

**EVALUATING  
ACADEMIC READINESS  
FOR APPRENTICESHIP TRAINING**  
Revised for  
**ACCESS TO APPRENTICESHIP**

**SCIENCE SKILLS  
BASIC ATOMIC STRUCTURE AND THEORY**

**AN ACADEMIC SKILLS MANUAL  
The Construction Trades: Mechanical Systems**

This trade group includes the following trades:  
Electrician (Construction, Maintenance & Industrial),  
Network Cabling Specialist, Plumber,  
Refrigeration & Air Conditioning Mechanic,  
Sprinkler & Fire Protection, and Steamfitter

*Workplace Support Services Branch  
Ontario Ministry of Training, Colleges and Universities*

*Revised 2011*

In preparing these Academic Skills Manuals we have used passages, diagrams and questions similar to those an apprentice might find in a text, guide or trade manual.

**This trade related material is not intended to instruct you in your trade. It is used only to demonstrate how understanding an academic skill will help you find and use the information you need.**

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# SCIENCE SKILLS

## BASIC ATOMIC STRUCTURE AND THEORY

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*An academic skill required for the study of the  
Construction Trades: Mechanical*

### **INTRODUCTION**

Hey, did you hear about the two atoms that went to the movies? As they were coming out of the theatre, one of the atoms said to the other, “*I think I forgot an electron back at my seat.*” The second atom said, “*Are you sure?*” The first atom answered, “*Yes, I’m positive.*”

If you didn’t get the punch line to the joke, it will be obvious by the time you finish reading this skill manual about atoms.

### **Importance of atomic structure**

Matter is made up of basic building blocks called atoms. Atoms are very small particles with a specific organization and design. Atoms bond together with other atoms to form all the materials found on earth. Different materials look and behave the way they do because of their underlying atomic structure.

Atomic theory explains how different atoms join together to form all matter, including the products used in the mechanical construction trades. Knowing about the underlying atomic structure of the substances you use at work assists you in recognizing their physical and chemical characteristics, helping you work efficiently and safely.

The development of mechanical structures advanced as technicians learned more about the organization of atoms. They used their knowledge of atomic structure to develop electrical circuits. Further understanding of the atom led to the production of electronic components.

Basic atomic theory provides the background needed to understand complex mechanical arrangements such as electrical and electronic circuits. The theory explains how materials such as metals conduct an electric current.

This skill manual covers basic atomic structure, including:

- ◆ Basic structure of an atom
- ◆ Elements
- ◆ Electrical charges
- ◆ Bonding between atoms
- ◆ Compounds

## BASIC STRUCTURE OF AN ATOM

### Subatomic particles

All matter is made of atoms. Atoms are very small particles with a specific organization and design. The atom is not actually a solid particle. It is made up of several different, smaller parts called *subatomic particles*. The main subatomic particles are the **proton**, the **neutron** and the **electron**. Figure 1 shows the subatomic particles that form an atom and where they are located. Notice that there is a lot of empty space within an atom.

