1

Lesson

Plastics Fundamentals

Subject Area	Plastics Fundamentals
Key Questions	How can plastics be defined?
	What are plastics made of?
	How are plastics classified?
	What plastic is a CD made of?
	Are plastics recyclable?
	What properties do plastics have?
	Where can we find plastics in use?
Contents	1.1 What are "Plastics"?
	1.2 What are Plastics Made of?
	1.3 How to Classify Plastics?
	1.4 How are Plastics Identified?
	1.5 What are the Physical Properties of Plastics?
	1.6 Performance Review – Lesson 1

■ 1.1 What are "Plastics"?

generic term

The name "plastic" does not stand for a single material. Just as "metal" is used to describe more than just iron or aluminum, the name "plastic" is the generic term for many materials that differ in structure, properties, and composition. The properties of plastics are so diverse that they often replace or supplement conventional materials, such as wood or metal.

macromolecules

All plastics have one thing in common, however. They are the result of the tangling or linking of very long molecular chains (chain molecules) known as "macromolecules" (Greek: macros = large). These macromolecules often consist of more than 10,000 individual structural elements. In these molecular chains, the individual building blocks are arranged one after the other like pearls on a necklace. The plastic can be thought of as something similar to a ball of wool made up of many individual threads. It is very difficult to pull a single thread out of the ball. The situation is similar in a plastic, in which the macromolecules "hold on" to each other. Since macromolecules, and thus the plastics, are made up of many individual structural elements, the monomer molecules (Greek: monos = individual, meros = part), they are also generally called polymers (Greek: poly = many).

definition

Plastics are materials whose essential components consist of macromolecular, organic compounds that are created synthetically or by the conversion of natural products. Usually, these materials can be shaped or undergo plastic deformation when processed under certain conditions (e.g., heat or pressure).

1.2 What are Plastics Made of?

monomers

The basic substances for polymers are called "monomers". It is often possible to produce several different polymers from the same individual basic substances by varying the manufacturing process or by creating different mixtures.

raw materials
refinery products

The basic materials for monomers are mainly crude oil and natural gas. Since carbon is the only relevant material for production, monomers could theoretically also be produced from wood, coal or even atmospheric CO_2. However, these substances are not yet being used because production from gas and oil is cheaper. Several years ago, some monomers were waste materials in the production of gasoline or fuel oil. Today, the high consumption of plastics makes it necessary to specifically produce these "waste monomers" in refineries.

1.3 How to Classify Plastics?

Three overall groups of plastic materials are distinguished from one another. Figure 1.1 presents each of these groups, along with examples.

