2 The atom and the periodic table

1. How do atoms make up matter?
2. & 3. Electrons, protons and the first atomic models
4. Atomic number and mass number
5. Bohr's atomic model (1913)
6. How are ions formed?
7. Isotopes
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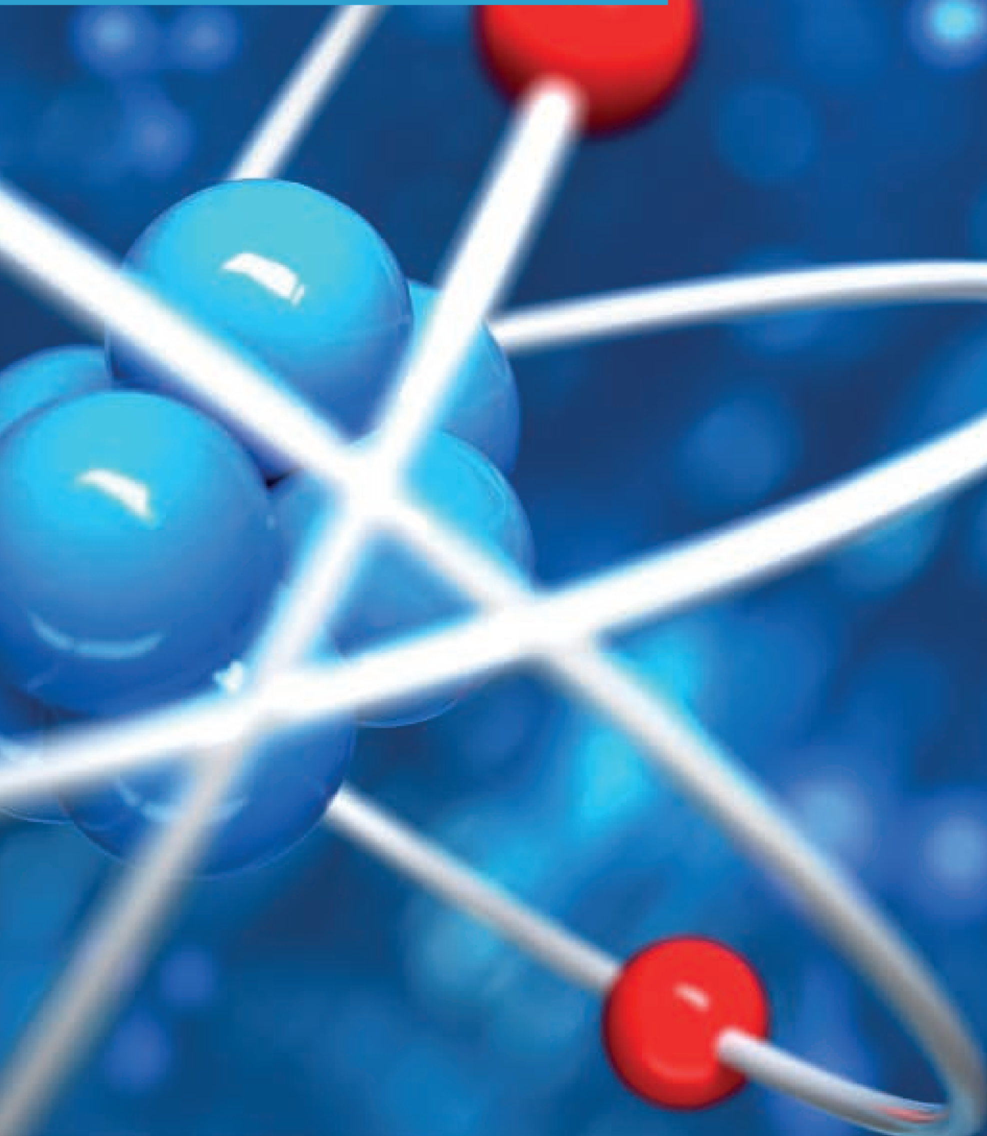