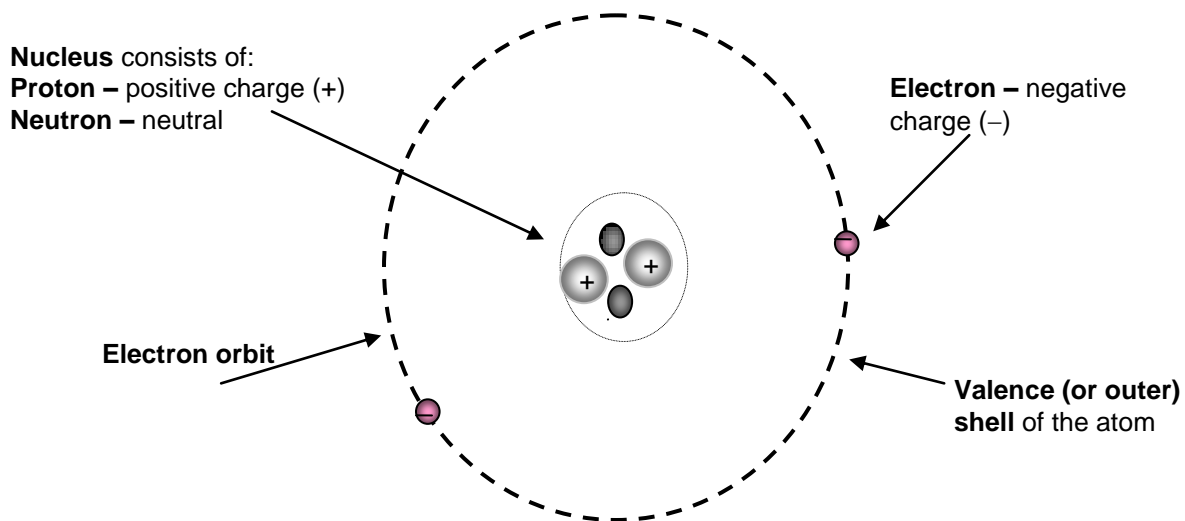


FIGURE 1: Basic Atomic Structure

Atoms are made of two main parts. The compact center of an atom is called the **nucleus**. Circling the nucleus are **orbits** or **shells** where the electrons are found. Both the nucleus and the shells contain smaller *sub-atomic particles*. The number and arrangement of these subatomic particles give each type of atom its distinctive qualities.

The nucleus, the small heavy centre of the atom, contains two main particles.

- ◆ **Protons and neutrons** are located in the nucleus.
  - The number of protons determines the kind of atom that is formed.

The **orbits** or shells surround the nucleus.

- ◆ Each shell contains one or more **electrons**.
  - Electrons are very small light particles that travel within a shell.
  - The outside shell, called the **valence shell**, is the most active.

The **number** of protons and electrons in each atom determine its characteristics.

- ◆ There are usually has the same number of protons as there are electrons in an atom.
- ◆ However, an atom can gain or lose electrons in certain circumstances.

### Charges on protons and electrons

- ◆ Protons and electrons have a very important property called **charge**.
  - Protons and electrons have different types of charge.
    - Protons have **positive** charge.
    - Electrons have **negative** charge.
- ◆ The charges on electrons and protons are responsible for much of the underlying **structure** of matter.

### The Nucleus

The **nucleus**, or the centre of the atom, consists of two types of particles, the proton and the neutron. Strong nuclear forces hold them together, preventing the protons from leaving the nucleus.

- ◆ The number of protons in an atom is usually the same as the number of neutrons.
- ◆ Each proton has one positive charge.
- ◆ The neutron has no charge and is considered neutral.

### Electron shells and electrons

One or more electron shells, or **energy levels**, surround the nucleus of an atom. Electrons in these shells orbit the nucleus of the atom. The area occupied by the electron shells and their electrons **forms the physical space an atom occupies** and gives the atom its distinct, indivisible nature.

Each shell can hold only a certain, **specific number of electrons before it is full**.

- ◆ There is a maximum number of electrons each shell can hold. There are:
  - **Two** in the first shell,
  - **Eight** in the second shell,
  - **Eighteen** in the third shell, etc.
- ◆ The outer shell of an atom is the most active. It is called the **valence shell**.

The outer or valence shell of an atom is the most important in determining how an atom will interact with other atoms.

- ◆ A few atoms have filled outer shells (two, eight, eighteen electrons, etc) but most do not.
- ◆ An atom is **more stable when its outermost shell is full**.
- ◆ To gain the stability of a full outer shell, an atom might give away or accept electrons, or share them. Thus, **the number of electrons in an atom can vary**.
- ◆ This is important both for the way **atoms bond together** to form molecules and for the way **electrical charges develop**.

Electrons are held in their orbit around the nucleus by the electrical attraction between electrons and protons that results from the fact that **they have different charges**.

