3 Atomic Structure

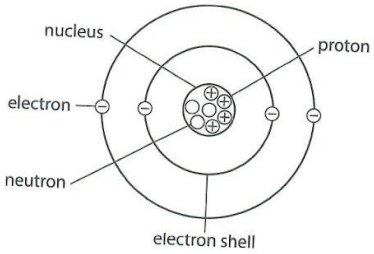
Study Station ▸▸

A What Is an Atom Made up Of?

Learning Outcomes

- Describe the structure of an atom, showing the three types of sub-atomic particles.
- State the relative masses and charges of the three types of sub-atomic particles.

1. An **atom** is the smallest unit that makes up an element.
2. Each atom consists of a **nucleus**, **electron shells** and **sub-atomic particles**.
3. Sub-atomic particles include **protons**, **neutrons** and **electrons**. Protons and neutrons are known as **nucleons**.
4. Protons and neutrons are found in the nucleus, while electrons are found in electron shells.
5. For example, a beryllium atom has four protons and three neutrons in its nucleus and four electrons arranged in its two electron shells.



6. The relative masses and charges of the sub-atomic particles in an atom are shown below.

Sub-atomic Particle	proton	neutron	electron
Relative Mass	1	1	$\frac{1}{1840}$
Relative Charge	+1 (positive)	0 (neutral)	−1 (negative)
Location in the Atom	nucleus	nucleus	electron shell

7. The mass of an electron can be considered negligible.
8. The number of protons in an atom is equal to the number of electrons.
9. An atom is electrically neutral as the number of positively charged protons is balanced by an equal number of negatively charged electrons.

Worked Example 3.1

Which of the following statements about an atom is **true**?

A An atom always has an equal number of neutrons and electrons.

B The nucleon number can be equal to the proton number.

C The nucleon number can be less than the proton number.

D The number of neutrons is never equal to the number of electrons.

Solution

B

Explanation

The nucleon number of an atom can be equal to the proton number if there are no neutrons in the atom and the protons are the only nucleons. It is not possible for the nucleon number to be less than the proton number as the nucleon number is the sum of the numbers of protons and neutrons.

An atom always has an equal number of protons and electrons. It is possible for the number of neutrons in an atom to be equal to the number of electrons. For example, a carbon atom has 6 protons, 6 electrons and 6 neutrons.

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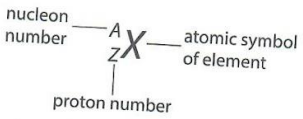
B How Many Sub-atomic Particles Does an Atom Have?

Learning Outcomes

- Define *proton number* and *nucleon number*.
- Deduce the numbers of protons, neutrons and electrons in atoms and ions from their proton and nucleon numbers.
- Interpret and use nuclide notations such as $^{12}_{6}C$.
- Define *isotopes*.

1. **Proton number**, or **atomic number**, is the number of protons in an atom.
2. **Nucleon number**, or **mass number**, is the number of protons and neutrons (nucleons) in an atom.
3. A **nuclide notation** can be used to represent the proton number and nucleon number of an element.



4. For example, $^{35}_{17}Cl$ represents a chlorine atom with 17 protons and 35 nucleons. Thus, a chlorine atom has $35 - 17 = 18$ neutrons.
5. An **ion** is formed when an atom or a group of atoms loses or gains electrons.
6. Examples of ions are Na^+, Mg^{2+}, F^- and OH^-.

7. The **charge** of an ion shows the number of electrons that are lost or gained.

   Examples:

   (a) The Na^+ ion has a charge of +1. This shows that there is 1 more proton than electron in the Na^+ ion. The Na atom loses one electron to form the Na^+ ion.

   (b) The F^- ion has a charge of –1. This shows that there is 1 more electron than proton in the F^- ion. The F atom gains one electron to form the F^- ion.

8. Atoms of the same element with the same proton number but different nucleon numbers are called **isotopes**.

9. For example, carbon-12 and carbon-14 are isotopes. Both of them have 6 protons. However, carbon-12 has 6 neutrons while carbon-14 has 8 neutrons.

10. Isotopes have the same number of electrons. Thus, they have similar chemical properties. However, they have different physical properties, such as density, melting point and boiling point.

Tip

Take note of the following:

- The number of protons determines the identity of an element.
- Electrons do not contribute to the mass of an atom.
- Neutrons do not contribute to the charge of an atom.

Worked Example 3.2

Deduce the number of protons, electrons and neutrons in each of the following.