LEARNING SITUATION

The 'healthy' elements of the periodic table

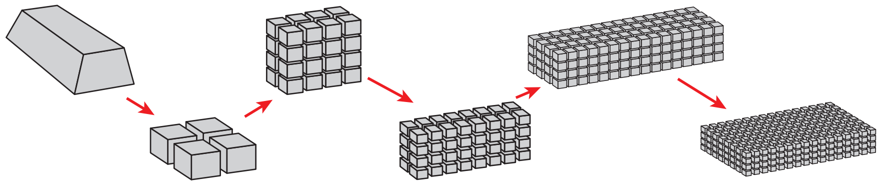
In this task, you'll research which elements of the periodic table are essential to maintaining good health, as well as the diseases that a deficiency or excess of those elements can cause.

Then you'll use the information to design a periodic table that highlights those elements.

1 How do atoms make up matter?

Matter has mass and occupies space. In nature, matter exist in three states: solid, liquid and gaseous.

Can a copper wire be divided indefinitely into ever smaller fragments?

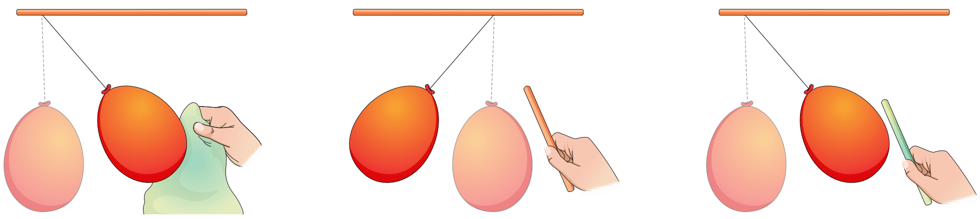


In the early 1800s, **John Dalton** proposed a theory:

1. Matter is composed of **indivisible**[1] particles called **atoms.**
2. **Elements** are made up of **identical atoms** with the same mass and properties.
3. The atoms that compose each element have different masses and properties.
4. The atoms of different elements can combine in specific ratios to form **chemical compounds.**

1.1. The electrical nature of matter

Look at the following experiment. What do you think happens in each case?



Experiment 1. Hang an inflated balloon by a string and rub it with a piece of cloth. Hold the cloth close to the balloon.

Experiment 2. Now rub a plastic rod with a piece of cloth and hold the rod close to the balloon.

Experiment 3. Finally, rub a glass rod with a piece of silk and hold it close to the balloon.

These experiments demonstrate two electrical phenomena: **attraction** and **repulsion**.

Experiment 1: the cloth attracts the balloon.

Experiments 2 and 3: the rods repel the balloon.

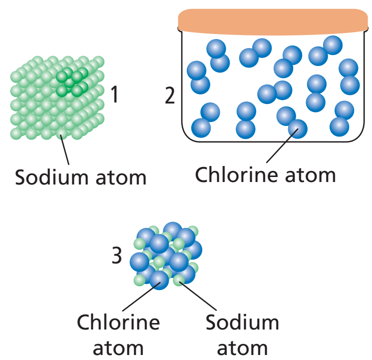
These experiments show that there are **positive and negative electrical charges**. Opposite charges attract and identical charges repel. Objects with an equal number of positive and negative charges are electrically neutral.

The phenomenon of electrical charge proves that **atoms are divisible**. The SI unit for charge is the **coulomb (C)**.

[1]**indivisible:** not able to be separated into parts.

The word 'atom'

The Greek philosophers **Leucippus** and **Democritus** used this word for the first time. It means 'indivisible.'



1 A sodium crystal is formed by sodium atoms.
2 Chlorine molecules are formed by two chlorine atoms.
3 A sodium chloride crystal is formed by one sodium atom and one chlorine atom.

CLIL activities

1 Listen to this teacher talking about Dalton's theory. List two of his ideas which we now know are incorrect. Share your answers with a classmate.