- ◆ The attraction between electrons and protons is weaker than the force that holds protons and neutrons together in the nucleus.
- ◆ The force that holds electrons close to the nucleus can be broken, allowing the electrons in the outer valence shells to be shared with or given to other atoms.

## Different kinds of atoms

Each kind of atom has a specific number of subatomic particles. Thus, the number of protons, neutrons and electrons varies in each particular kind of atom.

- Look back at Figure 1. The atom shown here has two protons, two neutrons and (usually) two electrons. This is a helium atom.
- A carbon atom has six protons, six neutrons and six electrons.
- An oxygen atom has eight of each subatomic particle, while a silicon atom has fourteen.

The number of protons and electrons an atom has is very important.

- ◆ This number determines what kind of atom is formed and how it will behave.
- ◆ Under certain conditions, the number of electrons in an atom may vary.
- ◆ But, the number of protons in any specific type of atom remains constant.
- ◆ ***The number of protons determines what type of atom is formed.***
- ◆ Because the number of protons in an atom is so important, it is called the ***atomic number***.

There are many different types of atoms – more than a hundred that we know about. Some common types of atoms include hydrogen, oxygen, copper, silicon, nitrogen and aluminum atoms. Each type of atom has a specific, unchanging number of protons. Each type of atom forms a pure substance. These substances are called ***elements***.

## ELEMENTS

Each specific type of atom forms a different ***element***. An element cannot naturally be broken down into other, more simple substances. Each element is a ***pure substance*** made of only one type (of the more than one hundred possible types) of atom.

- Gold is an element - pure gold cannot be broken down any further.
- Salt, or sodium chloride, ***is not*** an element – it can be broken down into separate particles consisting of the elements sodium and chloride. Sodium and chloride ***are*** elements because they cannot be broken down further by physical or chemical means.

Each element looks and behaves differently from any other element. What makes this difference? The answer lies in the structure of each different type of atom.

- ◆ Atoms of each different element have a specific ***atomic number*** and a specific number of protons. This number differs in every element.

***The atomic number and the number of electrons*** in any atom determine the following:

- ◆ The structure of the atom, including the number of electrons.
- ◆ The way the atom interacts with other atoms.
- ◆ The way the atom reacts to changes in the environment.

Every different element is made up of a different, unique type of atom, so every element has different characteristics.

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## Periodic table

The elements are classified in a chart called the *periodic table*. The periodic table lists the known elements in order according to the unique structure of the atoms which form each element. The table lists all the different elements in columns and rows. There is much information encoded in the arrangement of elements in the periodic table.

Elements are listed in order by their increasing atomic number in the periodic table.

**Example:** Hydrogen, the smallest element with one proton and one electron, is the first element listed in the periodic table.

**Example:** The next element on the table is helium, which has two protons and two electrons. A helium atom has a completely filled the first shell, which holds two electrons when full.

**Example:** The next element in the table, lithium, has three protons and three electrons.

- Its first shell is filled with two electrons, so its third electron is in the next, or second, shell.
- This second shell is full when it has eight electrons.
  - Since the lithium atom has only one electron in that shell, it tends to give away this lone electron so that it has a filled outer shell of two electrons.

**Note:** *When an element loses electrons to get a full outer shell, the number of shells it normally has will be reduced by one.*

Elements that have characteristics in common, such as similar metals or the inert gases, are associated in columns. There is an association between the number of electrons in the outer shell of an element and the column it appears in.

**Example:** Carbon and silicon are in the same column. Both are very common elements.

- Each has 4 electrons in their outer shells so they both react easily with other elements to form compounds.
- Carbon compounds form the basic materials of living organisms.
- Silicon joins with oxygen to form quartz, the most abundant mineral in surface rocks.

## Metals

Elements like lithium that have only a few electrons in their outermost shell are called *metals*. Many elements on the surface of the earth are metals. They include copper, aluminum and iron.

