DESIGN AND PLASTICS

MIKE HALL

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HODDER AND STOUGHTON
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CONTENTS

PREFACE

DESIGNING AND MAKING IN PLASTICS FOR CRAFT DESIGN TECHNOLOGY

The wide-ranging properties of plastics, their diverse and often exciting qualities, add sparkle to our everyday lives. Without plastics we would be unable to afford the many products we take for granted. Indeed many of the technological advances made by our society would not have been possible. Plastics are essential to the continuing development of our way of life through product design.

Craft Design Technology (CDT) seeks to develop technical and aesthetic awareness, originality, inquisitiveness and decision-making abilities through the experience of designing and making. Plastics play a major role in CDT. This book seeks to provide a foundation in plastics that will enable a young person fully to understand the qualities and potential of these exciting materials and enable them to make products that will fully exploit their properties. It covers, in considerable detail, the entire field of common plastics and attempts to demonstrate by practical examples how they can actually be used in designing and making objects. It aims to meet these needs over most of the CDT course from entry into secondary education at 11 through to 16-plus and GCSE requirements. Many topics barely touched upon in other school texts are treated in depth. The suggested projects and activities are designed to enable children to add to the text through personal investigation.

Plastics are the materials of our time and as such need to be understood and used to the benefit of all. Designing and making in plastics both fulfils our creative needs and educatcs through practical experiment and demonstration.

Acknowledgements

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As a lecturer the author has gained much technical advice from sources in the Plastics Industry and many reference works providing the detail necessary for this book and is deeply indebted to the originators of this information. In particular the tables shown on page 123 which are reproduced with the permission of SCDC Publications from Design with Plastics (Project Technology Handbook), (Heinemann Educational Books 1974) and Plastics Engineering by R. J. Crawford (Pergamon 1981/83). The cover photograph is reproduced by kind permission of the Design Council.

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INTRODUCTION: THE IMPORTANCE OF PLASTICS

The large range of plastics materials in use today have been discovered and developed by scientists during the last 120 years. They have been discovered because man is constantly searching for new ways of making things and making them longer-lasting, cheaper, lighter and better able to meet the needs of new technology.

Plastics are not cheap materials, but because they can be processed more efficiently on automated machines they are cheaper than many others after manufacture.

Today most people want a car, stereo, radio, TV set, video recorder, and all the labour-saving devices to be found in our homes. Plastics play an important part in all of them. Without these materials it would not be possible to make many of these products, and certainly not at a price we could all afford.

Outside the home, too, plastics are crucial to innumerable activities. If all plastics products were to vanish overnight, the effect on us and the way we live would be catastrophic. Virtually everything everywhere would stop. Plastics are essential to our computers, communications systems, leisure equipment, food industry, and medical and other services. Almost everything you can think of these days has at least one part made from plastics materials.

Devices incorporating plastics perform many different functions and plastics provide a wide variety of suitable properties to choose from. It is therefore important to choose the correct material for the job. Some plastics are much more expensive than others.

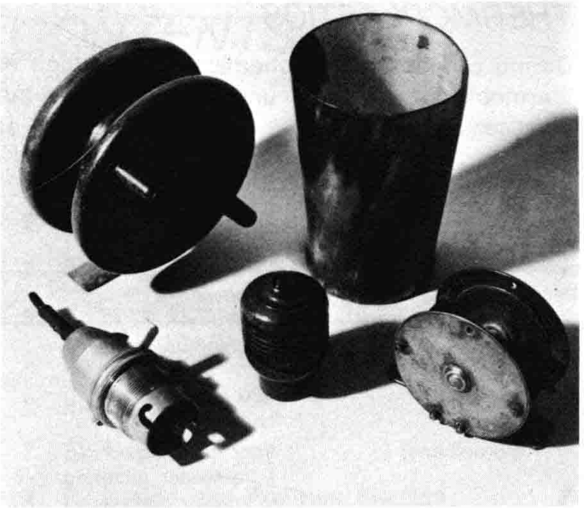
What are plastics? They are man-made substances that may be shaped under heat and pressure but are stable in normal use. There are two main types of plastics commonly used for making the products in our homes. They are called *thermoplastic* and *thermosetting plastics*. They are different in that: (a) the methods used to process them are different; and (b) thermosetting plastics ('thermosets') change chemically during processing, whereas thermoplastics do not. Tables 1 and 2 show common plastics, their applications and generic names. The common names are used to identify materials throughout the book.

Table 1 Thermoplastics

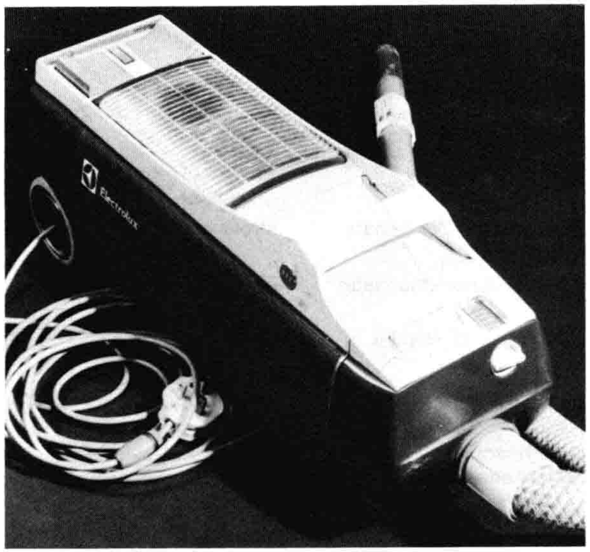
Common name	*Old generic name*	*New generic name*	*Applications*
polyethylene (polythene, PE)	polyethylene	poly(ethene)	washing-up bowls
high-density (HDPE)	high-density (HDPE)	high-density	milk-bottle crates
low-density (LDPE)	low-density (LDPE)	low-density	carrier bags
PVC (vinyl)	polyvinyl chloride	poly(chloroethene)	floor covering, rainwater guttering, shower curtains, upholstery fabrics
polystyrene (styrene, PS)	polystyrene	poly(phenylethene)	tape cassette boxes
polypropylene (propylene, PP)	polypropylene	poly(propene)	injection-moulded chairs
ABS	acrylonitrile butadiene styrene	poly(propenenitrile) buta-1, 3-diene poly(phenylethene)	suitcases
Acrylic (Lucite, Perspex, Oroglas, PMMA)	polymethylmethacrylate	poly(methyl 2-methyl propenoate)	car rear lights
SAN	styrene acrylonitrile	Poly(phenylethene propenenitrile)	translucent coloured drinking glasses
CAB (cellulose acetate butyrate)	CAB (cellulose acetate butyrate)	poly(cellulose ethanoate butanoate)	street signs
cellulose acetate (acetate, CA)	cellulose acetate	poly(cellulose ethanoate)	photographic film, spectacle frames
cellulose nitrate (Celluloid)	cellulose nitrate	poly(cellulose nitrate)	table tennis balls
nylon	polyamide		gears, curtain fittings
polycarbonate (Lexan, PC)	polycarbonate	poly(carbonate)	camera bodies, car bumpers
PET	polyethyleneterephthalate	poly(ethene polyester benzene-1, 4-dicarboxylate)	pressurised soft-drinks bottles, draughtsman's drawing film
acetal	polyacetal	poly(1, 1-diethoxyethane)	taps
EVA	ethylene vinyl acetate	poly(ethene ethenylethanoate)	lifejacket buoyancy foam
PTFE	polytetrafluoroethylene	poly(tetrafluoroethene)	non-stick pan coatings