2 & 3 Electrons, protons and the first atomic models

At the end of the 19th century, it was still believed that atoms were the fundamental **building blocks**[1] of matter. But scientists began to question this notion after studying the properties of atoms in large **electric fields**.

J. J. Thomson discovered that when he applied voltage to a low-pressure gas, a clearly visible **beam**[2] of light moved in a straight line. Thomson deduced that the beam was made up of negatively-charged particles. This was the discovery of **electrons.**

He also measured the **charge** and the **mass** of these particles and found that electrons are 1 840 times lighter than the most basic atom (hydrogen). This was very important, as it proved that the **atom could be divided** into even smaller particles of matter.

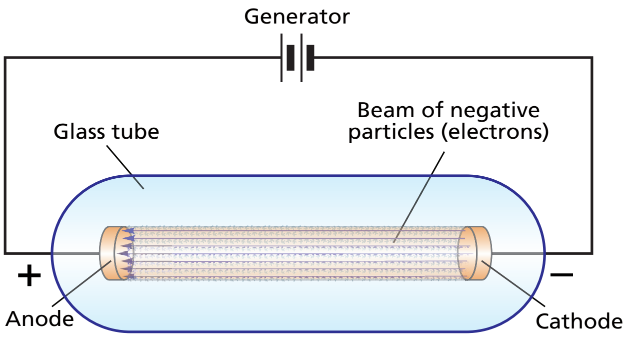
In 1886, E. Goldstein observed, in a similar experiment, a new beam travelling in the opposite direction from the electrons. He deduced it was made of positively-charged particles. This was the discovery of **protons**.

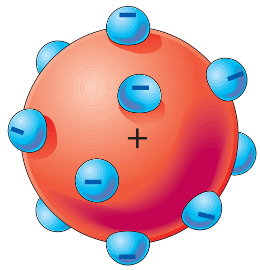
[1]**building block:** basic part which is necessary to make something else.

[2]**beam:** line of light.

[3]**foil:** very thin sheet of metal.

[4]**validity:** state of being officially accepted.





The **plum pudding model** was the atomic model proposed by Thomson in 1904. This model describes the atom as being composed of electrons surrounded by a 'soup' of positive charge to balance the electrons' negative charges. It's called the plum pudding model because the positively charged soup looks like a 'pudding' with negatively charged 'plums' in it. The 'pudding' part of the atom contained most of the mass. The model was accepted until 1909, when the **gold foil**[3] **experiment** questioned its **validity**[4].

	Electron	Proton
Electric charge	$-1.602 \cdot 10^{-19}$ C	$1.602 \cdot 10^{-19}$ C
Mass	$9.109 \cdot 10^{-31}$ kg	$1.673 \cdot 10^{-27}$ kg

A plum pudding

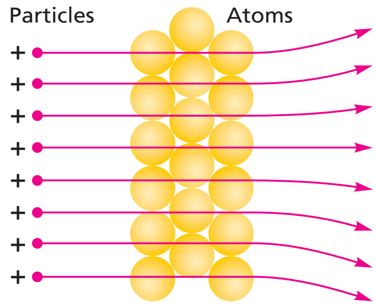
Note that, regardless of the sign (absolute value), the charge of the electron is the same as that of the proton, but the proton has a much greater mass. In an **electrically neutral body**, the number of electrons has to be equal to the number of protons.

CLIL activities

2. How much larger is the charge of the proton than the charge of the electron? What about the mass?
3. Thomson's atomic model has been compared to a watermelon. What do you think the red part represents? And the seeds?
4. Why do you think Thomson's discoveries were so important? Discuss your answer with a classmate.
5. Listen and write the sentences in your notebook. Complete them correctly with the words *electron(s)* or *proton(s)*.

The Rutherford model

In 1909, **Ernest Rutherford** designed an experiment to study the charge distribution in the atom. He bombarded a very thin sheet of gold foil with positively charged particles (**α particles**[1]). He expected that the particles would pass straight through the foil and only be **deflected**[2] by a small angle if the electrons were not homogenously distributed in the plum.