*When only a few electrons fill the outermost shell of an atom, those electrons can easily be dislodged. When many atoms of the same metal join together, they arrange themselves as a closely-spaced, ordered crystal. The outer electrons from each atom are easily dislodged and they are shared by the whole crystal. It is these free-flowing, shared electrons that carry the electrical charge in metal conductors.*

## Non-metals

Non-metallic elements, like oxygen and chlorine, have almost full outer shells. They need only one or two electrons to completely fill their outer shell. *Atoms which need only a few electrons to fill an outer shell readily accept electrons from other atoms such as metals, which have nearly empty outer shells.*

Elements such as carbon and silicon, which have half full outer shells, readily give away, accept or share electrons to get full outer shells. This is one reason they react so readily with other elements.

- ◆ This tendency to share, give away or accept electrons enables atoms to bond with other atoms.
- ◆ These bonded atoms come together to create all the complex substances found on earth.

### In brief:

- ◆ The atom consists of two parts:
  - an inner nucleus which contains protons and neutrons, and,
  - outer electron shells which contain the fast moving electrons that orbit the nucleus.
- ◆ The number of protons, called the atomic number, determines what element an atom forms.
- ◆ The number of protons is usually the same as the number of electrons.
- ◆ Forces holding neutrons and protons together in the nucleus are very strong; the forces holding electrons to the nucleus are much weaker.
- ◆ An atom is more stable when its outer electron shell is filled with the maximum number of electrons for that shell.
- ◆ Atoms can share, give away or accept electrons to obtain a filled outer shell.
- ◆ This exchange of electrons leads atoms to bond together.

Before looking at how bonds are formed, we will look at the properties of electrical charge.

## ***ELECTRICAL CHARGE***

Recall that a force is something that exerts a push or pull on an object. If the object is not held in place, it moves as a result of the applied force. Electrons and protons exert a force of ***attraction or repulsion*** on other electrons and protons. This force is called an ***electrical force or charge***.

- ◆ Similar particles, either two protons or two electrons, feel a force that pushes them apart.
- ◆ Dissimilar particles, a proton and an electron, feel a force that pulls them together.
- ◆ In other words, protons and electrons feel a force of attraction to each other. Electrons are repelled by other electrons. Protons are repelled by other protons.

An electrical force is similar to a magnetic force. The south and north poles of a magnet are attracted to each other and will be pulled together when they are brought near each other. Two magnetic south or north poles will push apart when they are near each other.

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## Charges on electrons and protons

Forces of attraction and repulsion exist between subatomic particles because protons and electrons have a different kind of charge.

- ◆ Protons have a **positive charge**; a positive charge is indicated by the symbol +.
- ◆ Electrons have a charge called a **negative charge**; a negative charge is indicated by the symbol -. These symbols are used in Figure 1.
- ◆ Neutrons have no charge.

In the atom, opposites attract:

- ◆ Protons, with their positive charge, are attracted to electrons, with their negative charge.
- ◆ Electrons, with their negative charge, are attracted to protons, with their positive charge.

In the atom, like charges repel:

- ◆ Protons repel or push away other protons.
- ◆ Electrons repel other electrons.

This is summed up by the saying: ***opposite charges attract and like charges repel.***

The forces of attraction and repulsion keep all the subatomic particles in their places and give the atom its size, shape and special characteristics.

- ◆ Electrons are kept from flying out of their orbits by *their attraction to the protons* in the nucleus.
- ◆ At the same time, the *electrons repel each other*, which causes them to spread as far apart from each other as possible in their orbits around the outside of the atom.

Because protons are held tightly in the nucleus by atomic forces and are not free to move, ***only the movement of electrons can give an atom a charge.***

- ◆ If an atom **gains** electrons, it has a **negative charge**.
- ◆ If it **loses** electrons, it has a **positive charge**.

So a negative charge comes from gaining extra electrons, while a positive charge comes from losing electrons.