THERMOPLASTICS

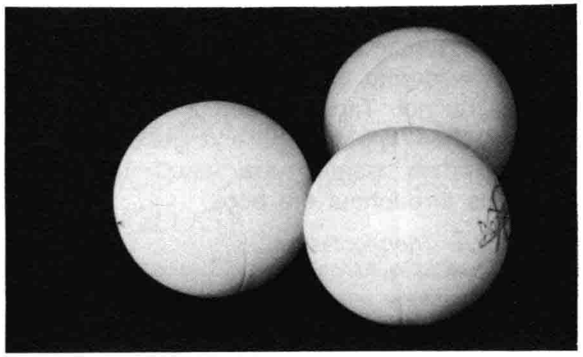
During processing the chemical composition of thermoplastics remains unchanged, but as the plastics are heated, the minute particles, or



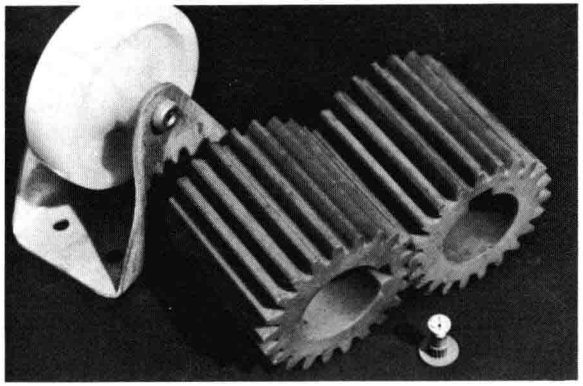
Products made before plastic came into general use.



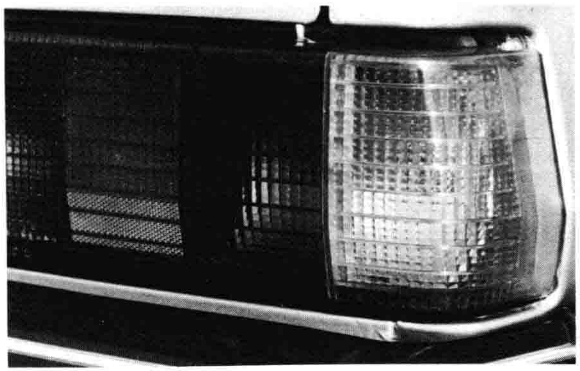
The parts of this domestic appliance have been injection moulded in ABS (acrylonitrile butadiene styrene).



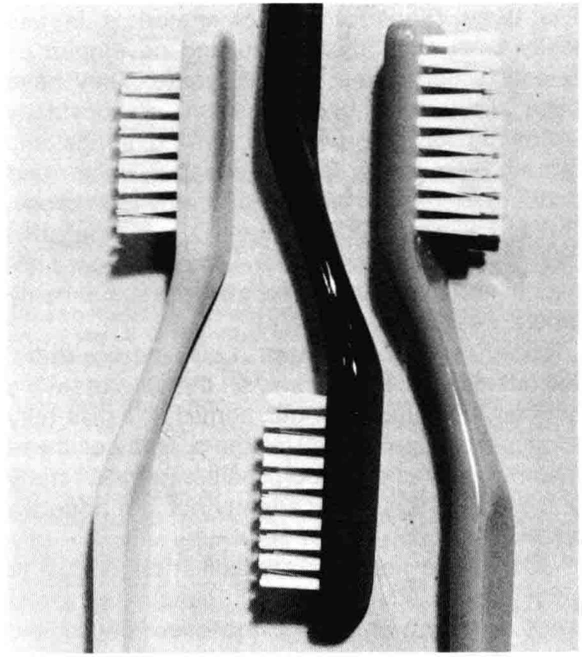
Cellulose nitrate table tennis balls.



Castor and gears in nylon.



Car rear light injection moulded in acrylic.



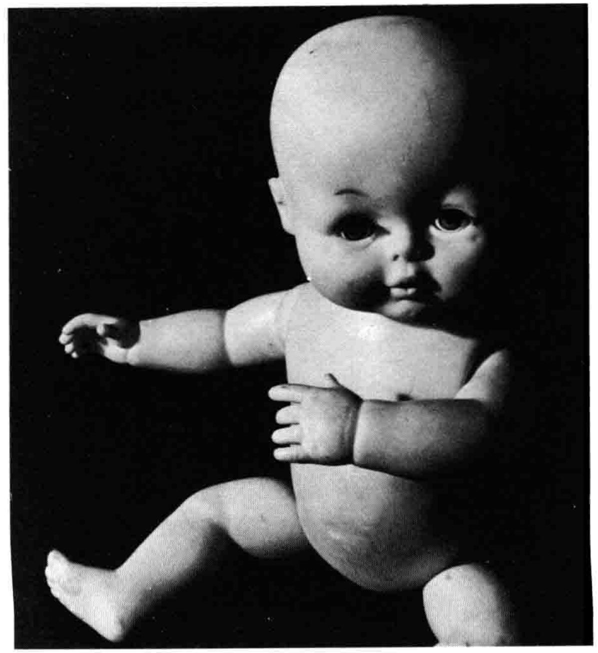
Cellulose acetate toothbrushes.

Injection moulded ABS ski boots.

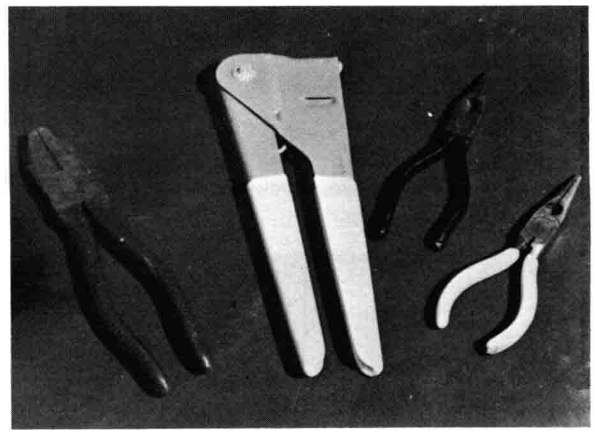
Injection blow moulded lemonade bottle in PET (polyethyleneterephthalate).

Motor cyclist's crash helmet injection moulded in polycarbonate.

Extrusion blow moulded bottle in high density polyethylene.



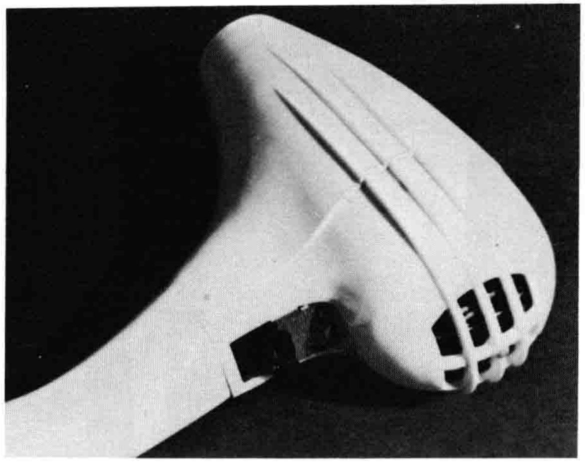
Doll rotationally cast in PVC plastisol.



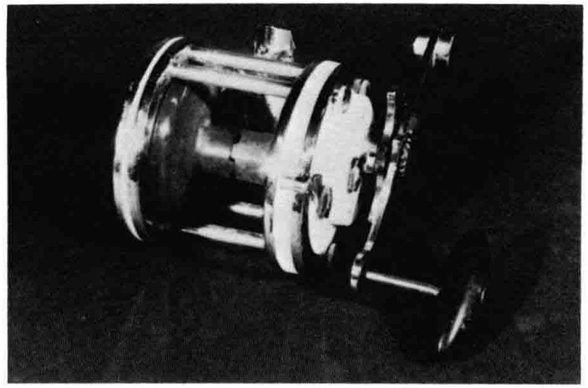
Tool handles dip-coated in PVC.

