Atoms and particles

Molecules are the essential building blocks of life. Without water molecules, life on Earth would not exist. All living organisms need protein molecules for structure and function. Therefore an understanding of how atoms combine to form molecules is key to understanding the origins of life. In your class Download instructions, a grid and prompt cards to play atoms, molecules and ions 4-in-a-line as MS Word or pdf. Download instructions, a grid and prompt cards to play atoms, molecules and ions 4-in-a-line from the Education in Chemistry website: rsc.li/2WayTn8 What students need to know Atoms, molecules and ions are all examples of particles that students might meet at 11–14. But these terms are often used incorrectly in the media and everyday language leading to students of all ages being confused as to which is the correct term to use. Students should understand that: Particles can be atoms, molecules or ions. Atoms are single neutral particles. Molecules are neutral particles made of two or more atoms bonded together. An ion is a positively or negatively charged particle. Ideas for your classroom The idea of the world being made of tiny particles is an ancient one. You could start the exploration of atoms with the ideas of Democratus (400 BC), who believed that all matter in the universe was made up of tiny, indivisible, solid objects. He called these objects atoma or 'indivisible units'. At the start of the 19th century Dalton found evidence to support Democratus' theory and proposed atoms to be solid spheres. Different spheres made up the different elements. One of the key problems for students learning about atoms, is that atoms are small. Really, really small. This makes it difficult for students to conceptualise atoms as they cannot be seen, or touched, or investigated directly. A good starting point to introduce atoms and illustrate their small size is to ask students to break up a piece of graphite (the element carbon) into as many small pieces as they can. No matter how many pieces the students break the graphite into, they will never get a single carbon atom. You can challenge higher attaining students to measure the size of an individual atom using this experiment from Practical physics. One of the key problems for students learning about atoms, is that atoms are small. Really, really small. This makes it difficult for students to conceptualise atoms as they cannot be seen, or touched, or investigated directly. A good starting point to introduce atoms and illustrate their small size is to ask students to break up a piece of graphite (the element carbon) into as many small pieces as they can. No matter how many pieces the students break the graphite into, they will never get a single carbon atom. You can challenge higher attaining students to measure the size of an individual atom using this experiment from Practical physics (bit.ly/2Km5cgt). When atoms combine, molecules are formed. For a few elements, when atoms of that element combine, a molecule of that element is formed eg H_2 and O_2. When atoms of some different elements combine, a molecule of a compound can form, eg H_2O. How to teach elements and compounds, in the 11–14 series, describes different strategies for teaching elements and compounds and the common misconceptions students may hold. When atoms combine, molecules are formed. For a few elements, when atoms of that element combine, a molecule of that element is formed eg H_2 and O_2. When atoms of some different elements combine, a molecule of a compound can form, eg H_2O. How to teach elements and compounds (rsc.li/2W6MKut), in the 11–14 series, describes different strategies for teaching elements and compounds and the common misconceptions students may hold. Particle diagrams can be used to help the students visualise the difference between an atom, a molecule of an element and a molecule of a compound. In fact even Dalton in the 1800s proposed a series of diagrams to represent the elements and compounds known at the time. Use of colour helps to distinguish between the atom types further. Venn diagrams help students organise their understanding of the different particle types, as described in Atoms, elements, molecules, compounds and mixtures. Particle diagrams can be used to help the students visualise the difference between an atom, a molecule of an element and a molecule of a compound. In fact even Dalton in the 1800s proposed a series of diagrams to represent the elements and compounds known at the time (Figure 1). Use of colour helps to distinguish between the atom types further. Venn diagrams help students organise their understanding of the different particle types, as described in Atoms, elements, molecules, compounds and mixtures (rsc.li/2wzLsxS). An atom or a