## Charges on a larger object

When a single atom gains extra electrons, it becomes negatively charged. In the same way, if an object such as a metal plate gains a large number of extra electrons, the whole object becomes negatively charged. On the other hand, if the atoms making up an object lose a large number of electrons, the object becomes positively charged.

If an atom has the **same number** of protons as electrons, the positive and negative charges balance each other, making the atom **neutral** (having no charge). An atom with the same number of electrons and protons is electrically neutral. In the same way, if the negative and positive charges on a large object are balanced, the object is neutral.

## In Brief

### The theory of charge:

- ◆ Each electron has one negative charge; each proton has one positive charge.
- ◆ Like charges repel; unlike charges attract.
- ◆ An extra electron transferred to an atom gives the atom a negative charge of  $-1$ .
- ◆ The loss of an electron gives an atom a positive charge of  $+1$ .
- ◆ An excess or deficiency of electrons determines the charge on a larger object.
  - **More electrons** than protons give a **negative charge**.
  - **Fewer electrons** than protons give a **positive charge**.

## BONDING BETWEEN ATOMS

Atoms of different elements without filled outer shells can share, give away or accept electrons. When atoms exchange electrons, they become joined into more complex structures.

Atoms can bond with other atoms of the same element or, more usually, they join with atoms of different elements. When two or more atoms bond together, they form a **molecule**. Molecules in turn combine to form all the different substances found on earth.

### Different types of bonds

There are three main types of bonds:

- ◆ When atoms or molecules **transfer** electrons, the bonds formed are called **ionic bonds**.
- ◆ When atoms or molecules **share** electrons, **molecular** or **covalent bonds** are formed.
- ◆ When metal atoms share electrons, **metallic bonds** are formed.

Substances on earth usually occur as molecules, not single atoms. This happens because one kind of atom will interact with another kind of atom so that both end up with a more stable, filled outer shell. These interactions result in molecules being formed. These molecules, in turn, often combine with other molecules to form new compounds.

All bonds are formed because of atomic interaction but the type of interaction varies in the three different kinds of bonds. Remember, bonds are formed because:

- ◆ Atoms with filled outer shells are more stable.
- ◆ The outer shell of an atom might lose or gain electrons or share electrons so it can have a filled outer shell.

Now we will outline how the different types of bonds are formed.

### **Ionic bonds**

An ionic bond is formed when an atom donates an electron to a different kind of atom so that both end up with stable, filled outer shells.

- Each of these atoms has now become charged.
- One has more protons than electrons, giving it a positive charge.
- The other has one more electron than protons giving it a negative charge.
- The negatively charged atom (which donated the electron) is attracted to the positively charged atom (which accepted the electron).
- This results in a molecule held together by an ionic bond.

**Covalent bonds:** A covalent bond is formed when atoms share electrons so that each ends up with a stable, filled outer shell.

- The shared electrons hold the atoms together in this more stable arrangement.
- This results in a molecule held together by a covalent bond.

**Metallic bonds:** A metallic bond is formed when atoms of solid metals pack closely together in a stable crystal formation. They release and share their loosely-held outer electrons so they each have filled outer shells.

- The free electrons are shared by all of the now stable atoms and move in a cloud around the outside.
- This results in molecules held together in a metallic bond.