◀Jug and beakers injection moulded in SAN (styrene acrylonitrile).

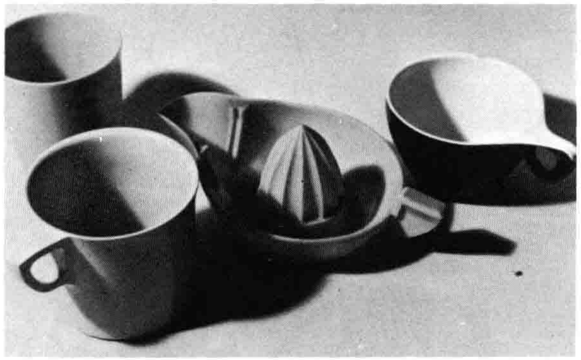
Urea formaldehyde compression mouldings.



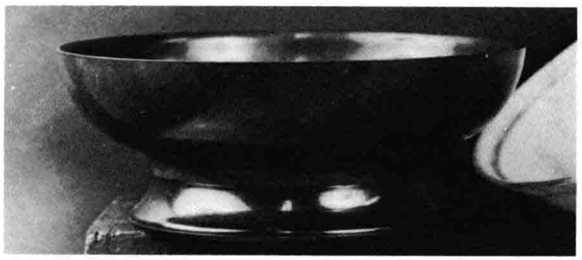
Casting for hairdryer made by compression moulding in urea formaldehyde.



Sea fishing reel moulded in glass reinforced polyester.



Melamine formaldehyde tableware made by compression moulding.



Phenol formaldehyde compression moulded bowl.

Sandwich toaster with phenol formaldehyde (bakelite) compression moulded, heat resistant handles and a non-stick coating of ptfe (polytetrafluoroethylene).

Clock parts embedded in polyester casting resin.

molecules, (see page 8) vibrate and become free to move past each other, so making it possible to shape the material. In some processes the plastics are heated until they become syrupy fluids. Then, when great pressure is applied, they can be forced through passageways into spaces (mould cavities) where they are cooled and become solid, taking on the exact shape of the space. Each mould cavity makes a new product or component.

Thermoplastics can be bought in the form of powders or granules, or as sheets, rods, tubes or sometimes as liquids. They can be heated and moulded by a variety of methods. Some materials are more suited to one process than another but in all cases the principle is the same: forming takes place with heat and pressure but chemically the material remains the same.

THERMOSETTING PLASTICS

A thermosetting plastics material is one that changes chemically during the moulding process. Usually it is formed by heat and pressure, but once this chemical change has taken place the new material cannot be reshaped by further heat and pressure. Some materials may be cast at room temperature and atmospheric pressure and hardened by the addition of chemical agents.

In school work very few thermosetting compounds are used. Polyester resin is the most important example: it is the most common material for bonding with glass fibre to make glass fibre-reinforced products such as canoes, chairs and many other items that consist essentially of thin shells with one good surface and high strength.

Plastics offer a wide range of materials for design. All work in this field demands planning and forethought, careful materials selection and meticulous processing of both moulds and finished products. A high standard of workmanship is essential, and when it is coupled with sensitive design, it will result in a high-quality product.

You must always base the selection of materials and processes on the uses to which the finished product will be put and the facilities and time available. Where possible this book indicates the applications of each process described and the materials required. Detailed methods of mould-making to suit the various processes are given so that you can see how to approach the design and plan a project. You should be able to think both about the product in its finished form and about the mould, which is its opposite or 'negative'.

Plastics materials can be used to solve many construction problems but they cannot be expected to do everything. There are many occasions when you have to use metals and wood for structural purposes, and you are encouraged to use the best material for the job. This is an essential part of good design.

Table 2 *Thermosetting plastics*

Common name	*Old generic name*	*New generic name*	*Applications*
phenolic (PF, Bakelite)	phenol formaldehyde	poly(phenol methanal)	pan handles, insulation foams
urea (UF)	urea formaldehyde	poly(carbamide methanal)	light switches
melamine (MF)	melamine formaldehyde	poly(melamine methanal)	cups, kitchen workbench laminates
polyester	polyester		GRP car bodies, canoes
epoxy	epoxy		commercial tooling, electrical casting medium, adhesives, coatings
polyurethane (PU, urethane) (Note: some of these are thermoplastics, depending on the mix.)	polyurethane flexible		upholstery foam, skateboard wheels, some coated fabrics, shoe soles
	polyurethane rigid		insulation foam, structural furniture foam, adhesives, coatings
synthetic rubbers			
neoprene rubber	polychloroprene	poly(2-chlorobuta-1, 3-diene)	divers' wet-suits, inflatable dinghies
butyl rubber			inner tubes for tyres
silicone rubber			medical, food-processing (for linings, seals, etc.)

1 THE STRUCTURE AND CHEMISTRY OF PLASTICS

THE RAW MATERIALS OF PLASTICS

Coal, oil, plants and milk are the most common raw materials from which plastics are made.

Coal and oil provide the main carbon compounds that form the chemical backbone for almost all plastics. Coal and oil are used for many purposes, and less than five per cent is consumed in the manufacture of plastics.

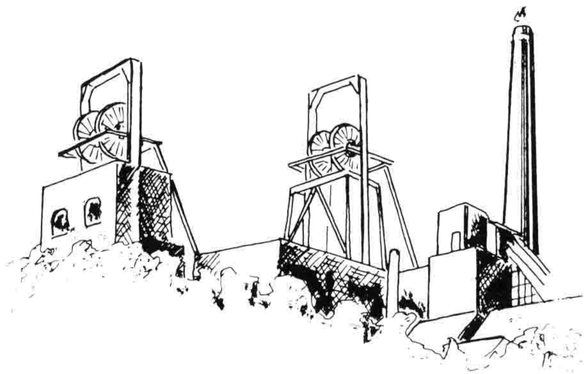
Plants provide cellulose, which is made into a variety of sheet thermoplastics, such as cellulose nitrate (for table-tennis balls etc.), cellulose acetate (for spectacle-frames etc.) and cellulose acetate butyrate (for some street signs etc.). Sugar can provide pure carbon and, being fast-growing, can be used as a renewal resource for plastics.

Milk provides casein, which, when chemically treated and compressed, forms another group of plastics.

CHEMICAL STRUCTURE OF ORGANIC COMPOUNDS

Most compounds based on the element carbon are said to be *organic*. An element is a substance that cannot be broken down into any simpler substances, and therefore its atoms are all of the same kind. An *atom* is the smallest part of an element that can take part in a chemical reaction. Hydrogen, oxygen and chlorine are all examples of elements.

A *compound* is made up of atoms of different elements, chemically combined in a particular ratio; for example, water has two hydrogen atoms combined with one oxygen atom. Different compounds result if the same elements are combined in different proportions; for example, hydrogen peroxide has two hydrogen atoms and *two* oxygen atoms combined. Identical atoms



can also join together; oxygen, for example, normally consists of pairs of oxygen atoms linked together.

These combinations of atoms are *molecules*, which are the smallest units of elements or compounds that can exist by themselves.

Chemists are able to make atoms combine with each other in special relationships to produce plastics. They have many ways of controlling the number and arrangement of the different atoms in the molecule of a compound.

An atom of hydrogen can form one link with an atom of carbon or another substance. An atom of oxygen can form two links, an atom of carbon four links. A link between atoms is known chemically as a *bond*. Carbon can make a greater number of chemical substances than can all the other elements combined.

Carbon atoms can link together to form chains or rings. And one kind of ring, known as a *benzene ring* can be attached at the side of a carbon chain. (See page 13.)

Sometimes one carbon atom forms two links with another carbon atom. The compound is called *unsaturated*, meaning that one of the two links can be broken in order to make a different molecule. When all the links between atoms are single, a *saturated* chemical compound is created. In this case the molecule cannot be altered by normal chemical means. Usually a double bond can be broken easily, and when this happens long chain molecules can be formed.

