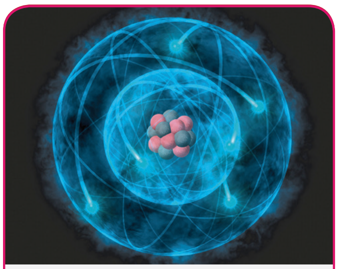
Atoms

CHEMISTRY • ATOMS AND BONDING • ATOMS

Section 1: Atoms

• What is an atom?



Atoms are too small for us to see inside of, so we use models to suggest how they are made up

Atoms are the building blocks of matter. They make up everything from living organisms to man-made plastics, from solid metals to gases invisible to the naked eye.

Atoms are very small, much smaller than a grain of sand. The number of atoms in a grain of sand is something like 1,000,000,000,000,000,000,000 or 10^{21}, more than a million million times greater than the total number of human beings in the world.

• Suggested Films

– What Is An Atom?

– Discovery of the Atom

• What are atoms made of?

As atoms are so small that we cannot see inside them, scientists have come up with various models to describe the make-up of an atom. The model we currently use was designed in the early 20th century, but we are still updating these ideas today. By understanding the make-up of an atom, we can explain why matter behaves in the way it does.

The centre of the atom is called the nucleus. The nucleus is very small compared to the whole atom, but over 99% of the mass of an atom is concentrated there. The nucleus contains positive particles, called protons, and usually neutral particles, called neutrons. Neutrons have zero charge, but have almost exactly the same mass as protons.

Around the nucleus is a cloud of negative electrons. Electrons have a negative charge: exactly the same charge as a proton, but of opposite sign. Electrons have a very low mass, about 1/1836 of the mass of a proton.

An atom always contains the same number of electrons and protons, because a proton attracts an electron (with its equal negative charge) with its positive charge. Because the amount of negative and positive charge must be the same, all atoms are neutral.

• Suggested Films

– FactPack: Structure of the Atom

– FactPack: Scale of the Atom

DIAGRAM 01:

Relative Mass of Protons, Neutrons and Electrons

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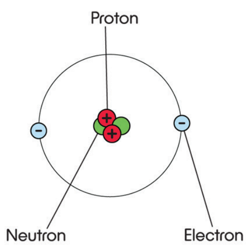
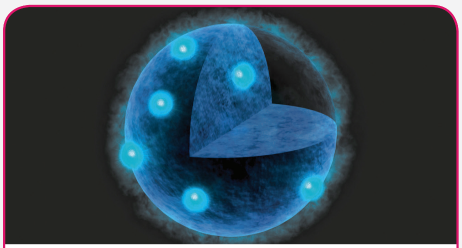


Atomic Particle	Relative Mass	Relative Charge
Neutron	1	0
Proton	1	+1
Electron	1/1836	-1

Extension Question

Q1. How did scientists discover the structure of the atom?

Modern study of the atom began with J J Thomson's discovery of the electron (1897) and his plum pudding model of the atom. The experiments of Geiger and Marsden (1909), and their interpretation by Rutherford (1911), led to the discovery of the nucleus, the discovery of protons in the nucleus (Rutherford, 1919), and the existence of neutrons (Chadwick 1932).



Thomson's early plum pudding model has since been discarded as a model for the structure of the atom

Section 2: Different Atoms and Elements

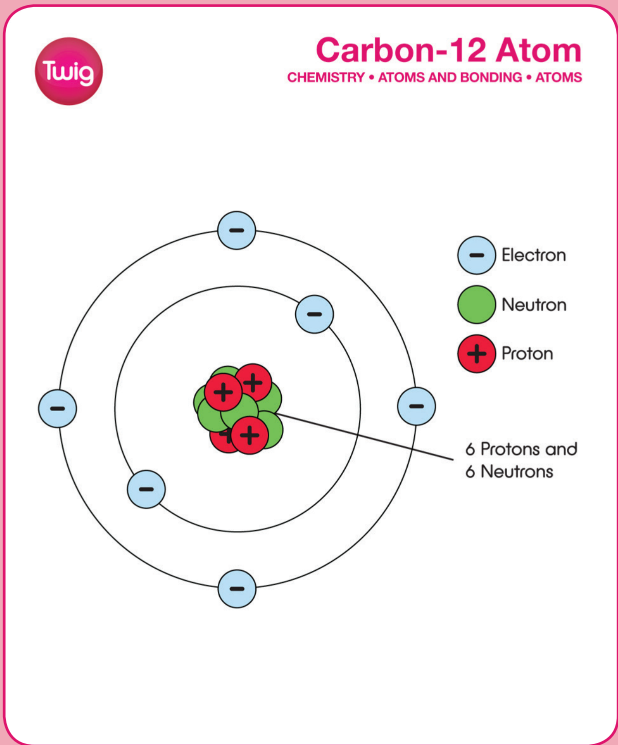
• How are elements related to atoms and how are the atoms of different elements different?