The size of the gold atom is 10^{-8} cm, while the size of its nucleus is 10^{-12} cm.

However, the actual results surprised Rutherford. Although most of the particles passed through as expected, some others were deflected by large angles and a few of them even **bounced back.** By counting the particles behaving in these three different ways, he determined the distribution of charges in the atom. Rutherford drew the following conclusions:

1. The atom is mostly **empty space**. This is why most of the α-particles went straight through the foil.
2. The atom has a concentration of **positive charge**. The α-particles passing close to each other were deflected due to the repulsive electric force between charges of the same sign. The very few particles that bounced back were those colliding with this concentration of positive charge.

In this model with protons and electrons, the mass of a helium atom (with two protons) should be twice that of a hydrogen (with 1 proton). However, the mass of helium atoms is actually **four times** larger than that of hydrogen. Rutherford suggested the existence of a new particle with a similar mass to the proton and with no electric charge. In 1932, **James Chadwick** found this new particle and called it the **neutron**.

The final atomic model, proposed by Rutherford, consisted of two distinct areas.

- A **central area**, or **nucleus**, where almost all the mass of the atom is concentrated and is **positively charged**. It's where protons and neutrons are found. The nucleus is 10 000 times smaller than the size of the atom.
- A **peripheral**[3] **area**, or **cortex**, in which **negatively charged** electrons spin around the nucleus, keeping some distance from it.

CLIL activities

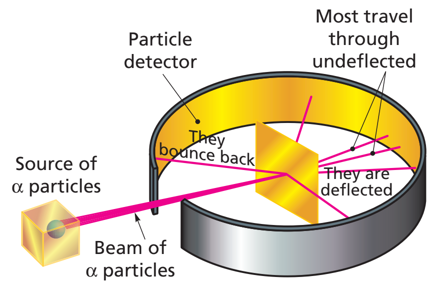
6. Listen and write the sentences in your notebook. Find the mistakes and correct them.

7. Which particles are responsible for the mass of the atom? Explain to a classmate why Rutherford proposed the existence of the neutron before it was actually discovered.

[1]**α particle:** nucleus of a helium atom. It's composed of two protons and two neutrons but no electrons.

[2]**deflect:** change direction after hitting something.

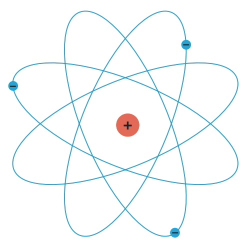
[3]**peripheral:** around the edge of, far from the centre.



The mass of the neutron

The **mass of the neutron**, m_n, is only slightly greater than the mass of the **proton**, m_p:

$$m_n = 1.675 \cdot 10^{-27} \text{ kg}$$
$$m_p = 1.673 \cdot 10^{-27} \text{ kg}$$



Rutherford's planetary model

4 Atomic number and mass number

All atoms of the same element have the same number of protons, which is called the **atomic number** (***Z***). This is what defines the element.

$$Z = \text{atomic number} = \text{number of protons}$$

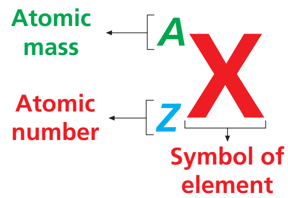
The number of protons plus the number of neutrons in an atom is called the **mass number** (***A***).

$$A = \text{number of protons} + \text{number of neutrons}$$

The number of neutrons (***N***) is therefore: $N = A - Z$

In an **electrically neutral atom**, the number of protons is **equal** to the number of electrons.

To represent an atom, the following **notation**[1] is used:



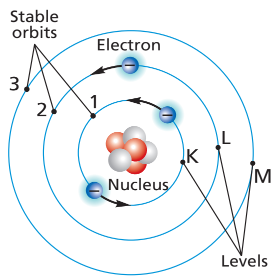
This notation informs us of the number of protons and neutrons in an atom, and in the case of a neutral atom, the number of electrons as well.