Polymerization

A basic unsaturated organic molecule containing double carbon-to-carbon bonds, is called a *monomer* (mono = one). When the double bonds are broken to form a long chain molecule, the new material is said to be a *polymer* (poly = many). This process is known as addition polymerization, because it consists of the addition of molecules of the same monomer to form chains of perhaps 10,000 carbon atoms. (See page 9.)

Another polymerization process is possible, involving the use of two or more monomers of different substances. The product of this reaction may be a long chain molecule, or a complex, cross-linked three-dimensional structure; usually water or hydrogen chloride is formed as a by-product, giving rise to the name condensation polymerization for the reaction. In this case the water or hydrogen chloride is the condensate.

Addition polymerization creates long chain molecules that have thermoplastic properties. These molecular chains lie on top of and alongside each other in a jumble, lightly held together by weak attractive forces known as van der Waals forces. Heat weakens these forces, very noticeably in the normally rigid thermoplastics material, which becomes soft and floppy. The heat permits the molecules to slide past one another, making the material mouldable under pressure. When the material has cooled, the van der Waals forces regain their strength and hold the molecules in their new positions. This heating and cooling can take place more than once, so that a thermoplastic can be shaped and reshaped many times.

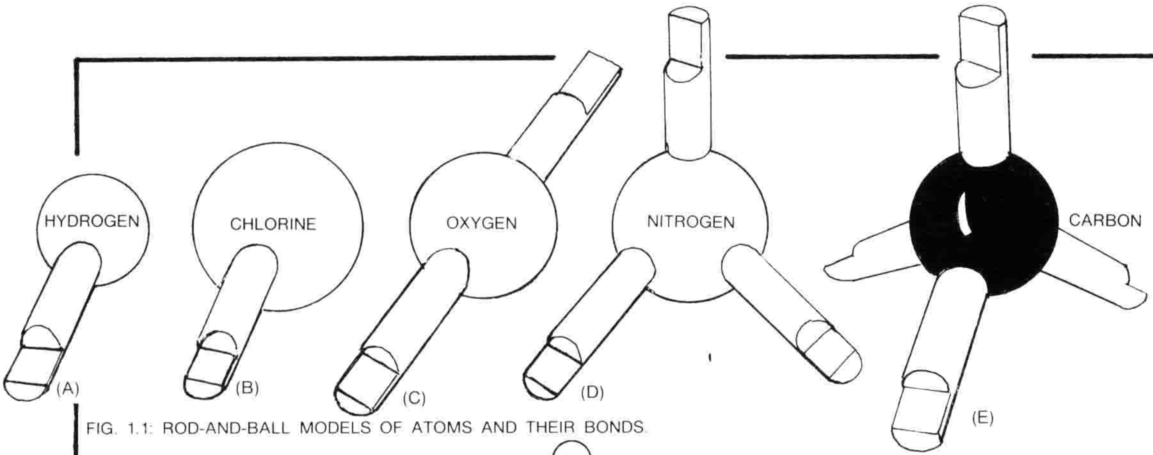


FIG. 1.1: ROD-AND-BALL MODELS OF ATOMS AND THEIR BONDS.

$$\begin{array}{ccc} H & & H \\ | & & | \\ C & = & C \\ | & & | \\ H & & H \end{array} \qquad \begin{array}{ccccccccccc} & H & & H & & H & & H & & H & \\ & | & & | & & | & & | & & | & \\ - & C & - & C & - & C & - & C & - & C & - \\ & | & & | & & | & & | & & | & \\ & H & & H & & H & & H & & H & \end{array}$$

MONOMER POLYMER

FIG. 1.5: FORMULA FOR POLYETHYLENE.

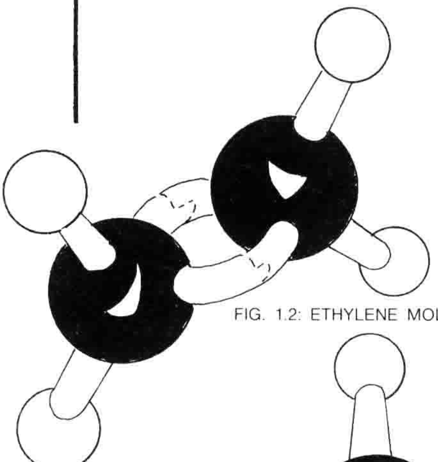


FIG. 1.2: ETHYLENE MOLECULE.

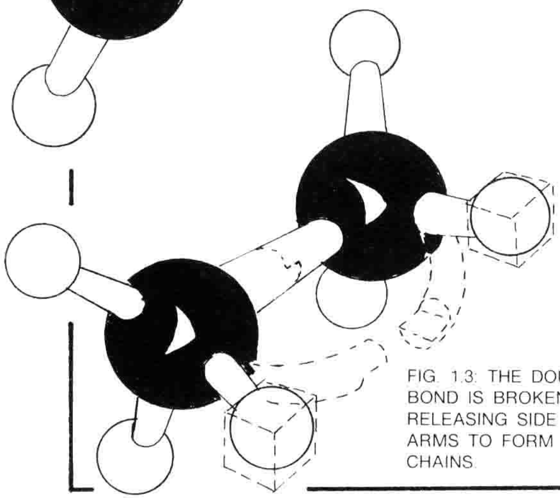


FIG. 1.3: THE DOUBLE BOND IS BROKEN RELEASING SIDE ARMS TO FORM CHAINS.

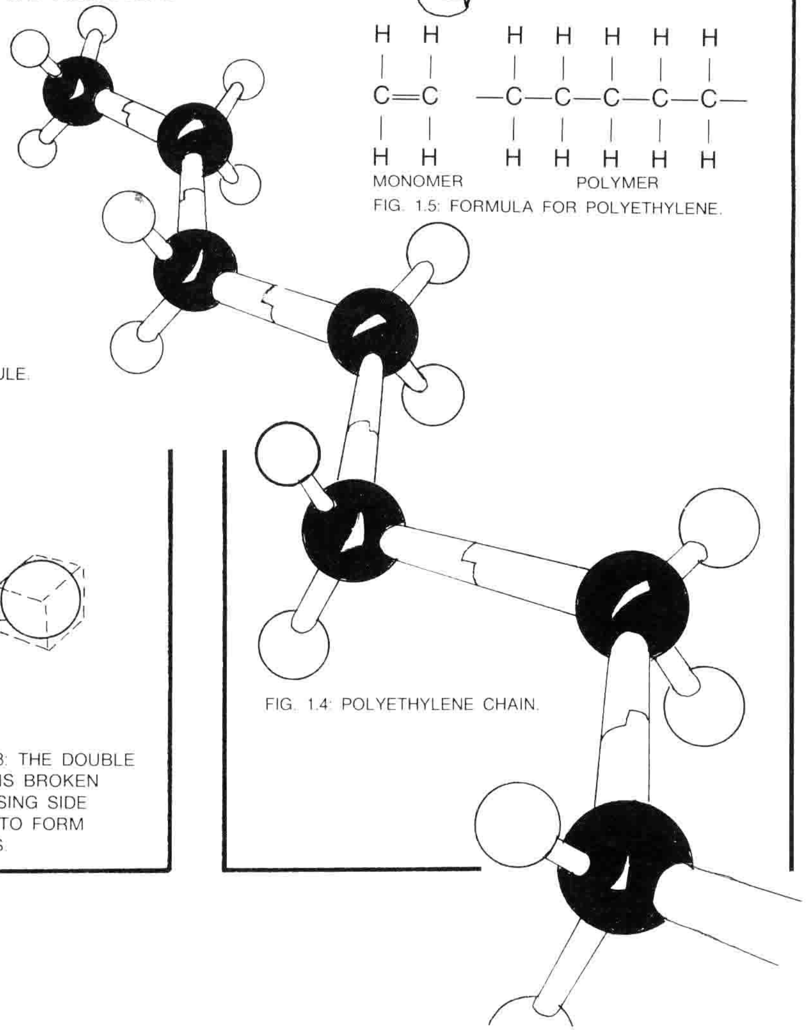


FIG. 1.4: POLYETHYLENE CHAIN.