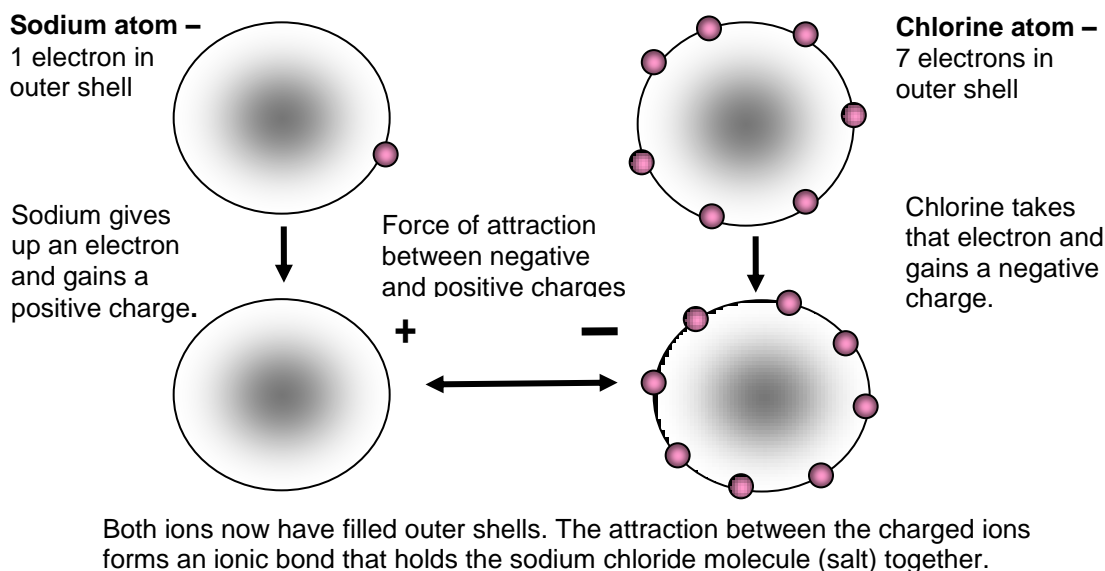
When atoms join together in these different ways, we say they are chemically bonded.

### **Ions**

If an atom or molecule loses electrons, it becomes positively charged. If an atom gains electrons, it becomes negatively charged. Atoms that gain a charge in this way are called *ions*. Ions with opposite charge are attracted to each other.

**Example:** Salt is a compound made of ions. If an atom of sodium loses an electron to an atom of chlorine, the sodium atom gains a positive charge of +1. It is now a charged sodium ion. The chlorine atom gains an electron and a negative charge of -1. It is now a chlorine ion.

The oppositely charged ions are attracted to each other and form ionic bonds. When many such sodium and chlorine ions are joined by ionic bonds, the compound salt is formed. See Figure 2.



**FIGURE 2: Ionic Bond Holding Sodium And Chlorine Atoms Together To Form Salt**

### Molecules

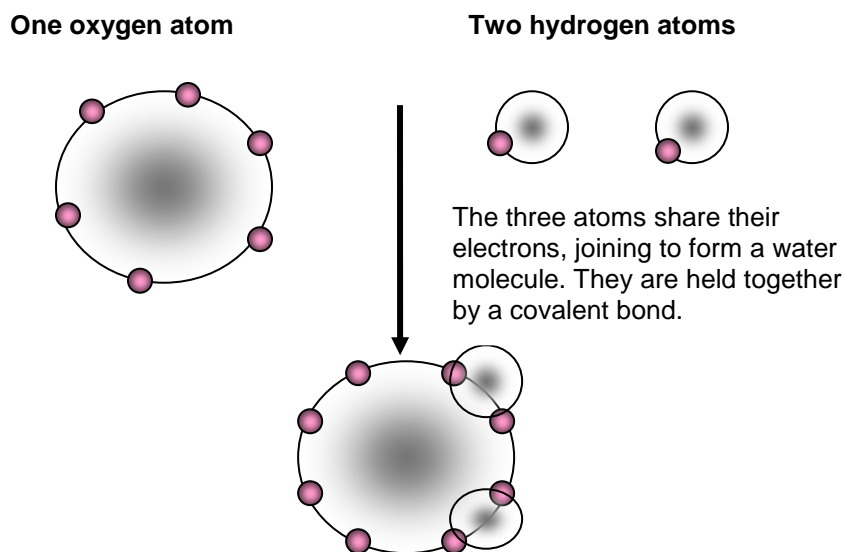
When atoms share electrons, they form a *molecule*. A molecule is held together by a covalent bond. The molecule shares electrons with another atom in the area where the bond is. This area has more electrons than the rest of the molecule. Because of the extra electrons, this area becomes slightly negatively charged. The rest of the molecule has wider spaces between the electrons and now has a slight positive charge.