5 Bohr's atomic model (1913)

Niels Bohr proposed the Bohr model of the atom in 1913, which states that:

1. the electron only moves in **stable circular orbits** of fixed energy. The energy of electrons depends on their orbit. The closer the electron is to the nucleus, the lower the energy. Orbits are called **energy levels**.
2. the loss of energy only occurs when an electron jumps from a **higher energy level** to a **lower energy level.** For an electron to pass from a lower energy level to a higher energy one, it must gain the right amount of energy.

Bohr's model was further **refined**[2] to better justify the chemical properties of the elements: each **stable orbit** or energy level can have different **sublevels.** Each level and sublevel admit a **maximum number of electrons.**



The **electron configuration** of an atom is the distribution of its electrons by levels and sublevels of energy. For example:

- the **helium** atom ($Z = 2$) has 2 electrons, which occupy level 1, so this level no longer admits electrons. Its electron configuration is **He: 2**.
- the **boron** atom ($Z = 5$) has 5 electrons, which fully occupy level 1 and partially level 2. Its electron configuration is **B: 2 3**.

[1]**notation:** set of written symbols.

[2]**refine:** improve by making small changes or removing errors.

CLIL activities

8 **Write these atoms using ${}^{A}_{Z}X$ notation.**

a. oxygen (O): 8 protons; 8 neutrons
b. nitrogen (N): 7 protons; 7 neutrons
c. calcium (Ca): 20 protons; 20 neutrons
d. magnesium (Mg): 12 protons; 13 neutrons

9 **The potassium atom has 19 electrons. Choose the correct electron configuration:**

a. 2 2 6 2 6 1
b. 2 2 5 2 5 3
c. 2 8 3 5 1

How do we draw atoms?

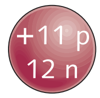
1. Draw a circle to represent the atomic nucleus, made up of protons and neutrons.
2. Write the number of protons and neutrons inside the circle.

The atomic number, Z, is the number of protons. The number of neutrons is the difference between the mass number and the atomic number: $N = A - Z$. For example, for $^{23}_{11}Na$ we know that the number of protons is $Z = 11$, so the number of neutrons will be $N = A - Z = 23 - 11 = 12$.

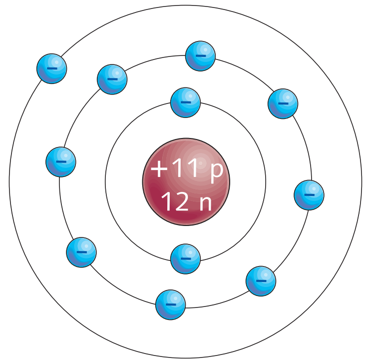
3. Draw energy levels around the core.
4. Place the electrons at the different levels.

In an electrically neutral atom, the number of positive charges is equal to the number of negative charges, that is, the number of electrons. In the $^{23}_{11}Na$ example, the number of electrons is 11.

As we've already seen, the first energy level contains at most 2 electrons; the second level 8, the third 18, and so on. As a result, the electron configuration of the $^{23}_{11}Na$ is **2 8 1**.



Nucleus of the sodium atom



Representation of the sodium atom.

6 How are ions formed?

In an **electrically neutral atom**, the **number of protons** in the nucleus **coincides** with the **number of electrons** in the shell.

- When a neutral atom **loses** electrons, it acquires a positive charge. We call this a **cation** or **positive ion**.
- When a neutral atom **gains** electrons, it acquires a negative charge. We call this an **anion** or **negative ion**.

Worked example

I The magnesium atom has a mass number of 24 and has 12 neutrons.

a. How many electrons does it have if the atom is neutral?

Since the atom is neutral, the number of electrons must be equal to $Z = A - N = 24 - 12 = 12$. It has 12 electrons.

b. How do you identify it? What's its electron configuration?