Thermosetting plastics have a cross-linked structure that, when cured either chemically or by heat, forms a group of fixed atoms held firmly in relation to one another. These atoms will not separate when reheated — they can be heat- and pressure-moulded once, or chemically cured once, but after this they cannot be re-moulded.

Thermosetting plastics mentioned in this book are rigid, but different properties can be achieved by modifying the chemicals used in the curing process. Once cured, reshaping can only be achieved by cutting or machining.

THERMOPLASTICS

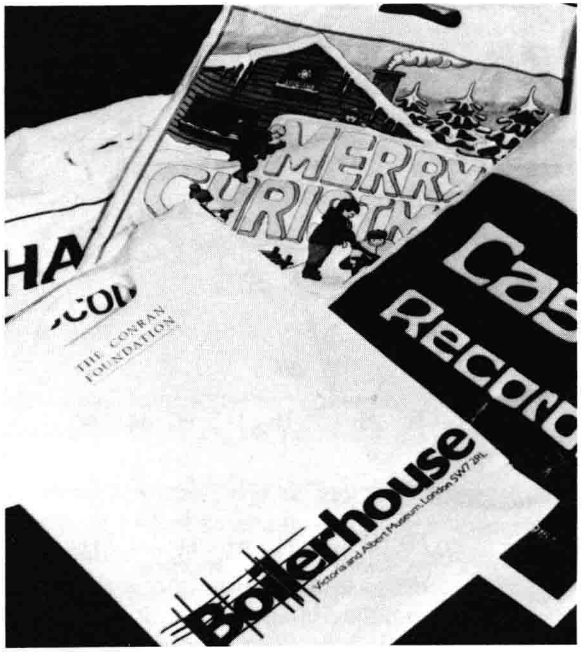
Polyethylene

Figures 1.1 A–E on this page show the main atoms found in many plastics materials and the number of 'arms' that each atom has. Hydrogen and chlorine, with one each, can attach themselves only to one other atom, while oxygen, nitrogen and carbon can link with two or more other atoms. Each arm is shown with a half-joint to suggest that it must 'mate up' with a similar half-joint on a spare arm of another atom. Figure 1.2 shows a molecule of ethylene (an unsaturated compound) with two carbon atoms linked by a *double bond* (two arms joined). When this double bond is broken (Figure 1.3), many of these ethylene molecules can join up to form one very long chain. Figure 1.4 shows the end of such a chain, and since there are many 'ethylene' molecules in it, it is now called 'polyethylene'.

When polyethylene is made by the industrial chemist, large numbers of the chains are created, which lie entangled like spaghetti in tomato sauce. When cold these chains stick to one another like a solid block of spaghetti; when warm they are free to slide around, until they are cooled again, when they 'set' in another shape. The van de Waals forces of attraction act like the tomato sauce in holding the long chains together.

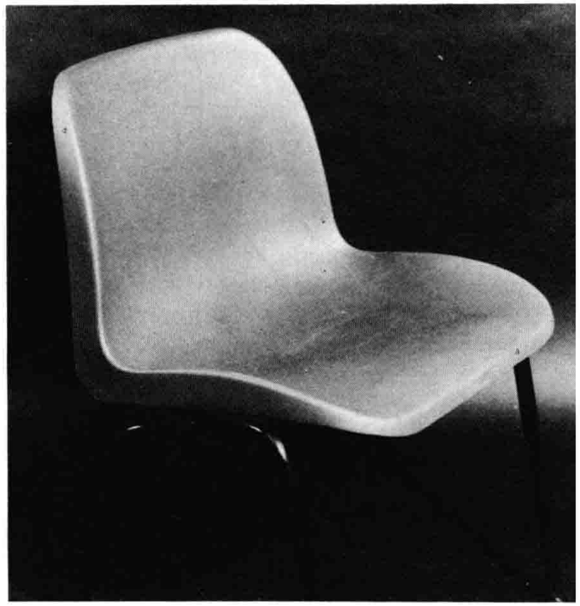
Figure 1.5 shows a diagrammatic representation of the ethylene monomer, and the polymer formed after the double bonds have been broken and linked up to form a chain.

High density polyethylene material, extrusion blow moulded to form a strong container for domestic chemicals.

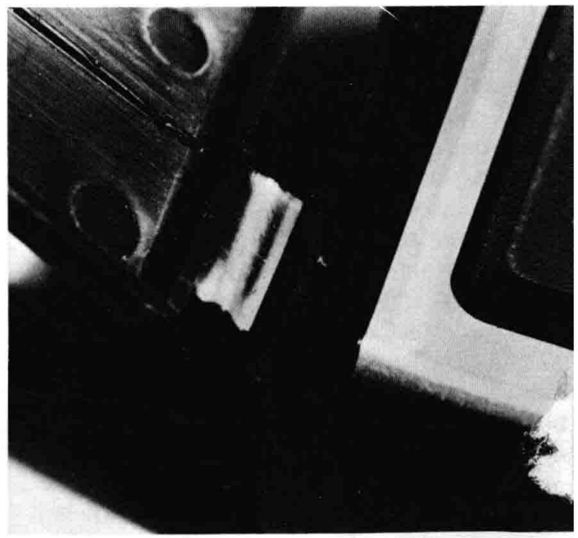


Low density polyethylene has been screen printed and welded to make these carrier bags.

High density polyethylene has been injection moulded to make this washing-up bowl.



Injection moulded chair made from polypropylene.

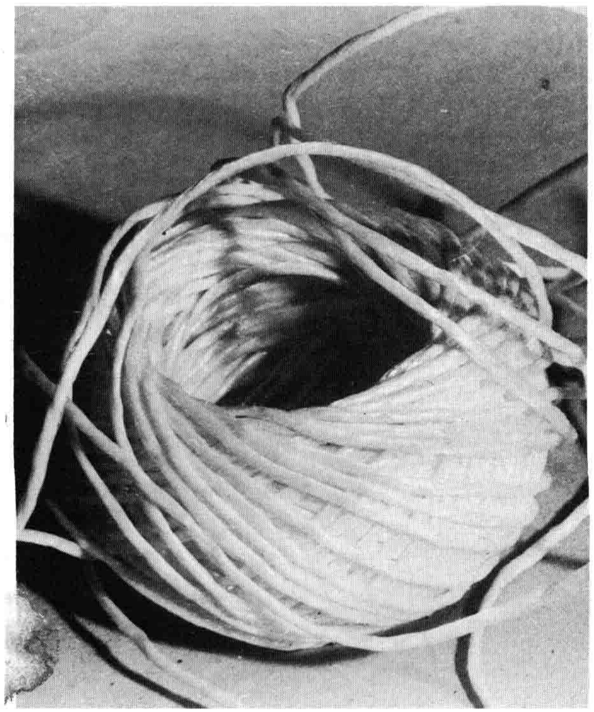


Polypropylene 'integral' hinge.

Polypropylene

Polypropylene, or polypropene, (Figure 1.6), is a very similar material to polyethylene, in appearance, touch and many other properties. It is a member of the same family and has almost the same chain structure, except that on every other carbon atom one of the hydrogen atoms is replaced by another carbon and three hydrogen atoms. These are always arranged in the same pattern and, because they stick out, tend to interfere with neighbouring chains.

