electron in its fourth shell (Figure 3(b)). Calcium will have two electrons in its fourth shell. (For elements beyond number 20, the arrangement of the electrons becomes more complicated.) As you will learn in Chapter 8, it is the arrangement of the electrons that determines the characteristics and chemical behaviour of an element.

To summarize, the atomic theory we will use is as follows: GO

The Atomic Theory of Matter

- All matter is made of atoms.
- Atoms are the smallest pieces of an element.
- Elements combine to form compounds. The atoms in the compound are held together by electrical attractions.
- An atom is composed of a nucleus surrounded by electrons.
- The nucleus is composed of positively charged protons and uncharged neutrons.
- All the atoms of an element have the same unique number of protons.
- All the nucleus contains most of the mass of the atom and all of the positive charge.
- There is only empty space between the electrons and the nucleus.
- Electrons have a negative charge and very little mass.
- Electrons orbit the nucleus only in specific, allowed shells.
- For the first 20 elements, the first shell contains a maximum of two electrons, the second shell contains a maximum of eight electrons, and the third shell contains a maximum of eight electrons.
- Electrons absorb or emit specific amounts of energy to change shells.

Standard Atomic Notation

As described earlier, elements give off an emission spectrum when energized. The light emitted is visible light, ultraviolet light, and X-ray energy (all are part of the electromagnetic spectrum). In 1913, Henry Moseley studied the X-ray part of the emission spectra of elements, and noted that a characteristic energy peak increased by one unit for each element in order of increasing atomic mass, with a few exceptions. (You will learn more about atomic mass in the next section.) Thus, the elements could each be given a specific number, called the **atomic number**. Scientists now know that the atomic number is the number of protons in the nucleus. The Periodic Law can now be stated as: *The properties of the elements are a periodic or regularly repeating function of their atomic number.* It is the atomic number (not the atomic mass) that determines the order of the elements in the modern Periodic Table.

The total number of protons and neutrons in the nucleus of an atom is called the **mass number**. The mass number of an element is often written after the element name, as in chlorine-35. The mass number, along with the chemical symbol for an element and the atomic number, can also be written in standard atomic notation (Figure 4). Like the symbols for the elements, standard atomic notation allows scientists to communicate and share their ideas efficiently.

LEARNING TIP

What does Figure 4 tell you? Atomic number is the number of protons in the nucleus of an atom. What is the atomic number for chlorine? An element's mass number is the number of protons and neutrons in its atom. What is the mass number for chorine? What is the symbol for chlorine?

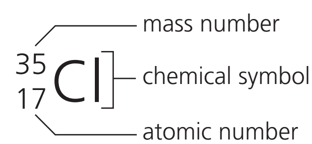


Figure 4 The standard notation for chlorine

Standard Notation for Ions

Normally, an atom has the same number of electrons as protons. Chlorine, atomic number 17, normally has 17 electrons. An atom obtains a charge when electrons are either added or removed. For example, heating a metal drives off electrons from the metal atoms, and friction between a piece of wool and vinyl plastic transfers electrons to the vinyl from the wool.

When an atom becomes charged, there are more or fewer electrons than protons in the atom. A charged atom is called an **ion**. When there are more electrons than protons, the atom has a negative charge and is called a **negative ion**. When there are fewer electrons than protons, the atom has a positive charge and is called a **positive ion**. For example, if there are 2 fewer electrons than protons, the ion has a charge of 2+. If there are 3 more electrons than protons, the ion has a charge of 3−. The charge of an ion, whether positive or negative, is called the **ion charge**. In standard atomic notation the ion charge is written above and to the right of the symbol (Figure 5). If the charge is 1+ or 1−, the "1" is not usually written. It is important to note that, when an atom becomes charged, the number of protons in the atom does not change. The ion charge is due *only* to a change in the number of electrons in the atom.

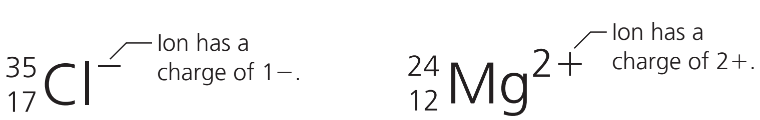


Figure 5 The standard notations for a chlorine ion and a magnesium ion

7.2

CHECK YOUR Understanding

1. Explain how each of the following differs in Bohr's model and Rutherford's model of the atom.
   (a) the location of electrons
   (b) the energy of electrons
2. In Bohr's model of the atom, how many electrons occupy the first shell. How many electrons occupy the second shell and the third shell?
3. Refer back to sections 7.1 and 7.2 and complete Table 1:

Table 1

Particle	Charge	Mass (relative to proton)	Location
proton			
neutron			
electron			

4. Explain why different elements produce different colours when heated in a flame.
5. Write the following elements in standard notation.
   (a) bromine-80; atomic number 35
   (b) calcium-40; atomic number 20
   (c) carbon-14; atomic number 6
   (d) nitrogen-15; atomic number 7
   (e) sodium-20; atomic number 11
   (f) neon-20; atomic number 10
   (g) gold-179; atomic number 79
   (h) uranium-238; atomic number 92
   (i) polonium-210; atomic number 84
6. Write the following ions in standard notation.
   (a) sodium-23; charge of 1+; atomic number 19
   (b) sulfur-32; charge of 2−; atomic number 16
   (c) calcium-40; charge of 2+; atomic number 20
   (d) silver-108; charge of 1+; atomic number 47
   (e) tin-119; charge of 2+; atomic number 50
   (f) gold-179; charge of 3+; atomic number 79
   (g) tin-119; charge of 4+; atomic number 50
   (h) oxygen-16; charge of 2−; atomic number 8
   (i) nitrogen-14; charge of 3−; atomic number 7
7. If an atom contains eight electrons, how many electrons are in each of the first two shells? Explain.
8. Calcium is an element in the fourth row of the Periodic Table.
   (a) How many shells does it have?
   (b) How many electrons does it have in each shell?
9. How many shells would an element in the sixth row of the Periodic Table have?
10. A sample element, E, has 14 protons and 15 neutrons. It has no charge.
    (a) What is its atomic number?
    (b) What is its mass number?
    (c) How many electrons does it have?
    (d) Write the standard notation for the element.
11. A sample element, X, has 17 protons and 18 electrons. The mass number is 35.
    (a) What is the charge?
    (b) Write the standard notation for this element.
12. What property of elements did Bohr use to revise the Rutherford theory of the atom?
13. Electrons in different orbits are similar to balls sitting on different steps of a staircase. A ball on a higher step has more energy than a ball on a lower step. An electron orbiting a nucleus farther away (a higher shell) has more energy than an electron orbiting closer (a lower shell). If an electron "jumped down" to a lower shell, would the atom be absorbing energy or emitting energy (Figure 6)? Explain.

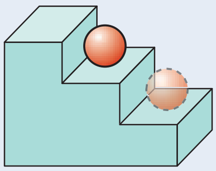


Figure 6