molecule can lose or gain electron(s) to form an ion. At this level students only need to know that an ion is a positively or negatively charged particle. However it may be worth introducing students to the electron at this point. When an atom/molecule gains negatively charged electron(s), a negative ion is formed. When an atom/molecule loses negatively charged electron(s), a positive ion is formed. This latter point is something students often struggle with later on in their studies. Introducing the electron now, before students meet the other sub-atomic particles, can help to embed the idea that the loss of electrons results in a positively charged ion, and may help reduce confusion later on. Owing to the interweaving of the terms atom, ion and molecule when describing the different particles, it is unsurprising that students get confused. Using games and an element of competition can be helpful to bring some variety to the necessary student practice. One such game is based on the classic Connect 4 game. You can download instructions, an example grid and game cards below. Common misconceptions As the students develop their understanding of chemical bonding further, it is common for students to refer to ionic compounds as molecules or to refer to intermolecular forces when explaining properties of ionic compounds. To avoid these misconceptions, it is important to introduce, and emphasise, the correct use of the terms ion and molecule from early on in a student's chemical studies. A molecule is a neutral particle, composed of a set number of atoms bonded together. The particle of the substance is the molecule, rather than the atoms that make up the molecule. By contrast, ionic compounds are made up of an indeterminate number of ions, in a fixed ratio. The particle of the ionic substance remains the ion. Using hands-on models can help students with these tricky concepts – eg TIMSTAR MO84200 for molecules and Molymod MKO-127-27 for ionic structures. You can further explore the use of chemical models and their limitations in Using molecular models and in the 7 simple rules to for science teaching series. A molecule is a neutral particle, composed of a set number of atoms bonded together. The particle of the substance is the molecule, rather than the atoms that make up the molecule. By contrast, ionic compounds are made up of an indeterminate number of ions, in a fixed ratio. The particle of the ionic substance remains the ion. Using hands-on models can help students with these tricky concepts – eg TIMSTAR MO84200 for molecules and Molymod MKO-127-27 for ionic structures. You can further explore the use of chemical models and their limitations in Using molecular models (rsc.li/2wAsOpA) and in the 7 simple rules to for science teaching series (rsc.li/2XmwHKr). Other misconceptions students may hold are discussed in Beyond appearances: Students misconceptions about basic chemical ideas (rsc.li/2WBsd5L), including that atoms share the properties of the bulk material and that molecules have different properties in different states. Progression to 14–16 At 14–16, students are introduced to sub-atomic particles and how these define the nature of atoms and ions. Students then go on to study the difference between the nature of the forces that exist between atoms, molecules and ions, which they use to explain the physical properties of ionic and covalent compounds. The resource, Why do atoms form ions allows students to assess their understanding of atoms, ions and ionic compounds and enables the teacher to identify any misconceptions. The resource, Why do atoms form ions (rsc.li/2Kptsyq) allows students to assess their understanding of atoms, ions and ionic compounds and enables the teacher to identify any misconceptions. Take-home points Particles can be atoms, molecules or ions. The term molecule is often used incorrectly to refer to any type of chemical compound. A molecule is a neutral particle made of two or more atoms bonded together. Take care with your own language, especially when referring to compounds formed during chemical reactions. Make the distinction between each particle type explicit. Give students the opportunity to organise their understanding of the different particle types with Venn diagrams. A good understanding of the different particle types will help students when they study structure and bonding at 14–16. The properties of elements and compounds are determined by their structures. The simplest structural unit of an element is an atom. Atoms are very small. A hundred million (100,000,000) hydrogen atoms put side-by-side is only as long as one centimeter! Some elements are monatomic, meaning they are made of a single (mon-) atom (-atomic) in their molecular form. Helium (He, see Fig. 2.8) is an example of a