Figure 1.7 shows the propylene monomer in diagrammatic form, with the single unsaturated double bond, which, when broken, allows the molecules to link up to form the long chain molecule of polypropylene.



Polypropylene string.

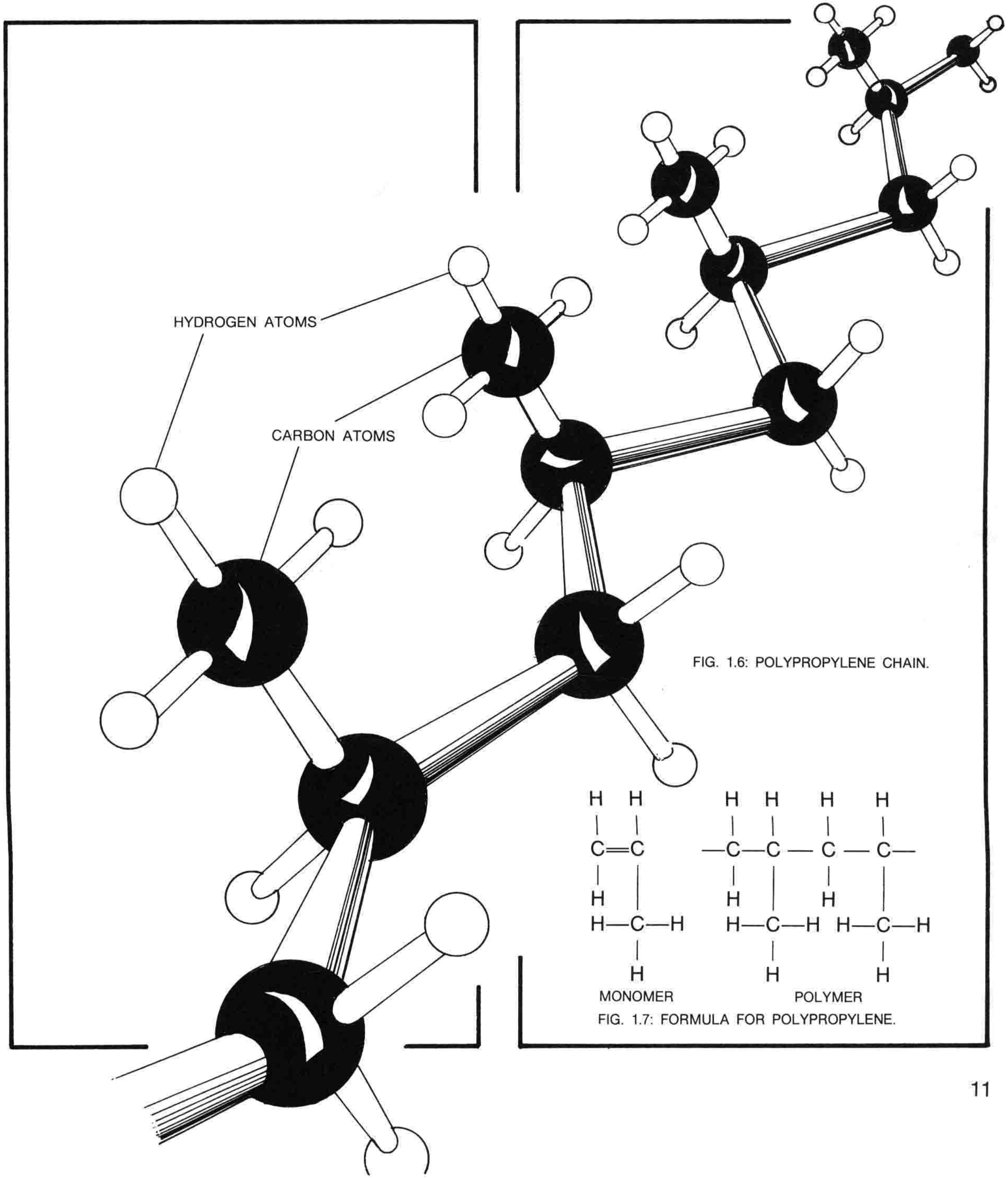


FIG. 1.6: POLYPROPYLENE CHAIN.

MONOMER

POLYMER

FIG. 1.7: FORMULA FOR POLYPROPYLENE.

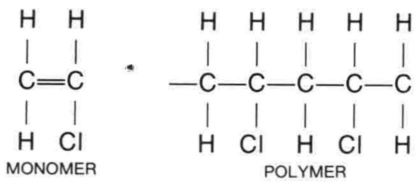


FIG. 1.8: FORMULA FOR PVC.

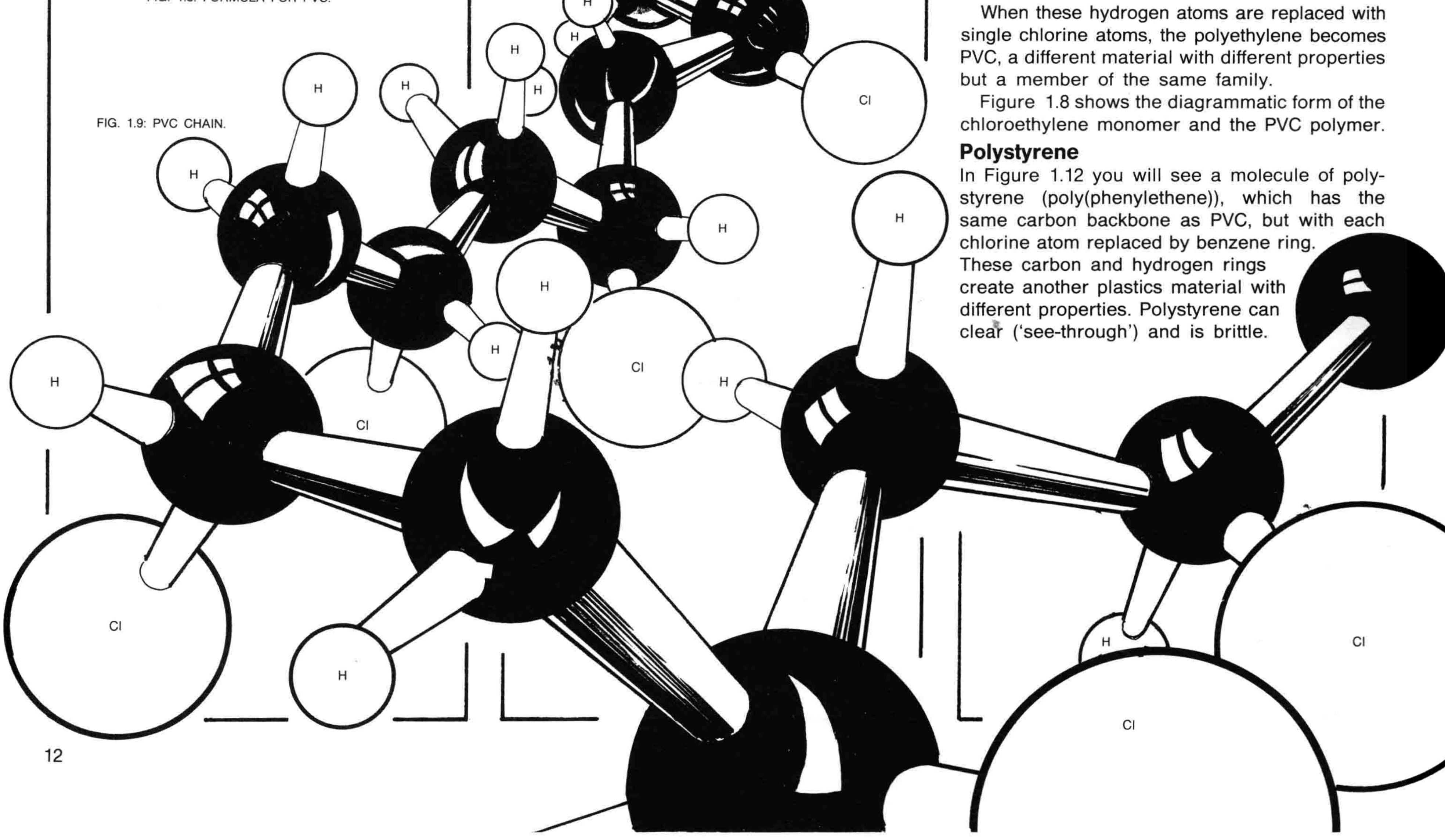


FIG. 1.9: PVC CHAIN.