Although the molecule has areas where charge is unequally distributed, the molecule itself is not a charged particle because the total number of protons still equals the total number of electrons.

The unequal distribution of electrons in the molecule causes areas of greater negative and positive charge. The negative part of one molecule is attracted to the positive part of another, similar molecule. This attraction holds individual molecules together as larger substances.

Molecules can be formed by bonds between similar atoms, or more usually, by bonding between different types of atoms.

- ◆ Oxygen gas is formed from molecules made of only oxygen atoms. To form an oxygen molecule, two oxygen atoms each share two electrons so they both have eight in their outer shell. This gives them both a filled outermost shell.
- ◆ Most molecules are made of combinations of atoms from two or more different elements. For example, two hydrogen atoms and one oxygen atom combine to make a water molecule. The two hydrogen atoms and the one oxygen atom share their outer shell electrons so they each get a filled outer shell. This creates a molecular or covalent bond between the two different elements and a water molecule is formed. See Figure 3.



**FIGURE 3: A Water Molecule**

## Metals

Metal atoms are held together because each atom donates the loosely held electrons in their outer shell. They pack close together in a stable, regularly-arranged crystal. The donated electrons are shared by all the atoms in a free flowing cloud of electrons.

- ◆ When metal atoms share a large number of free electrons, there is a general attraction between all the protons and all the electrons.
  - This force of attraction holds metals together as strong solids.
- ◆ Electrons on the outside of thin wires of metal can move freely. This structure enables metals to be excellent conductors of electricity.
  - Because of this property, metal wire is used to send electrical currents long distances to where it is needed to do electrical work.

## COMPOUNDS

When large numbers of similar molecules bond together, a **compound** is formed. We are aware of about ten million compounds so far, many of them man-made. A compound is formed when numerous molecules of two or more elements **chemically combine** in a definite proportion. The ratio of one element to another in a compound is always the same for that compound.

**Example:** There is always one atom of sodium for every atom of chlorine in a molecule of salt.

**Example:** Water is a common, naturally occurring compound. Each individual water molecule is made from two atoms of the element hydrogen (H) and one atom of the element oxygen (O). We write the name of the water molecule  $H_2O$  using the symbols that represent

hydrogen (H) and oxygen (O). The  $_2$  tells us there are two hydrogen atoms in each molecule of water.

A compound has different properties from the elements that form it.

**Example:** Water is made of hydrogen and oxygen but it has very different properties from the elements that make it up. Oxygen and hydrogen are both flammable gases at room temperature, while water is a liquid.

**Note:** *Water is an unusual substance for several reasons. It can be found in each of the three states, solid, liquid or gas, at temperatures that occur on earth. It is the most commonly found liquid and it often acts as a solvent, dissolving many other substances.*

### Chemical changes

The chemical properties of a substance are determined by the types of atoms that make up the substance, and by the bonds that hold the atoms together. When the bonds holding a compound together are broken, the compound undergoes a chemical change. Its basic chemical structure is changed. A new substance different from the original substance is formed.

When a chemical change occurs, the process releases energy.

**Example:** A simple electrical circuit gets its energy from a lead-acid battery. Grids of lead and lead dioxide are immersed in sulphuric acid solution. The sulphuric acid combines with the lead to cover the grids with the newly formed compound, lead sulfate. This chemical change reduces the amount of sulphuric acid but, in the process, energy is released that causes negative and positive charges to accumulate on the different plates. These built up charges can be used to do electrical work when needed.

Chemical change can occur at different rates.

**Example:** When iron, a solid metal, is exposed to oxygen, the iron and oxygen slowly combine chemically. The resulting new substance, iron oxide, or rust, is a solid that is rusty red and much softer than iron.