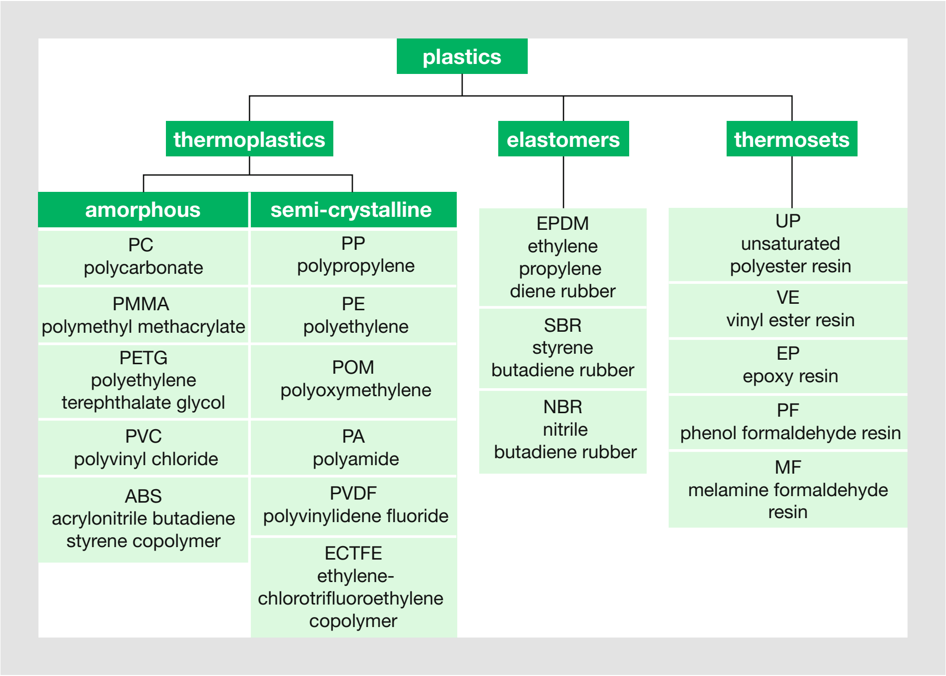

Figure 1.1 Classification of plastics

thermoplastics

amorphous thermoplastics semicrystalline thermoplastics

Thermoplastics (Greek: thermos = warm; plasso = shape, shapable) are fusible and soluble. They can be remelted several times and are soluble or at least swellable in many solvents. They vary from being soft to tough or hard and brittle at room temperature. A distinction is made between amorphous (Greek: amorphos = formless) thermoplastics, which resemble glass with respect to their molecular structure and are crystal clear, and semicrystalline thermoplastics, which have a opaque milky appearance. If a plastic is as transparent as glass, it is reasonably safe to conclude that it is an amorphous thermoplastic. Thermoplastics make up the largest proportion of plastics by quantity.

CD

We will therefore make the cover of the sleeve for our CD from an amorphous material because it is supposed to be transparent in order to be able to read the list of titles. The plastic of the CD itself is also transparent. Usually, it is vapor-coated on one side with aluminum (the aluminum layer acts like a mirror) and then printed so that the laser beam does not pass through it, but is reflected instead.

thermosets

Thermosets are hard and tightly cross-linked in all spatial directions. They are not plastically deformable, cannot be melted and are highly heat-resistant. Because thermosets are very densely cross-linked, they cannot be dissolved and are very difficult to swell. At room temperature, they are hard and brittle. Plug sockets, for example, are made of thermosets.

elastomers

Elastomers (Greek: elastiko = springy; meros = part) are non-meltable, insoluble, but swellable. They have a wide-meshed spatial cross-linking and are therefore in an elastically soft state at room temperature. Examples of elastomer applications are sealing rings or tires.

■ 1.4 How are Plastics Identified?

DIN EN ISO 1043-1

According to the international standard DIN EN ISO 1043-1, plastics are designated by character sequences (abbreviations) that indicate their chemical structure. Additional letters (codes) indicate the application, fillers, and basic properties such as density or viscosity according to DIN EN ISO 1043-2 and DIN EN ISO 1043-3. An example is given in Table 1.1.

HDPE

Table 1.1 Example of Standardized Plastic Identification

Identification of the plastic:
HDPE
Material name:
Linear high-density polyethylene
Abbreviation of the basic polymer product:
PE = polyethylene
Code letters of the additional properties:
H = first code letter for special properties: H = high
D = second code letter for special properties: D = density

example: PC

The CD is made of polycarbonate (PC). PC is a thermoplastic classified according to DIN EN ISO 7391.

In the designation “PC, MLR, 61-09-3”, PC stands for polycarbonate, M stands for the injection molding process, L refers to the light and weather stabilizer, and R stands for a mold release agent. The number sequence 61 stands for the viscosity (59 ml/g), the number sequence “0” stands for the melt volume flow rate (MVR 300/1.2 of 9.5 cm^3/g) and the number 3 denotes the impact strength (35 kJ/m^2).

quantities and values

The various quantities and values given here are only to be noted for the time being. Perhaps after reading this book, you will read this section again to see if you can correctly classify many of the previously unknown terms such as “molding compounds” or “MFR value” (melt flow rate), which describes the flowability of the plastic.