monatomic element. Other elements contain two or more atoms in their molecular form (Fig. 2.8). Hydrogen (H_2), oxygen (O_2), and chlorine (Cl_2) molecules, for example, each contains two atoms. Another form of oxygen, ozone (O_3), has three atoms, and sulfur (S_8) has eight atoms. All elemental molecules are made of atoms of a single element. Molecules of compounds have atoms of two or more different elements. For example, water (H_2O) has three atoms, two hydrogen (H) atoms and one oxygen (O) atom. Methane (CH_4), a common greenhouse gas, has five atoms, one of carbon (C) and four of hydrogen (H, see Fig. 2.9). Electrostatic Forces Electrostatic forces hold atoms in molecules. The electrostatic forces that hold atoms together in molecules are the same type of forces that cause static electricity. Common examples of static electricity are when someone gets a shock when reaching for a doorknob or when a child's hair is raised when going down a plastic slide (Fig. 2.10). Activity Determine how charged matter interacts. Parts of Atoms The particles that make up an atom are called subatomic particles (sub- means "smaller size"). These particles are the proton (p+), which is positively (+) charged; electron (e–), which is negatively (–) charged; and neutron (n0), which has no charge, it is neutral (0). Protons and neutrons occupy the nucleus, or center, of the atom. Electrons exist in regions called shells outside of the atom's nucleus (Fig. 2.11). Electrostatic forces hold atoms together in molecules—like the two hydrogen atoms held together in H_2 gas. Electrostatic forces also hold electrons and protons together in the atom. The attraction between negatively charged electrons and positively charged protons in an atom give the atom its structure. The strong force holds neutrons and protons together in the nucleus. This force got its name because it is strong enough to overcome the force of the positively charged protons repelling each other. The number of electrons and protons in an atom determines its chemical properties. Chemical properties include the specific ways that atoms and molecules react and the energy that they release or use in these reactions. Size of Subatomic Particles One hundred million (100,000,000) hydrogen atoms put side-by-side equals about a centimeter. Protons and neutrons are both about one-thousandth (1/1000) the diameter of a hydrogen atom. This means it would take about one hundred billion (100,000,000,000) protons or neutrons put side-by-side to equal a centimeter. Electrons are about one-thousandth (1/1000) the diameter of a proton or neutron. This means that it would take one hundred trillion (100,000,000,000,000) electrons put side-by-side to equal a centimeter! Neutral Atoms The subatomic particles in an atom determine the properties of the atom. Some atoms exist naturally as neutral, or uncharged, atoms. A single uncharged atom has an equal number of protons (+) and electrons (–). An uncharged atom is electrically neutral because electrons and protons have opposite charges of equal sizes. When the number of protons and electrons in an atom are same, the charges cancel out, or counteract each other. Protons and Neutrons Every atom of a particular element has the same number of protons. The atomic number is equal to the number of protons in an element. On the periodic table, the atomic number is usually given as the whole number above the symbol for the element (see Fig. 2.13). For example, hydrogen (H) has an atomic number of one (1). This means a hydrogen atom has one proton. If a hydrogen atom is neutral, it must also have one electron. An oxygen atom (O) has an atomic number of eight (8). This means a neutral oxygen atom has eight protons and eight electrons. The element Actium (Ac) has an atomic number of 89, so it has 89 protons and 89 electrons in a neutral atom. Table 2.2 shows the atomic number, atomic symbol, atomic structure, and number of protons, neutrons, and electrons for the first three elements. Table 2.2. The first three elements in the periodic table showing atomic numbers, atomic symbols, number of protons, number of electrons, number of neutrons, and atomic structure. Hydrogen Helium Lithium Atomic Number 1 2 3 Atomic Symbol H He Li Number of Protons 1 2 3 Number of Electrons 1 2 3 Number of Neutrons 0 2 4 Atomic Structure Neutrons affect the mass of an atom and play a role in the stability of atoms. Unlike protons, the numbers of neutrons in elements varies. For example, most hydrogen atoms have no neutrons, but a few have one neutron, and some rare hydrogen atoms have two neutrons. Most helium atoms have two neutrons, but some have three neutrons. Periods, Groups, and the Periodic Table The periodic table (Fig. 2.12) is a commonly used method of organizing the elements