6.2 Atomic Theory

Around 1800, John Dalton revived the ancient Greek concept of atoms as the smallest pieces of matter. He used this idea to explain the chemical behaviour of elements. Dalton's theory worked very well to explain the behaviours of chemical substances, as they were known during the 1800s. Over time, further discoveries led to a refinement of the atomic theory, particularly with regard to the structure of the atom itself. In 1898, J.J. Thomson discovered the electron, a tiny negatively charged particle much smaller than the atom it was a part of. This established that the atom must have an internal structure. Shortly afterward, Ernest Rutherford showed that the atom had a nucleus, a very small space in the centre of the atom that contained almost all of the mass of the atom, and all of the positive charge. Niels Bohr proposed the concept of electron shells, to explain the emission spectra of elements.

LEARNING TIP

Active readers ask questions to check their understanding. Ask yourself, "Can I tell the meaning of the words in this section from the sentences in which they are found?"

Atomic Structure

Although new developments have since continued to refine and advance the atomic theory, we will use Bohr's version in our studies. According to Bohr's theory of the atom, every atom is composed of three types of **subatomic particles**: protons, neutrons, and electrons. The dense centre of the atom is called the **nucleus**, which contains the positively charged **protons** and the uncharged **neutrons** (Figure 1). Protons and neutrons have approximately the same mass. Each element has a unique number of protons in its nucleus, and this is called the **atomic number** of the element. Hydrogen atoms have only 1 proton, so the atomic number of hydrogen is 1. Oxygen atoms have 8 protons, so the atomic number of oxygen is 8.

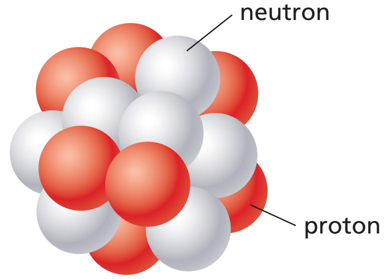


Figure 1 The structure of the nucleus of an atom according to Bohr's theory of the atom

Although every atom of any one element will have the same number of protons, the atoms might have a different number of neutrons. The **mass number** of an atom is the total number of protons and neutrons in the nucleus. The mass number of an element is written after the element name. For example, oxygen-18 is oxygen with a mass number of 18. Different mass numbers will not affect the physical and chemical properties of the element.

The **atomic mass** of an element is the average mass of the atoms of the element. It reflects the abundance of the different mass numbers of the element (Figure 2). It is this average that is given for each element in the Periodic Table. For example, the most common atoms of bromine are bromine-79 (50.7 % of naturally occurring bromine) and bromine-81 (49.3 %), so the atomic mass of bromine is 79.90 *u*.

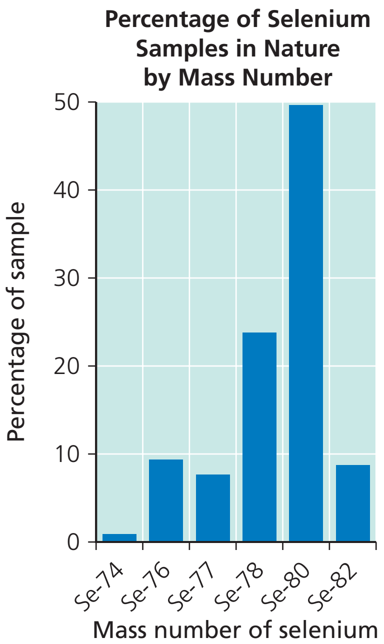
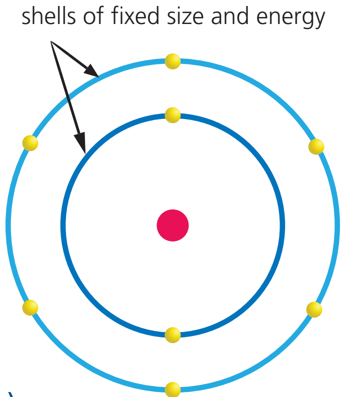


Figure 2 The relative abundance of selenium atoms found in nature. The atomic mass of selenium is 78.96 *u*.