(a) $^{23}_{11}Na$

(b) O^{2-}

Strategy

The difference between the nucleon number and proton number of an element is the number of neutrons. The number of electrons in an atom is equal to the number of protons in the atom. The charge of an ion shows the difference in the number of protons and number of electrons in the ion.

From the periodic table, O has a proton number of 8 and a nucleon number of 16. The charge of the O^{2-} ion shows that there are 2 more electrons than protons in the ion. The O atom gains 2 electrons to form the O^{2-} ion.

Solution

(a) Number of protons in Na = 11

Number of electrons in Na = number of protons in Na = 11

Number of neutrons in Na = 23 – 11
= 12

(b) Number of protons in O^{2-} = 8

Number of electrons in O^{2-} = 8 + 2
= 10

Number of neutrons in O^{2-} = 16 – 8
= 8

Worked Example 3.3

Hydrogen can form both H^+ and H^- ions.

Which of the following statements is **correct**?

A The H^+ ion has more protons than the H^- ion.

B The H^+ ion has no electrons.

C The H^- ion has one more electron than the H^+ ion.

D The H^- ion is formed when the H atom loses an electron.

Solution

B

Explanation

The H atom has one proton and one electron. It loses the electron to form the H^+ ion. Thus, the H^+ ion has no electrons. When the H atom gains one electron, it forms the H^- ion, which has two electrons. Thus, the H^- ion has two more electrons than the H^+ ion. Both the H^+ ion and H^- ion have one proton each.

Worked Example 3.4

The numbers of protons, electrons and neutrons in some particles are shown below.

Particle	Number of Protons	Number of Electrons	Number of Neutrons
P	26	23	30
Q	12	12	12
R	26	24	30
S	13	10	14
T	25	23	30
U	12	12	14

Which two particles are isotopes?

A **P** and **R**

B **Q** and **U**

C **R** and **T**

D **S** and **U**

Solution

B

Explanation

Q and **U** are isotopes as they have the same number of protons and different numbers of neutrons.

Common Error

✗ Isotopes have different numbers of electrons.

✓ Isotopes have the same number of electrons.

Explanation
The number of protons in an atom is equal to the number of electrons. Since isotopes have the same number of protons, they will also have the same number of electrons.

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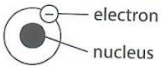
C How Are Some Sub-atomic Particles Arranged in an Atom?

Learning Outcome

- Assign electrons to different electron shells or energy levels.

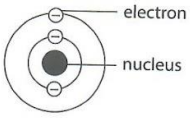
1. An atom has one or more electron shells.
   - The first or innermost shell is the lowest energy level. It is closest to the nucleus.
   - The outermost shell is the highest energy level. It is furthest from the nucleus.
2. Electrons occupy the inner shells with the lowest energy first. **Electronic configuration** refers to the arrangement of electrons in an atom.
3. The first or innermost electron shell can contain at most two electrons, while the second and third electron shells can contain at most eight electrons.
4. The outermost electron shell is also called the **valence shell**. Electrons found in the outermost shell are thus called **valence electrons**.
5. The electronic configurations and structures of three different atoms are shown below and on the next page.

   (a) Hydrogen has 1 electron. Thus, its electronic configuration is 1.



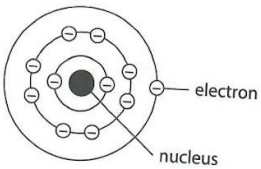
H atom

   (b) Lithium has 3 electrons. Its first electron shell is filled with 2 electrons, while its second or valence shell is filled with 1 electron. Thus, its electronic configuration is 2, 1.



Li atom

(c) Sodium has 11 electrons. Its first electron shell is filled with 2 electrons, while its second shell is filled with 8 electrons. Its third or valence shell is filled with 1 electron. Thus, its electronic configuration is 2, 8, 1.



Na atom

6. Helium and argon are noble gases, or Group 18 elements. Helium and argon have two valence electrons and eight valence electrons respectively. Their valence shells are full. Thus, they are stable and unreactive.

7. Atoms with valence shells that are not full are reactive. They tend to gain, lose or share electrons to achieve the stable electronic configuration of a noble gas.

Worked Example 3.5

Determine the electronic configuration for the following elements.

(a) Potassium

(b) Calcium

(c) Fluorine

Strategy

Find out the number of electrons in each element. Fill the first electron shell with two electrons. Then, fill subsequent shells with eight electrons until there are insufficient electrons to fill the valence electron shell fully.

Solution

(a) Potassium has a proton number of 19. It has 19 electrons. Thus, its electronic configuration is 2, 8, 8, 1.