that provides useful information about the elements and their behavior. In Fig. 2.12, elements in blue are metals and elements in yellow are nonmetals. In Figure 2.13, the entry for hydrogen highlights the placement of the atomic number, element symbol, element name, and atomic weight. The periodic table has three prominent features. First, the periodic table is arranged in horizontal rows, which are called periods. There are seven periods. In Period 1 there are two elements, hydrogen (H) and helium (He). The second and third periods both contain eight elements, the fourth and fifth periods contain 18 elements, and the sixth and seventh periods contain 32 elements. Second, all of the elements are listed sequentially according to their atomic numbers. The atomic number corresponds to the number of protons and is found above the elements' symbol. For example, in Figure 2.13, the atomic number of hydrogen is 1, found over the H. Third, the periodic table is arranged in columns of elements that react similarly. These columns are called groups. The group number is found at the top of the column. Groups 1–12 contain only metals, Groups 13–16 contain both metals and nonmetals, and Groups 17 and 18 contain only nonmetals. One exception is hydrogen. Although technically a nonmetal, hydrogen has properties of both metals and nonmetals and is often placed in Group 1. The two long rows that are at the bottom of the periodic table are exceptions. The elements in each of these rows behave similarly, so are considered groups. These two groups are arranged in rows rather than columns. Metals and Nonmetals Metals are elements that conduct heat and electricity. Metals are usually malleable, they can be bent or molded without breaking, and lustrous, or shiny. Most metals are silvery in color (Fig. 2.14 A–C), although some are not, like copper (Cu, Fig. 2.14 D). Most metals are solid at room temperature. One exception is mercury (Hg), which is a liquid at room temperature (Fig. 2.14 A). The elements in Group 1, including lithium (Li), sodium (Na, Fig. 2.14 B), potassium (K, Fig. 2.14 C), and rubidium (Rb), are all metals. These metallic Group 1 elements have similar reactive properties. In Fig 2.12, the metals are shown in blue. Nonmetals are poor conductors of heat and electricity; they are not lustrous and exist in nature as solids, liquids, or gases. When solid, non-metals tend to be brittle, such as sulfur, which flakes apart rather than bending like a metal would (Fig. 2.15 A). The elements in Group 17, including fluorine (F_2), chlorine (Cl_2, Fig. 2.15 B), bromine (Br_2, Fig. 2.15 C), and iodine (I_2, Fig. 2.15 D), are all nonmetals. The nonmetals in Group 17 are all diatomic (two atoms) in their elemental form and have similar reactive properties. In Fig 2.12, the nonmetals are shown in yellow. See Table 2.3 for a summary of the properties of metals and nonmetals. Table 2.3. Properties of metals and nonmetals Metals Nonmetals Physical Properties Good conductor of heat and electricity Poor conductor of heat and electricity Malleable - can be beaten or deformed without cracking; pliable Brittle Ductile - can be made into wire Non-ductile Lustrous Not lustrous, may be opaque or transparent Solid at room temperature (except Hg and a few other metals that are liquid at or near room temperature) Solid, liquid, or gas at room temperature Chemical Properties Usually have 1-3 valence electrons Usually have 4-8 valence electrons Tend to lose valence electrons Tend to gain electrons Other Organizational Features of the Periodic Table There are other organizational features of the periodic table. Most periods have the first element of the period in Group 1 and the last element in Group 18. An exception is the first period. In Fig 2.12, hydrogen (H) is in Group 1. Sometimes hydrogen (H) is placed in Group 17, above fluorine (F), because it has similar properties to the nonmetals in that group; for example, in its elemental state hydrogen exists as a diatomic gas, H_2. Sometimes hydrogen is placed in both Groups 1 and 17. Groups of elements have similar properties. The properties of some groups are so unique or important that the groups are referred to by special names. The last group, Group 18, includes helium (He), neon (Ne), argon (Ar), krypton (Kr), xenon (Xe), and radon (Rn). The elements in this group are called the noble gases. Noble gases seldom react with other elements. Noble gases have many uses, for example, they are used in neon signs (Fig 2.16). Group 1 is often referred to as the alkali metals, Group 2 as the alkaline earth metals, and Group 17 as the halogens. The two groups that are pulled out on the bottom of the periodic table in rows are called the lanthanide rare earth series (top row) and the actinide series (bottom row).