1.5 What are the Physical Properties of Plastics?

Plastics are Lightweight

Plastics are typically lightweight construction materials, usually lighter than metals or ceramics. Because some plastics are lighter than water, they can float on the surface. They are used as lightweight components in the construction of airplanes, in automobile production, and for packaging or sports equipment. For example, aluminum is three times as heavy, and steel eight times as heavy, as polyethylene (PE).

lightweight construction materials

The CD spins at a speed of 200 to 500 revolutions per minute. In order for the motor of the CD player to start up quickly and to be small, it is important that the CD is lightweight.

CD

Plastics Are Easy to Process

The processing temperature of plastics ranges from room temperature to approximately 250 °C (482 °F) and in some special cases even up to 400 °C (752 °F). Due to this low processing temperature, which for steel is over 1400 °C (2552 °F), processing is not very complex and relatively little energy is required. This is one reason for the rather low production costs, even for complicated parts. The various processing methods such as injection molding or extrusion will be presented in detail later.

processing temperature

The Properties of Plastics Can be Selectively Optimized

The low processing temperature facilitates the incorporation of additives of various kinds, such as colorant, fillers (e.g., wood flour, mineral powder), reinforcing agents (e.g., glass or carbon fibers) and blowing agents for the production of foamed plastics.

additives

Colorants enable the material to be colored. This eliminates the need for subsequent painting or varnishing in most cases.

colorants

Inorganic fillers in the form of powder and sand can be used in a high proportion (up to 50%). They increase the modulus of elasticity and compressive strength and help to make the plastic more cost effective in many cases. Organic fillers such as (textile) woven fabrics or cellulose webs increase the toughness. Carbon black is incorporated, for example, into car tires (elastomers!). It improves the mechanical properties (abrasion resistance), increases thermal conductivity and light resistance. Incorporation of plasticizers (certain esters and waxes) can change the mechanical behavior of hard plastics to an elastomer-like state.

fillers

reinforcements

Glass, carbon, and aramid fibers, for example, are used as reinforcing materials. They are applied in various forms, e.g., as short or long fibers, as woven fabrics, or mats. The incorporation of specific fibers can boost strength and stiffness several times over.

blowing agents

The use of blowing agents produces synthetic foams whose density can be reduced to 1/100 of the starting material. Foams have particularly effective insulating properties and allow the production of ultra-lightweight components.

Plastics Possess Low Conductivity

insulation

Plastics not only insulate electrical current, as in the case of electricity cables, but also insulate against cold or heat. Examples are a refrigerator or a plastic cup. Plastic's thermal conductivity is about 1,000 times lower than the thermal conductivity of metals.

electrical conductivity

The reason for the poorer conduction of plastics in comparison to metals is that they have practically no free electrons. In metals, these electrons are responsible for transporting heat and electricity. It is precisely this property of plastics that can be significantly influenced by additives.

thermal conductivity

Plastics therefore make suitable insulation materials. However, their low thermal conductivity leads to problems during processing because, for example, the melting heat is transported only very slowly into the interior of the material.

Because of their high insulating properties, plastics can become electrostatically charged. If conductive substances, such as metal powder, are added to the plastic before processing, the insulating effect decreases and with it the tendency to electrostatic charging.

Plastics are Resistant to Many Chemicals

corrosion

The bonding mechanism of atoms in plastics is very different from that of metals. For this reason, plastics are not as susceptible to corrosion as metals. Some plastics are very resistant to acids, bases, or aqueous salt solutions. However, many are soluble in organic solvents such as gasoline or alcohol.

CD
CD-ROM
DVD

Optical storage media, like CDs, CD-ROMs or DVDs, should therefore not be cleaned with turpentine if they become dirty, as it could damage the plastic.

solvents

When dissolving plastics, the best solvents are those that have a similar chemical composition to the plastics. As the saying goes, "like dissolves like".