PVC Polychloroethene

Figure 1.9 shows part of a molecule of PVC (polyvinylchloride or polychoroethene). Figure 1.10 on page 13 is a reminder of the polyethylene molecule, with the now familiar carbon backbone and small hydrogen atoms attached in a regular formation. In this figure imaginary blocks surround atoms of hydrogen on alternate carbon atoms.

When these hydrogen atoms are replaced with single chlorine atoms, the polyethylene becomes PVC, a different material with different properties but a member of the same family.

Figure 1.8 shows the diagrammatic form of the chloroethylene monomer and the PVC polymer.

Polystyrene

In Figure 1.12 you will see a molecule of polystyrene (poly(phenylethene)), which has the same carbon backbone as PVC, but with each chlorine atom replaced by benzene ring. These carbon and hydrogen rings create another plastics material with different properties. Polystyrene can clear ('see-through') and is brittle.

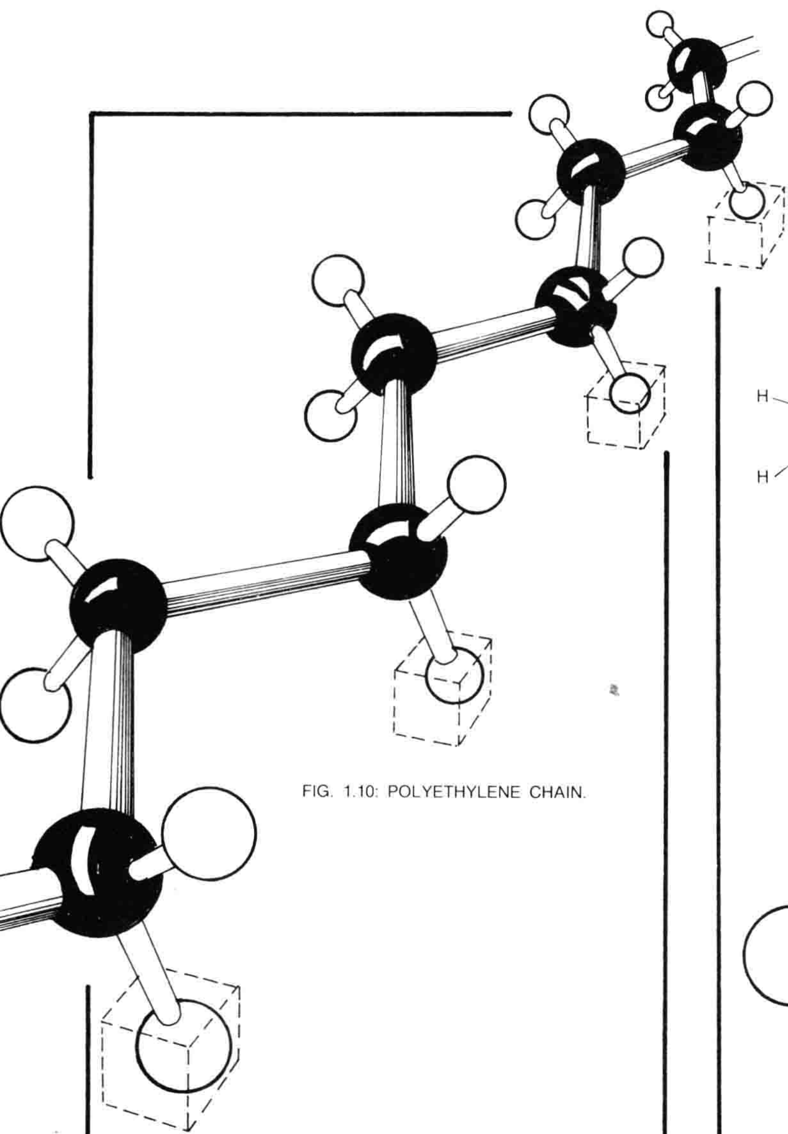


FIG. 1.10: POLYETHYLENE CHAIN.

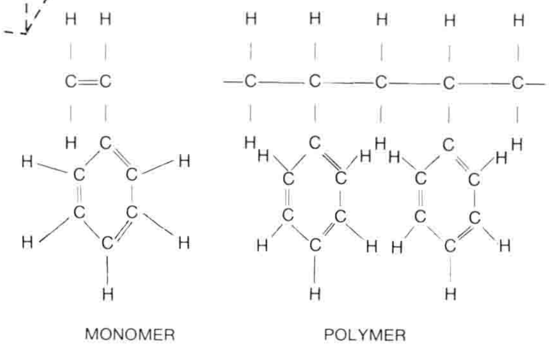


FIG. 1.11: FORMULA FOR POLYSTYRENE.