Atomic mass is measured in units called atomic mass units, with the symbol *u* (or *amu*). One atomic mass unit is defined as $\frac{1}{12}$ the mass of the carbon-12 atom. You will learn more about atomic mass in the next unit.



(a)

(b)

Figure 3 The structure of an atom according to Bohr's theory of the atom: (a) a 2-D drawing and (b) a 3-D drawing.

Electrons and the Bohr Theory

Outside the nucleus are found the negatively charged **electrons**, which are approximately $\frac{1}{1800}$ the mass of a proton, but have a negative charge of the same size (strength) as the positive charge on the proton. An atom has the same number of electrons as protons. (Recall that if an atom has more or fewer electrons than protons, it will have a net electric charge, and is then called an *ion.*) The electrons are arranged around the nucleus in specific regions or **electron shells** (Figure 3). Electron shells are sometimes referred to as "orbitals" or "energy levels."

Electrons can only exist in electron shells, with only a particular number in each shell. The shell closest to the nucleus (first shell) can contain a maximum of 2 electrons. The second shell can contain a maximum of 8 electrons. For the first 20 elements, the third shell can contain a maximum of 8 electrons. Potassium and calcium, the 19th and 20th elements, have 1 and 2 electrons respectively, in their fourth shells. You will learn about the arrangement of electrons for the rest of the elements in senior chemistry courses.

Bohr Diagrams

It is useful to visualize the arrangement of electrons in an atom using a Bohr diagram. A Bohr diagram shows the number of electrons that are found in each electron shell. There are many ways to write Bohr diagrams as shown in Figure 4. You may see these different styles on worksheets, exams, and in other texts. In this text, the Bohr diagrams you see will be similar to (c).

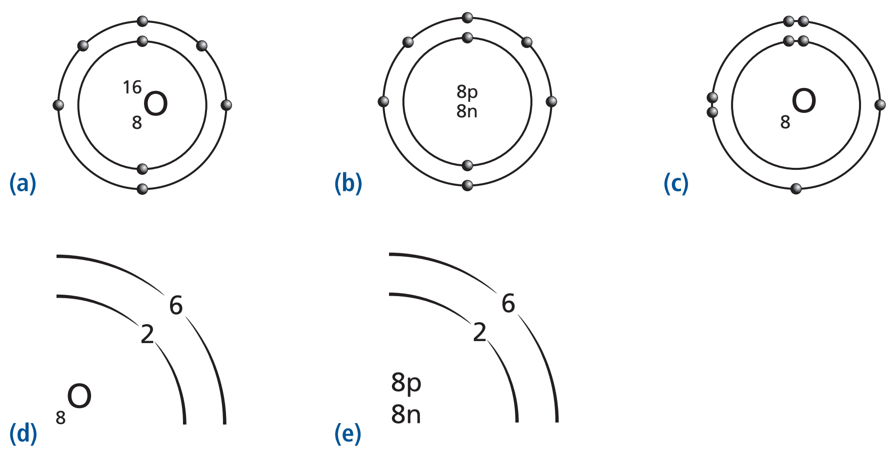


Figure 4 Some possible Bohr diagrams for oxygen: (a) The atomic number (number of protons) and mass number is shown in the centre; (b) Only the number of protons and neutrons is listed; (c) Only the atomic number is indicated in the centre with the element symbol. Electrons are paired when possible; (d) and (e) show variations that use numbers for the electrons in each shell to save space.

When drawing Bohr diagrams, a maximum of only 2 electrons can occupy the first shell, with a maximum of 8 electrons for the second and third shells. It is convenient to place electrons as a pair in the first shell. In the second and third rings, place the first 4 electrons equally around the shell, then pair up the remaining electrons. Always fill an inner shell completely before placing electrons in the next shell. Single electrons in shells are called **unpaired electrons,** and 2 electrons together are called **paired electrons**. GO

To learn more about drawing Bohr diagrams, go to **www.science.nelson.com** GO

Figure 5 shows the steps to follow to draw Bohr diagrams for the first 20 elements. Depending on the element, you might stop the process before completing all steps, or continue past Step 5.