Each element is made up of atoms with a specific number of protons. The atoms of different elements have different numbers of protons.

The number of protons for a given element is called the atomic number, symbol Z. Since atoms of an element all have the same number of protons, they all have the same atomic number. For example, all carbon atoms have 6 protons; all gold atoms have 79 protons. It is the atomic number that makes carbon so different in its properties from gold. We indicate the atomic number of an element by writing the atomic number as a subscript before the symbol of the element, for example carbon ${}_{6}C$ and gold ${}_{79}Au$.

The number of electrons in these atoms is always the same as the number of protons, as the atom is neutral. For example, all carbon atoms have 6 protons and 6 electrons; all gold atoms have 79 protons and 79 electrons.

DIAGRAM 02:



• **Suggested Film**
  - **– What Is An Atom?**
  - **– Heavy Water**

• Are all the atoms of a specific element the same?

There are over 100 elements, but there are many more different types of atoms. This is because there can be some atoms of an element that have the same number of protons, but different numbers of neutrons: we call these atoms isotopes. Isotopes have different numbers of neutrons, but the same numbers of protons. They have very similar chemical properties but have different masses, so some properties of the different isotopes, such as density, are different.

We can specify which isotope we are talking about by giving its mass number. The mass number is defined as (number of protons + number of neutrons), symbol A. We do not include the number of electrons in the mass number because electrons have so little mass compared with the other two subatomic particles.

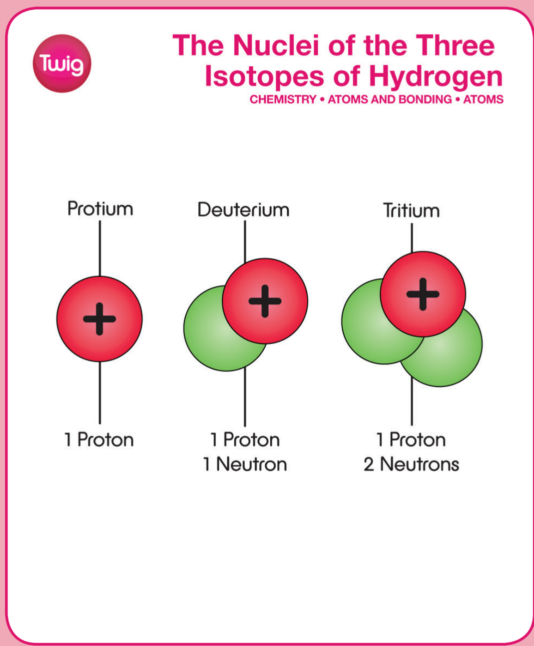
If the nucleus of a carbon atom contains 6 protons and 6 neutrons, the mass number of the atom is 6 + 6 = 12. We write the mass number as a superscript before the symbol of the element, for example $^{12}_{6}C$. We call this isotope carbon-12.

For example, there are three isotopes of hydrogen: hydrogen-1 (protium) $^{1}_{1}H$, hydrogen-2(deuterium) $^{2}_{1}H$, and hydrogen-3 (tritium) $^{3}_{1}H$. Hydrogen-1 is the most important isotope of hydrogen.

• Suggested Activity

– Ask students to research the use of some important isotopes, such as carbon-14 (carbon dating), americium-241 (smoke detector), cobalt-60 (food irradiation)

DIAGRAM 03:



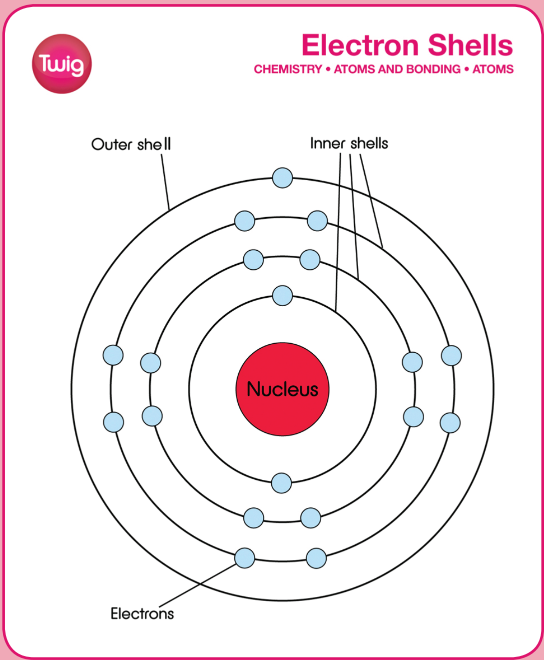
• How are the electrons arranged within an atom?

Scientists use models as pictures to describe and explain what they observe. When they gather more evidence they may have to change their model, so that this new model is a better explanation of their observations.

In the model proposed by Niels Bohr in 1913, electrons orbit the nucleus in regions of space known as electron shells. There can be a number of shells depending on how many electrons must orbit the nucleus, each of these shells has a particular energy level; the closer the shell is to the nucleus, the lower its energy level, the further the shell is to the nucleus, the higher its energy level.

As you go further from the nucleus, the shells are larger and so can hold more electrons. You can think of the shells a bit like the rings which are made when you cut open an onion.

DIAGRAM 04:



The maximum number of electrons in each shell is

- 1st shell: 2 electrons
- 2nd shell: 8 electrons
- 3rd shell: 8 electrons
- 4th shell: 18 electrons

In fact, this is a simplification, and the 3rd shell can hold up to 18 electrons, and the 4th shell up to 32 electrons, but these shells do not fill up in a simple way. We can understand the electron configurations of the elements, from hydrogen to calcium, by using this simplified version of the shell structures above.

Electrons tend to fill lower energy shells first. For example, lithium has atomic number 3, so lithium atoms all have 3 electrons. Two electrons go into the first shell, leaving one for the second shell or outer shell. We can write this configuration as 2,1. The comma separates one shell from the next shell.

• Suggested Films

– Atom Structure: Electron Shells
– Flame Colours and Fireworks
– Northern Lights
– FactPack: Structure of the Atom

Extension Question

Q2. What can we use the noble gases for?

Helium has a very low density but (unlike hydrogen gas) it does not burn, so it is used in balloons. At low pressures, the noble gases glow when electricity is passed through them, and this property is used in neon signs for advertisements. Argon is used when an inert atmosphere is needed, for example in light bulbs with tungsten filaments or in making titanium. Several noble gases are used in lasers. Xenon has been found useful as an anaesthetic.

• How do we know that electrons exist in discrete shells?

There are two main pieces of evidence. One is that the emission spectra of elements show a series of lines at different frequencies or colours. These lines can be interpreted as caused by electrons jumping from a higher energy level to a lower energy level, emitting a specific colour or frequency of light as they do so. A mathematical model of the atom, using these ideas, gives very good agreement with the experimental results. The other piece of evidence comes from studying the energy needed to pull an electron away from an atom, known as the ionisation energy. As successive electrons are pulled away, we can deduce the energy levels of each electron. This pattern shows that the electrons exist in discrete shells.

• Suggested Films

– Flames and Spectroscopy
– Atom Structure: Electron Shells

Extension Question

Q3. What do electrons have to do with the Northern Lights?

The Sun emits high energy particles, known as the solar wind. When these particles hit our atmosphere, the atoms in the atmosphere, such as oxygen and nitrogen, gain energy and their electrons move to higher energy levels. As the electrons fall back to lower energy levels, light is emitted. It is this light which we see as the Northern Lights.

Section 3: Behaviour of Atoms

• Why do different atoms behave differently?

Different atoms have different properties because of their different structures. Chemical properties of atoms, such as how they react with other atoms, is mainly decided by the number of protons and electrons each atom has. Physical behaviour, such as its density, is affected by the combination of protons, electrons and neutrons an atom has.

• Suggested Film

– What Is An Atom?

• Why do electrons affect the chemical behaviour of an atom?