Plastics are Permeable

diffusion
material values

The penetration of a substance, e.g., a gas, through another material is called diffusion. The high permeability to gases, resulting from large distances between molecules or a low density, can be disadvantageous. However, permeability differs from one plastic to another. Permeability does have certain practical applications, such as membranes for seawater desalination plants, for certain packaging films or, for example, organ replacement. Suitable plastics for a particular field of application can be found via such material values as the density, e. g., listed in the manufacturer's specifications or data sheets.

Plastics are Recyclable

recycling

Plastics can be reused or processed into other products using various methods. This is referred to as recycling. If recycling does not prove to be economical, various plastics can also be incinerated to generate energy.

incineration

product labeling

However, incineration of some substances is problematic and requires specific incineration technology as well as special filter technology. Particularly in the case of plastics that contain chlorine (such as PVC) or fluorine (such as PTFE, better known under the trade name Teflon, for example), the gases produced must be extracted and filtered accordingly. In the meanwhile, labeling of plastic products is obligatory. This makes it possible to identify which plastic the product was made of when being recycled. It is thus possible to sort the waste according to type and recycle it in a specific way.

Additional Characteristics of Plastics

flexibility

Some plastics are flexible. Although the modulus of elasticity and strength of plastics are wide-ranging, they are usually much lower than the corresponding properties of metals. In many cases, the high degree of flexibility is an advantage for production and application.

impact strength

Several plastics have better impact strength, compared to mineral glass, with equally good optical properties. This means that plastics do not break as quickly as glass, but in return they are not as scratch-resistant. For this reason, plastics are increasingly replacing glass, for example in civil engineering and in the automotive industry or in the field of optics.

transparency

In the case of transparent plastics, in addition to better impact strength, the lower weight also offers an advantage over mineral glass. In automotive engineering, this not only saves weight but allows the vehicle's center of gravity to be lowered. Plastic lenses are more comfortable to wear than glass lenses.

1.6 Performance Review – Lesson 1

No.	Question	Answer Choices
1.1	Plastics are divided into the groups consisting of thermoplastics, elastomers and ______________.	monomers thermosets
1.2	Thermoplastics are divided into two subgroups: amorphous thermoplastics and ______________ thermoplastics.	thermosetting semicrystalline
1.3	Thermoplastics are ______________.	meltable non-meltable
1.4	Thermosets are strongly cross-linked and therefore they are non-meltable and ______________.	soluble insoluble
1.5	Elastomers are ______________ cross-linked.	densely loosely
1.6	Elastomers are ______________.	meltable non-meltable
1.7	Most plastics are ______________ than metals.	lighter heavier
1.8	The processing temperature of plastics is ______________ than that of metals.	higher lower
1.9	Different plastics show ______________ degrees of permeability to gases.	identical different
1.10	Plastics are very ______________ insulators for heat and electrical current.	poor good
1.11	Most plastics ______________ be recycled.	can be cannot be
1.12	The compact disc (CD) is made from the transparent plastic ______________.	polyethylene (PE) polycarbonate (PC)

2

Lesson

Raw Materials and Polymer Synthesis

Subject Area	Plastics Chemistry
Key Questions	What raw materials are plastics made of?
	What are the steps of refining from crude oil to the basic substances of plastics?
	How are plastics structured?
	What is a monomer?
	What are macromolecules and what are chain units?
	What methods of polymer synthesis exist?
Contents	2.1 Raw Materials for Plastics
	2.2 Monomers and Polymers
	2.3 Polyethylene Synthesis
	2.4 Methods of Polymer Synthesis
	2.5 Performance Review – Lesson 2
Prerequisite Knowledge	Plastics Fundamentals (Lesson 1)

■ 2.1 Raw Materials for Plastics

carbon chemistry

The raw materials for plastics production are natural substances such as cellulose, coal, crude oil, and natural gas. The molecules of all these raw materials contain carbon (C) and hydrogen (H). Oxygen (O), nitrogen (N) or sulfur (S) might also be involved. The most important raw material for plastics is crude oil.

crude oil

Figure 2.1 shows the proportion of the various products made from crude oil as a percentage of total crude oil production. It is evident that only six percent of total petroleum is processed into plastics.