1. Label the centre of the diagram with the atomic number and symbol for the element.

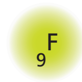
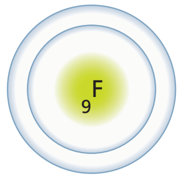
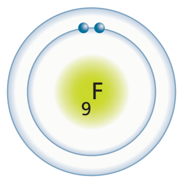


Figure 5 Drawing a Bohr diagram for the element fluorine. These steps can be used for the first 20 elements.

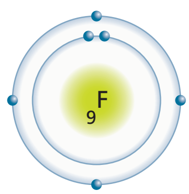
2. Determine the number of shells needed.



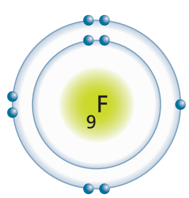
3. Fill the first shell with 1 set of paired electrons.



4. Place the next 4 electrons equally around the second shell.



5. Pair up remaining electrons. Do not go past a total of 8 electrons in the second shell.



STUDY TIP

It is helpful to know how you can be tested on an exam. Some context-dependent questions can be based on information such as the diagrams in Figures 3–6. To carefully read a graphic in your text or on an exam try the **4-S** system: **S**tudy the graphic. **S**ay the purpose of the graphic. **S**earch out the information in the graphic. **S**ummarize the information.

Figure 6 shows completed Bohr diagrams for 4 other elements.

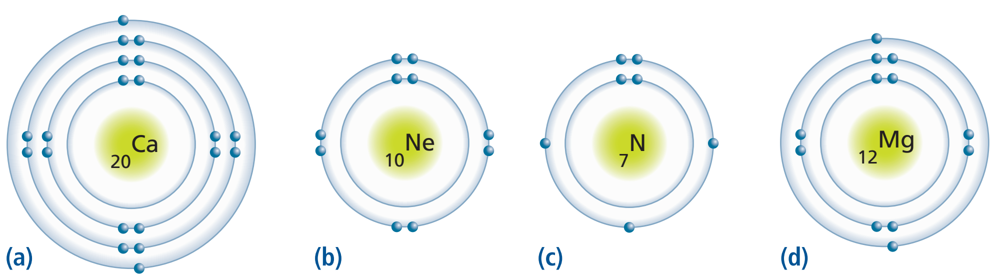


Figure 6 Bohr diagrams for (a) calcium, (b) neon, (c) nitrogen, and (d) magnesium.

6.2 CHECK YOUR Understanding

1. Copy Table 1 and use the Bohr theory of the atom to complete it.

Table 1

Subatomic particle	Mass, compared to a proton (larger, smaller, the same)	Charge (+ or −)	Location in the atom
proton	1 *u*		
		−1	
			in the nucleus

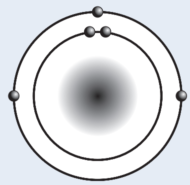
2. Copy Table 2 and complete it.

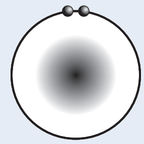
Table 2

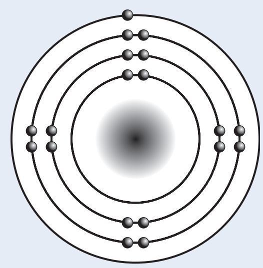
Atom	Number of protons	Number of neutrons	Number of electrons
nitrogen-14			
bromine-79			
lithium-7			
phosphorus-31			

3. Draw the Bohr diagrams for atoms of
   (a) carbon
   (b) boron
   (c) argon
   (d) sodium
   (e) sulfur
   (f) aluminum
   (g) beryllium
   (h) phosphorus

4. Which element does each of the following Bohr diagrams of neutral atoms represent?

(a)


(b)


(c)


5. How many electrons are in an atom of the element with atomic number 24?

6. Consider a neutral atom that has 17 electrons.
   (a) How many protons does it have?
   (b) What is its atomic number?
   (c) Which element is it?

7. List the following for an atom with 33 protons and 42 neutrons:
   (a) the name of the element
   (b) the atomic number
   (c) the number of electrons
   (d) the mass number