**Example:** Oxygen gas combines slowly with iron but it can combine rapidly with other substances in a rapid chemical process called combustion or burning. Burning gives off energy as heat and light.

**Example:** Wood and gas are made of compounds that contain carbon. When the carbon combines chemically with oxygen, a new substance, carbon dioxide, is formed along with heat. The heat is produced by the rapid motion of the molecules undergoing this chemical reaction. It can be used to do work such as driving the wheels of a vehicle or heating a building.

## **CONCLUSION**

The basic structure and organization of the atom is responsible for many of the characteristics of matter. Two facts about the atom are especially important in helping us understand why things act the way they do.

First is the fact that the number of protons and electrons in different types of atoms varies. The number of protons in an atom, called the atomic number, determines what element it forms.

The second is that electrons and protons have the property of being charged. An individual atom is neutral when it has the same number of positively charged protons and negatively charged electrons because their charges balance each other. But because an atom is more stable when its outer shell is full, it will gain, lose or share electrons in order to get a full outer shell. If an atom gains an extra electron, it has a charge of - 1. If an atom loses an electron, it has a charge of + 1.

Some elements donate or accept electrons to obtain filled outer shells, causing them to become charged. The charged particles are called ions. Ions will be attracted to other ions with the opposite charge, resulting in molecules held together by ionic bonds.

Other elements share electrons to fill their outer shells. The need to share electrons causes the atoms to bond together. These bonds are called covalent bonds.

Metals are solids that have only a few electrons in their outer shell. Metal atoms join together to form atomic crystals by sharing the easily dislodged, outer electrons. These shared electrons are free to flow along the surface of the metal. This is the reason metals are good conductors of electricity.

You cannot see the underlying atomic structure of the objects around you. You see an object's colour, shape and texture, but not the atoms and molecules that make up the object.

- ◆ This is the same as the way that a building's framework is not all visible. You see the wall and floors but not the structural elements that support the outer components

Being familiar with basic atomic structure helps you understand why the different materials you use in the mechanical construction trades have unique qualities that make them useful for different applications.

And now you know why the atom coming out of the movie was *positive* about losing its electron.

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**Answer the following questions about the structure of the atom. The answers are on the last page.**

1. An element is made up of \_\_\_\_\_ type of atom.
2. The number of protons determines which \_\_\_\_\_ an atom forms.
3. The centre of an atom is called the \_\_\_\_\_ .
4. The nucleus has two types of particles, the \_\_\_\_\_ and the \_\_\_\_\_ .
5. The tiny, fast-moving particles that orbit around the nucleus are called \_\_\_\_\_
6. The number of protons in an atom is called the \_\_\_\_\_ number.
7. In the nucleus, the particle called the \_\_\_\_\_ has no charge and is electrically neutral.
8. Protons have a \_\_\_\_\_ charge; electrons have a \_\_\_\_\_ charge.
9. Like charges \_\_\_\_\_ ; unlike charges \_\_\_\_\_ .
10. It is either the absence of or an excess of \_\_\_\_\_ which determines the charge on an atom.
11. If an atom had four protons and only three electrons, the atom would have a \_\_\_\_\_ charge of one.
12. If an atom had six protons and eight electrons, it would have a negative charge of \_\_\_\_\_
13. An atom with the same number of protons and electrons is electrically \_\_\_\_\_.
14. Usually each smaller shell in an atom is filled with the maximum number of \_\_\_\_\_ allowed in that shell before the next shell begins to be filled.
15. The flow of \_\_\_\_\_ occurs because electrons can move easily through conductors made of metals such as silver or copper.

**Answer page**

1. one
2. element
3. nucleus
4. proton, neutron
5. electrons
6. atomic
7. neutron
8. positive, negative
9. repel, attract
10. electrons
11. positive
12. two
13. neutral
14. electrons
15. electricity