Identification: $^{24}_{12}Mg$ Configuration: **2 8 2**

c. If it had 10 electrons, how many protons would it have now and what would its ionic charge be? How would you identify it?

It would be a cation, since it would have lost 2 electrons. However, it would still have the same number of protons: 12.

Ionic charge $= 12 - 10 = +2$ Identification: $^{24}_{12}Mg^{2+}$

d. What would its electron configuration now be?

Configuration: **2 8**

CLIL activities

10 The chlorine atom has 17 electrons. Which of these electron configurations is correct? Write the number of electrons in each level.

a. 2 2 6 2 6

b. 2 2 6 2 5

c. 2 8 8 1

11 Discuss with a classmate which one of these ions is more common and why.

a. $_{11}Na^{+}$ or $_{11}Na^{++}$

b. $_{17}Cl^{-}$ or $_{17}Cl^{++}$

c. $_{8}O^{2-}$ or $_{8}O^{+}$

d. $_{12}Mg^{2+}$ or $_{12}Mg^{2-}$

...is more common because...

7 Isotopes

Isotopes of an element have the same atomic number, (*Z*), but different mass number (*A*).

Radioactive isotopes (radioisotopes) have a larger number of neutrons than protons. This gives them have an excess of nuclear energy that makes them unstable. They **radiate**[1] this excess in different ways.

We call this property **radioactivity**.

Radiation is used in a variety of fields.

- **Medicine**: it's used both in the diagnosis and in the treatment of cancer.
- **Industry and agriculture:** it allows quality control of products. It's also useful in **pest**[2] control and food preservation.
- **Archaeology and geology**: it's used to date organic residue, rocks, etc.
- **Energy generation**: the controlled fission of uranium-235 nuclei generates a large amount of energy and doesn't contribute to global warming.

[1]**radiate:** produce energy in the form of waves or particles.

[2]**pest:** small insect or animal that damages food or crops.

[3]**row:** horizontal line in a table.

8 The periodic table

So far, 118 chemical elements have been discovered. We can arrange them in order according to their atomic number in the **periodic table,** or **periodic table of elements**.

A **chemical element** is made up of atoms of the same type, which have the same atomic number, *Z*.

The elements are organised according to their atomic number, that is, according to their electron configuration. They're arranged from left to right and top to bottom in increasing order of their atomic number, in columns called **groups** and in **rows**[3] called **periods**.

- **There are 18 groups**. The elements of the same group have the same number of electrons in the last layer or level (valence electrons) and therefore, have similar chemical properties.

  The elements in groups 1, 2, 13, 14, 15, 16, 17 and 18 are called **representative elements**.

- **There are 7 periods**. The elements from the same period have the same number of electron levels.

  Elements with atomic numbers 58 to 71 (lanthanoids) and 90 to 103 (actinoids) are in two rows outside the table, which are extensions of periods 6 and 7.

Marie Curie (1867-1934)

She won two Nobel prizes: one in Physics for her work on radiation and another in Chemistry for the discovery of radium and polonium.

CLIL activities

12 **Search for information about which isotopes are used in the diagnosis and treatment of thyroid cancer.**

8.1. Metals and non-metals

We can classify elements as metals and non-metals.

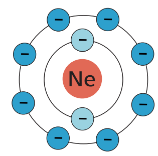
	Examples	Properties
Metals	Iron (Fe) Copper (Cu) Zinc (Zn) Tin (Sn) Gold (Au) Mercury (Hg)	• opaque and lustrous (shiny) • good conductors of heat and electricity • malleable (for making thin sheets) • ductile (for making long, thin threads) • high melting points and boiling points • solid at room temperature (except mercury)
Non-metals	Hydrogen (H) Carbon (C) Oxygen (O) Bromine (Br)	• not lustrous • poor conductors of heat and electricity • low melting points and boiling points • solids, liquids or gases at room temperature

8.2. Groups of elements on the periodic table

Elements in the same column of the periodic table have the same number of electrons in their last energy level.