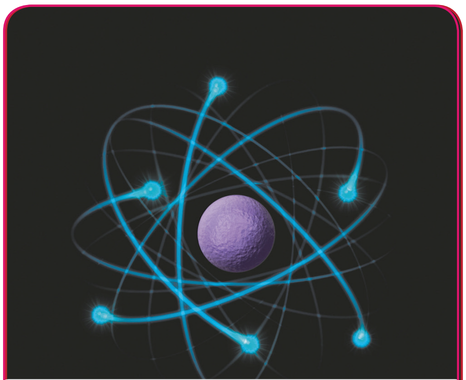
The most stable arrangement of electrons in an atom is when all the electron shells present in an atom are full. It is then very difficult to remove an electron from the atom, as it takes a great deal of energy to disrupt a full shell of electrons. Atoms react in order to achieve this very stable configuration.

All the atoms of the noble gases (Group 8 or Group 0) behave in similar ways because they all have a full outer shell. The atoms of the noble gases (helium, neon, argon) all have this very stable arrangement of electrons, so they are generally not very reactive with other elements, although some do form compounds. This arrangement of electrons is what defines these gases as ‘noble’.

Similarly, the atoms of the elements in Group 1 only have 1 electron in their outer shell, and tend to react in similar ways. This pattern is very useful to chemists in predicting the behaviour and reactivity of elements.

• Suggested Film

– Atom Structure: Electron Shells



The most stable arrangement of electrons in an atom is when all the electron shells are full

• Quizzes

What Is An Atom?

Basic

• What is made of atoms?

A – all matter

B – liquids

C – gases

D – solids

• The subatomic particles in an atom are usually

A – protons and neutrons

B – protons and electrons

C – protons, neutrons and electrons

D – neutrons and electrons

• The nucleus usually contains

A – electrons

B – protons and neutrons

C – neutrons

D – neutrons and electrons

• An atom with 8 protons is an atom of

A – hydrogen

B – gold

C – copper

D – oxygen

Advanced

• 99% of the mass of the atom is in the

A – electrons

B – neutrons

C – protons

D – nucleus

• The number of protons in an atom is always equal to the

A – number of neutrons

B – number of electrons

C – number of electrons + number of neutrons

D – number of electrons - number of neutrons

• The atomic number is the

A – number of protons

B – number of neutrons

C – number of electrons

D – number of electrons - number of neutrons

• The unique identity of an atom of a specific element is decided by the

A – size of its nucleus

B – mass of its nucleus

C – number of protons in its nucleus

D – number of neutrons in its nucleus

Electron Shells

Basic

• The nucleus is

A – about the same size as the atom

B – about half the mass of the atom

C – very much smaller than the atom

D – very much lighter than the atom

• What is the maximum number of electrons in the first electron shell?

A – 1

B – 2

C – 8

D – 18

• How many electrons are there in the outer shell of a sodium atom?

A – 1

B – 2

C – 8

D – 18

• How many electrons are there in the outer shell of a fluorine atom?

A – 1

B – 2

C – 7

D – 9

Advanced

• The chemical behaviour of an atom depends on

A – the number of electrons in the first shell

B – the number of neutrons + number of protons

C – the mass of the nucleus

D – the number of electrons in the outer shell

• If an atom X has 12 electrons, how many electrons will there be in its outer shell?

A – 1

B – 2

C – 8

D – 10

• If an atom of element Y has 6 outer electrons in its second (outer) shell, how many MORE electrons does an atom of Y need in order to have a full outer shell?

A – 1

B – 2

C – 6

D – 8

• If an atom of an element Z has 7 outer electrons, which of these elements will be most similar to Z in its chemical behaviour?

A – sodium

B – fluorine

C – potassium

D – neon

• Answers

What Is An Atom?

Basic

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- **A – all matter**
- B – liquids
- C – gases
- D – solids

• The subatomic particles in an atom are usually

- A – protons and neutrons
- B – protons and electrons
- **C – protons, neutrons and electrons**
- D – neutrons and electrons

• The nucleus usually contains

- A – electrons
- **B – protons and neutrons**
- C – neutrons
- D – neutrons and electrons

• An atom with 8 protons is an atom of

- A – hydrogen
- B – gold
- C – copper
- **D – oxygen**

Advanced

• 99% of the mass of the atom is in the

- A – electrons
- B – neutrons
- C – protons
- **D – nucleus**

• The number of protons in an atom is always equal to the

- A – number of neutrons
- **B – number of electrons**
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- A – size of its nucleus
- B – mass of its nucleus
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Basic

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Advanced

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B – the number of neutrons + number of protons

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B – 2

C – 6

D – 8

• If an atom of an element Z has 7 outer electrons, which of these elements will be most similar to Z in its chemical behaviour?

A – sodium

B – fluorine

C – potassium

D – neon