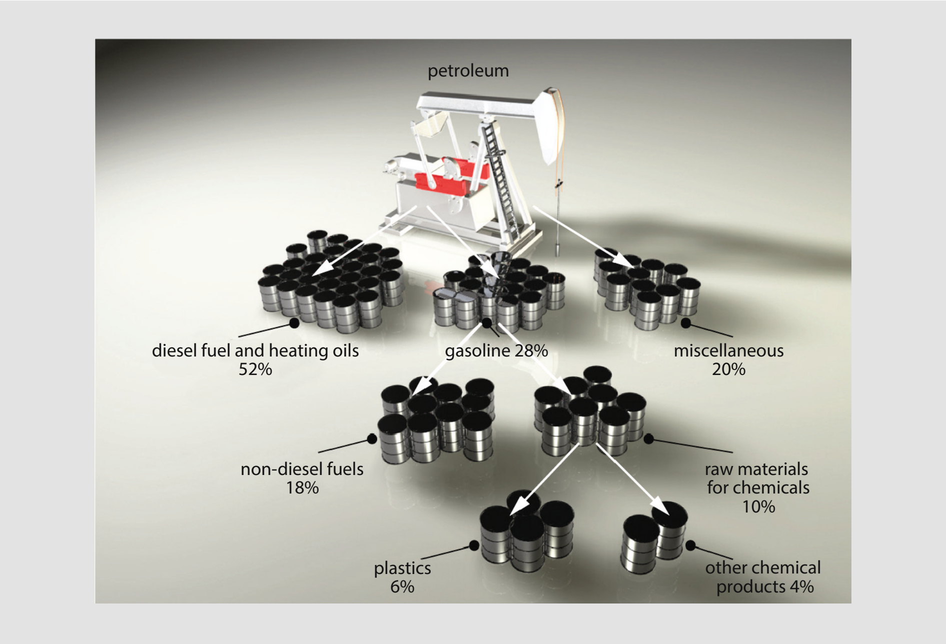

Figure 2.1 Breakdown of raw material products (source: Läpple 2011)

intermediate steps

However, plastics are not produced directly from crude oil. Several intermediate steps are required.

distillation

In a refinery, crude oil is separated into its various components by distillation (a process for separating liquids). For the separation, the differences in boiling points of the various components are exploited. The following are separated: gas, gasoline, petroleum, gasoil, and the residue on distillation is bitumen, which is used in road construction.

cracking

The most important distillate for plastics production is crude gasoline. In a further thermal separation process, the distilled gasoline is broken down into ethylene, propylene, butylene, and other hydrocarbons. This process is also known as cracking. The proportions of the individual cracked products can be controlled via the process temperature. At 850 °C (1562 °F), for example, more than 30% ethylene is obtained.

basic substances

Styrene and vinyl chloride, for example, can also be obtained from ethylene in downstream reaction steps. Like ethylene, propylene, and butylene, these two substances are basic substances (monomers) from which plastics can be produced.

energy expenditure

It is well known that all work processes require a certain amount of energy (pressure, heat, motor power, etc). Figure 2.2 shows how energy-efficiently plastic products are manufactured compared to other materials. The graph shows the energy input (calculated in tons of crude oil) required to manufacture items such as pipes and beverage bottles.