Group 18: Noble gases (H, Ne, Ar, Kr, Xe, Rn)

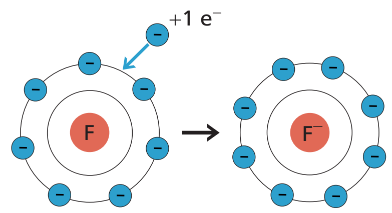
Noble gases are non-metals. Their last level is complete so they don't tend to combine with other elements. Helium has one level with two electrons. The other noble gases have eight electrons in their last level.



Neon atom

Group 17: Halogens (F, Cl, Br, I)

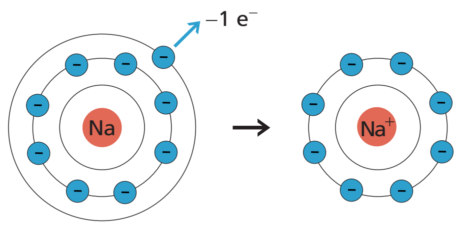
Halogens are also non-metals. Their last level is incomplete, with seven electrons. Halogens tend to form ions with a negative charge (anions). Halogen anions have eight electrons in their last level, like noble gases.



Flourine atom Flourine anion

Group 1: Alkali metals (Li, Na, K, Rb, Cs, Fr)

Alkali metals have one electron in their last level. They tend to form positive ions (cations) by losing one electron. A lithium cation has a one complete level with 2 electrons, like helium. The other alkali cations have eight electrons in their last level, like neon and the other noble gases.



Sodium atom Sodium cation

8.3. Representative elements

Groups 1-2 and 13-18 are representative elements. They have between 1 and 8 electrons in their last level.

8.4. Bioelements and living things

Bioelements form part of living things. Our own bodies are mostly carbon, oxygen, hydrogen and nitrogen, along with small amounts of phosphorus and sulphur.

CLIL activities

13 Use the periodic table (Annex The periodic table) to name the groups and periods of these elements: Fe, P, Hg, Zr, H, He, Co and Rb.

The 'healthy' elements of the periodic table Information cards

Of the 118 chemical elements currently identified in the periodic table, fewer than 30 are found in living things and 21 of them are present in our bodies. Deficiencies of these elements, due in most cases to a poor diet, cause various symptoms and diseases. Therefore, it's necessary to have a balanced and healthy diet that provides us with the necessary amount of each of these bioelements.

On the other hand, certain radioactive isotopes of some chemical elements are used in medicine for the diagnosis and therapy of cancer.

The **objective** of this task is to identify which elements exist in our bodies and which are isotopes used in cancer diagnosis and therapy.

Organising the task

- Form groups of four or five.
- All members of the group should be involved in creating the information cards.

Research

1. Find out which chemical elements, such as phosphorus or potassium, are found in our bodies and are essential for health.
2. Find out which foods contain these elements.
3. Look up the health problems caused by deficiencies of these elements.
4. Research which radioactive isotopes are used to diagnose tumours. Which radioactive isotopes are used to treat them?

Development

5. Draw a periodic table containing only the elements you have researched. Present it so that the following aspects are clearly visible:
   - the bioelements. Make sure that you include their atomic symbols, atomic numbers and their origin and function.
   - the radioactive isotopes used to treat cancers. Make sure that you include their atomic numbers and mass numbers.
6. Plan a personal, balanced diet containing these elements. You should include:
   - a list of the elements necessary to maintain your health and the proper functioning of your body.
   - the foods in which these elements are present and the weekly amount of each food that you should consume in a balanced diet.
7. In a small group, make cards with the properties and uses of each of the elements you found out about. Display all the cards from all the groups in the class on a physical or digital wall.

Share your findings

8. In your group, discuss:
   a. the arguments you could use to convince someone that they should follow a balanced and healthy diet.
   b. the use of radioactivity in medicine to treat illnesses and save lives.
   c. recommendations on how to achieve the related Sustainable Development Goals.

Task guide