(b) Calcium has a proton number of 20. It has 20 electrons. Thus, its electronic configuration is 2, 8, 8, 2.

(c) Fluorine has a proton number of 9. It has 9 electrons. Thus, its electronic configuration is 2, 7.

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Checkpoint 3.1

1. Complete Table 3.1.

Table 3.1

Particle	Proton Number	Nucleon Number	Number of Protons	Number of Electrons	Number of Neutrons
Li	3	7	3		4
F^-				10	10
Ar		40	18		
Ca^{2+}			20		20
I				53	74
Sn		119		50	

2. Figure 3.1 shows the valence electrons of an atom of element **E**. The atom has two electron shells.

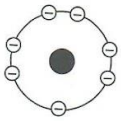

Figure 3.1

(a) Write the electronic configuration of an atom of element **E**. Explain your answer.

(b) Element **E** forms an ion. Predict, with a reason, the chemical formula of the ion formed.

3. The most abundant isotope of hydrogen, hydrogen-1, can form the hydride ion, H^-.

The hydride ion contains the following sub-atomic particles.

Table 3.2

Sub-atomic Particle	Number of Sub-atomic Particles
X	0
Y	1
Z	2

(a) Identify the sub-atomic particles, **X**, **Y** and **Z**.

(b) Briefly describe the formation of a hydride ion from a hydrogen atom.

(c) Another isotope of hydrogen is hydrogen-2, which is also known as deuterium.

Complete Table 3.3 to show the number of each type of sub-atomic particle in a deuterium atom.

Table 3.3

Sub-atomic Particle	Number of Sub-atomic Particles
X	
Y	
Z	

Test Station ▸▸

1. _____ have the same number of protons and neutrons but different numbers of electrons.

   A An atom and an ion of different elements

   B An atom and an ion of the same element

   C An atom and an isotope of different elements

   D An atom and an isotope of the same element

2. Which of the following contain 10 electrons?

   [Proton number: Mg = 12, Na = 11, Ne = 10]

   1 Mg^{2+}

   2 Na

   3 Na^{+}

   4 Ne

   A 1, 2 and 4 only

   B 1 and 3 only

   C 1, 3 and 4 only

   D 3 and 4 only

3. Figure 3.2 represents the structures of four different atoms, **W**, **X**, **Y** and **Z**.

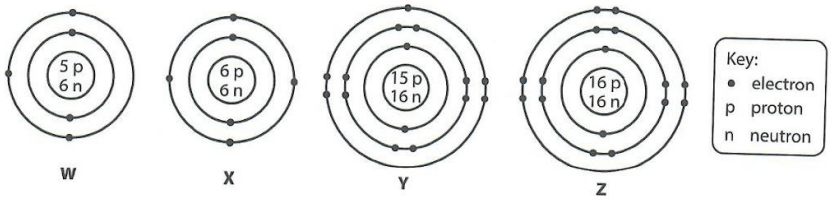

Figure 3.2

Based on Figure 3.2, complete Table 3.4. [4]

Table 3.4

Atom	Proton Number	Nucleon Number	Electronic Configuration
W			
X			
Y			
Z			

4. Table 3.5 shows the numbers of sub-atomic particles in six particles, which are either atoms or ions.

Table 3.5

Particle	Number of Electrons	Number of Protons	Number of Neutrons
L	6	6	6
M	2	2	2
N	12	12	12
O	10	12	12
P	6	6	8
Q	10	13	14

(a) Which particles are ions? [1]

(b) Which particle is an atom of a noble gas? [1]

(c) Which particles are an atom and an ion of the same element? [1]

(d) Which particles are isotopes? [1]

(e) Which particle has the largest atomic mass? [1]

5. Figure 3.3 shows the atomic structure of an element based on the discovery made by a scientist called James Chadwick.

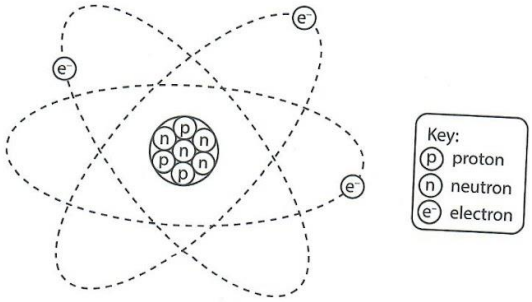

Figure 3.3

(a) Compare **two** of the sub-atomic particles in terms of relative charge and mass. [1]

(b) Using the periodic table, identify the element and write a nuclide notation to represent the element. [2]

(c) Based on Figure 3.3, describe the atomic structure of the element in **(b)**. [2]