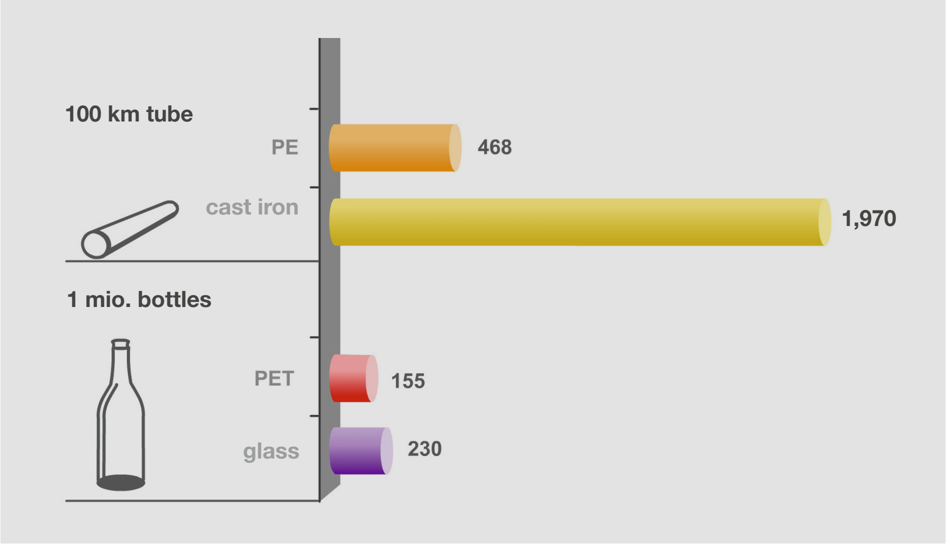

Figure 2.2 Energy required to produce pipes and bottles compared to classic materials (cast iron and glass)

■ 2.2 Monomers and Polymers

monomers
macromolecules

The basic substances of plastics are called monomers (Greek: mono = single; meros = part). The plastic macromolecules can be manufactured from these basic substances. The term macromolecule is derived from the size of the plastic molecules (Greek: makros = large), since they result from the combination of many thousands of monomer molecules.

polymer

Prior to the formation of the macromolecule, the monomers exist individually (Figure 2.3). The synthetic material made up of many of these particles is called a polymer (Greek: poly = many). Only by means of a chemical reaction will the individual molecules become a macromolecule.

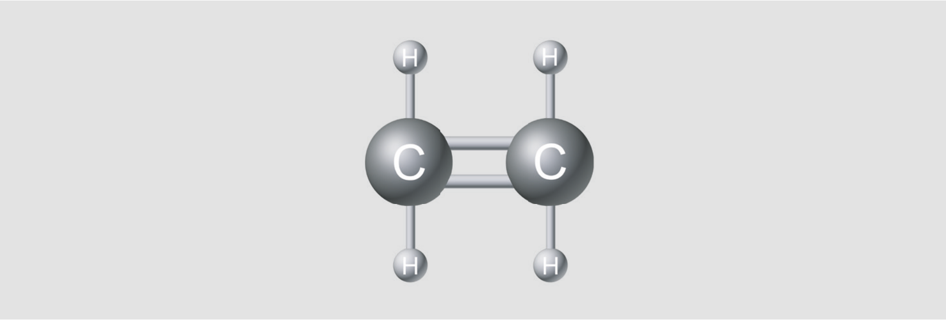

Figure 2.3 Monomer molecule (schematic example of ethylene)

chain elements

Since macromolecules are created from many identical monomers in the simplest case, they consist of identical chain elements that are continuously repeated (Figure 2.4).

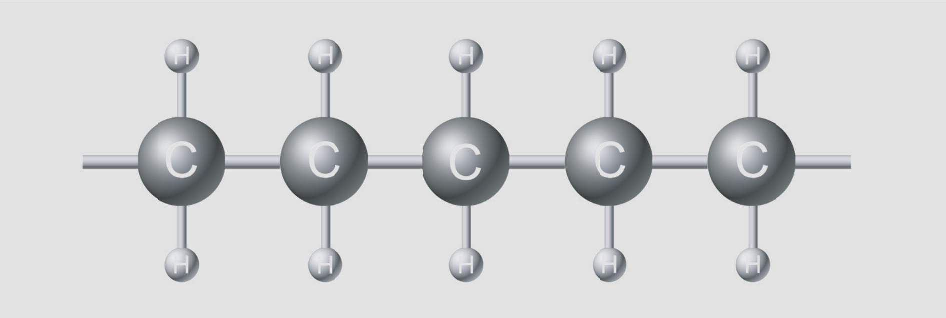

Figure 2.4 Macro molecule (chain units – example of polyethylene)

backbone

Each molecular chain has a continuous line of chain units to which others are attached that are not located in this line. This continuous line of the macromolecule, called the backbone, is most often composed of nothing but the element carbon (C). Oxygen (O) or nitrogen (N) sometimes may also be present. Carbon has the characteristic that it easily forms chains with itself and with oxygen and nitrogen. With other chemical elements, this property is not as prominent.

side chains

Attached to the backbone are various other elements or groups of elements, for example hydrogen (H). If the groups of elements consist of chain-building blocks that actually form a molecular chain, they are referred to as branches or side chains. These branches occur to a greater or lesser extent in all plastics.

2.3 Polyethylene Synthesis

One example of a macromolecular substance is polyethylene (Figure 2.5).

polyethylene

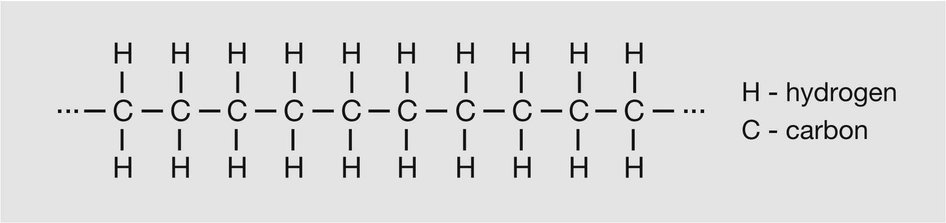

Figure 2.5 Structure of a polyethylene linear molecular chain

The monomer from which polyethylene is derived is called ethylene. It consists only of carbon and hydrogen, as shown in the structural formula in Figure 2.6.

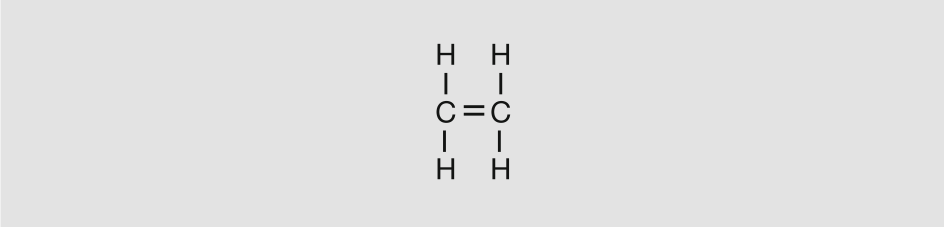

Figure 2.6 Structural formula of ethylene (monomer of polyethylene)

The lines in the figure represent the bonds between the atoms. One bond consists of a pair of electrons. The double lines between the carbon atoms represent a double bond.

bond

The double bond is important for the reaction to form a macromolecule. The ethylene molecules are activated one after another and gradually form a macromolecule, whose structural formula is shown in Figure 2.7.

double bond

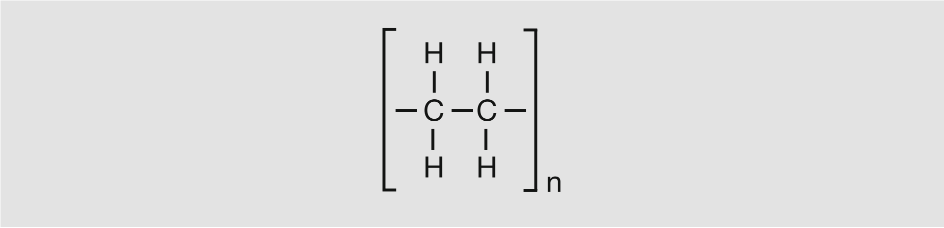

Figure 2.7 Structural formula of polyethylene (PE)