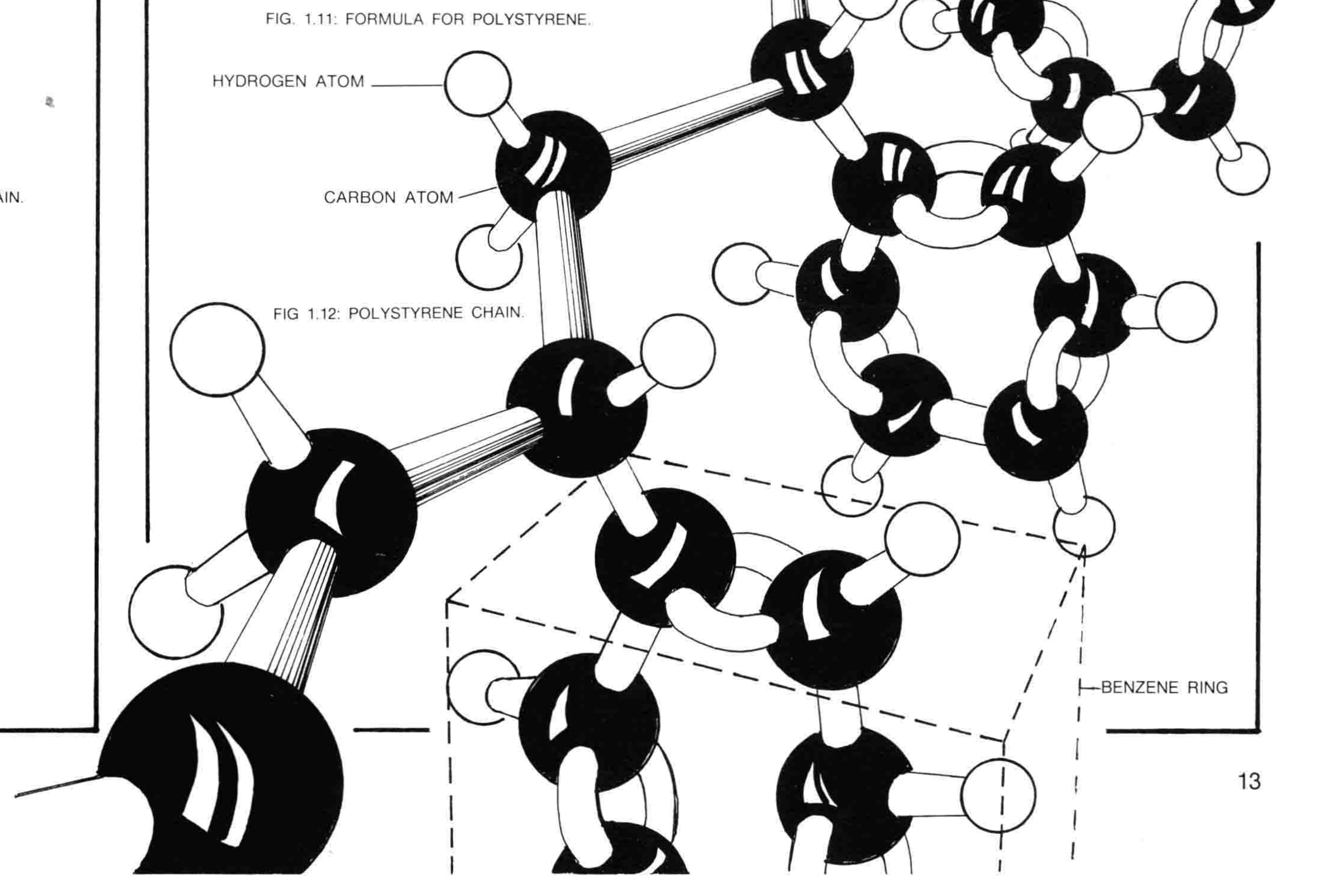


FIG 1.12: POLYSTYRENE CHAIN.

PMMA (Polymethylmethacrylate)

Polymethylmethacrylate (Figure 1.13) again has the familiar carbon backbone, but now two hydrogen atoms have been replaced on each alternate carbon. On one side an additional carbon and three hydrogens have been attached, while on the other there is a more complex arrangement of carbon, oxygen and hydrogen atoms. Notice that in this grouping a double bond exists between one oxygen and the carbon attached to the main chain, while another oxygen links this carbon by single bonds to a second carbon and three further hydrogens.

From this structure it can be deduced that the material will be thermoplastic.

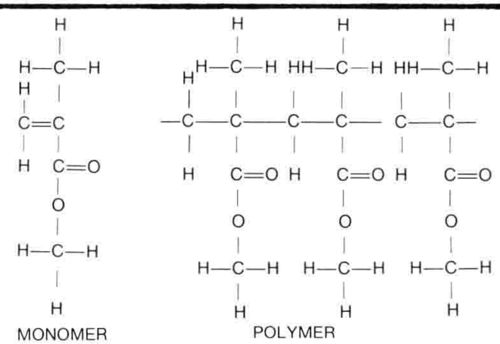


FIG. 1.14: FORMULA FOR PMMA.

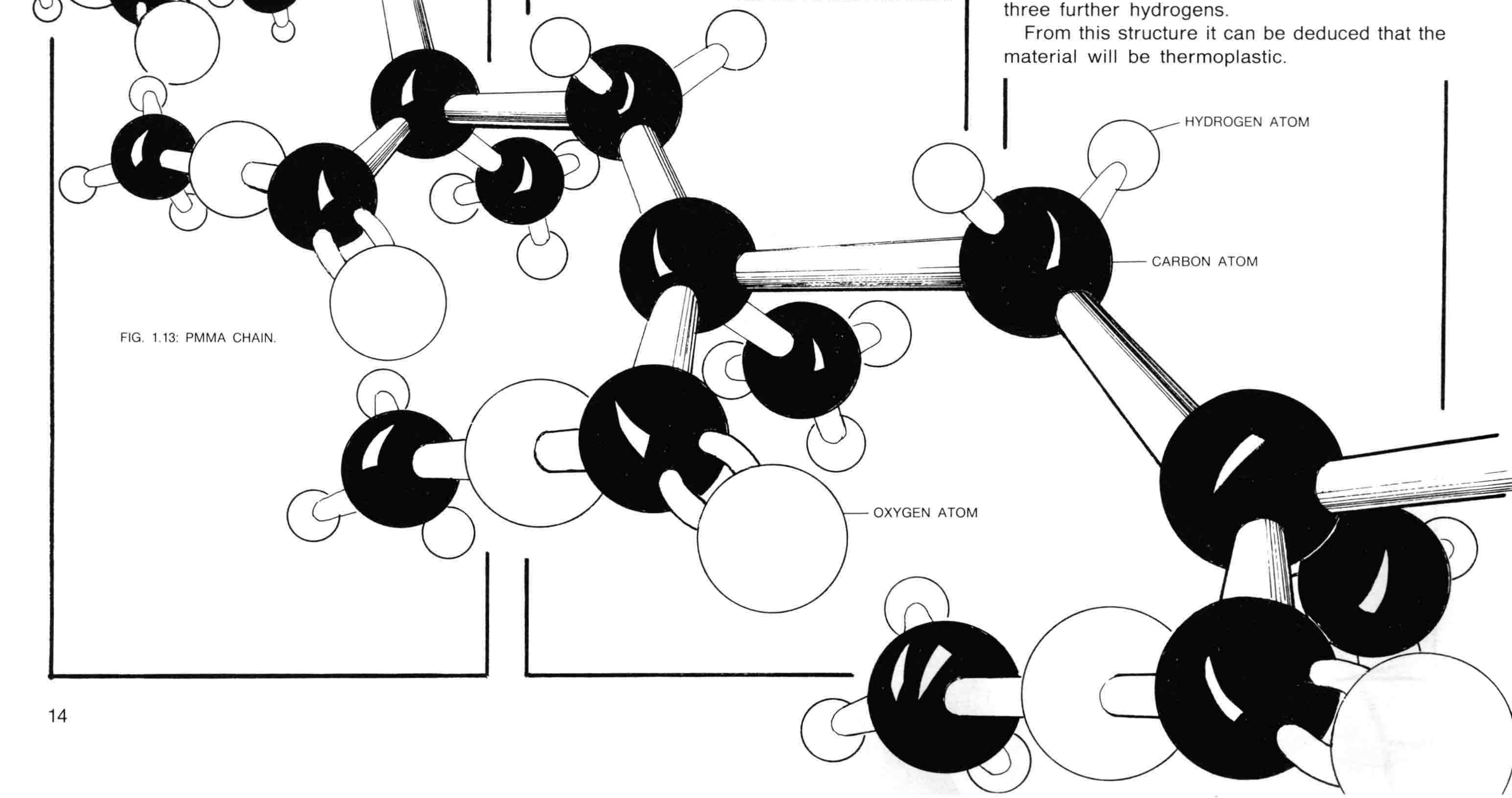


FIG. 1.13: PMMA CHAIN.

THERMOSETTING PLASTICS

Urea formaldehyde

Figure 1.15 shows a large molecule formed from five molecules of urea and four molecules of formaldehyde. This is the product of a condensation reaction between two dissimilar types of molecule.

It is important to notice that the shape of the urea formaldehyde molecule is unlike any of the others previously shown. It links three-dimensionally, and the schematic drawing shows it spread out in a box to suggest its arrangement in space.

Imagine many more combined together and tightly packed. They would become interwoven and inseparable, like twigs and branches in an old hedge, forming one giant molecule. So it is with all thermosetting plastics. The atoms become chemically linked and cannot be reshaped because they will not separate and slide on heating. In effect, when they are processed to make a product the heat causes a chemical reaction to take place, and the pressure compacts the atoms into a form that is then permanent. The new material cannot easily be attacked by other chemicals, is unaffected by heat and when properly moulded makes strong, long-lasting, hard-surfaced components.

Figure 1.16 shows diagrammatically the arrangement of the molecules of urea and formaldehyde before and after combining to form the new material. Examine Figure 1.16 and find where the molecules start and finish on Figure 1.15. Notice how the molecule in the centre is an incomplete bridge between the other four. The formaldehyde carbon and two hydrogen atoms form links between the molecules and are shared.

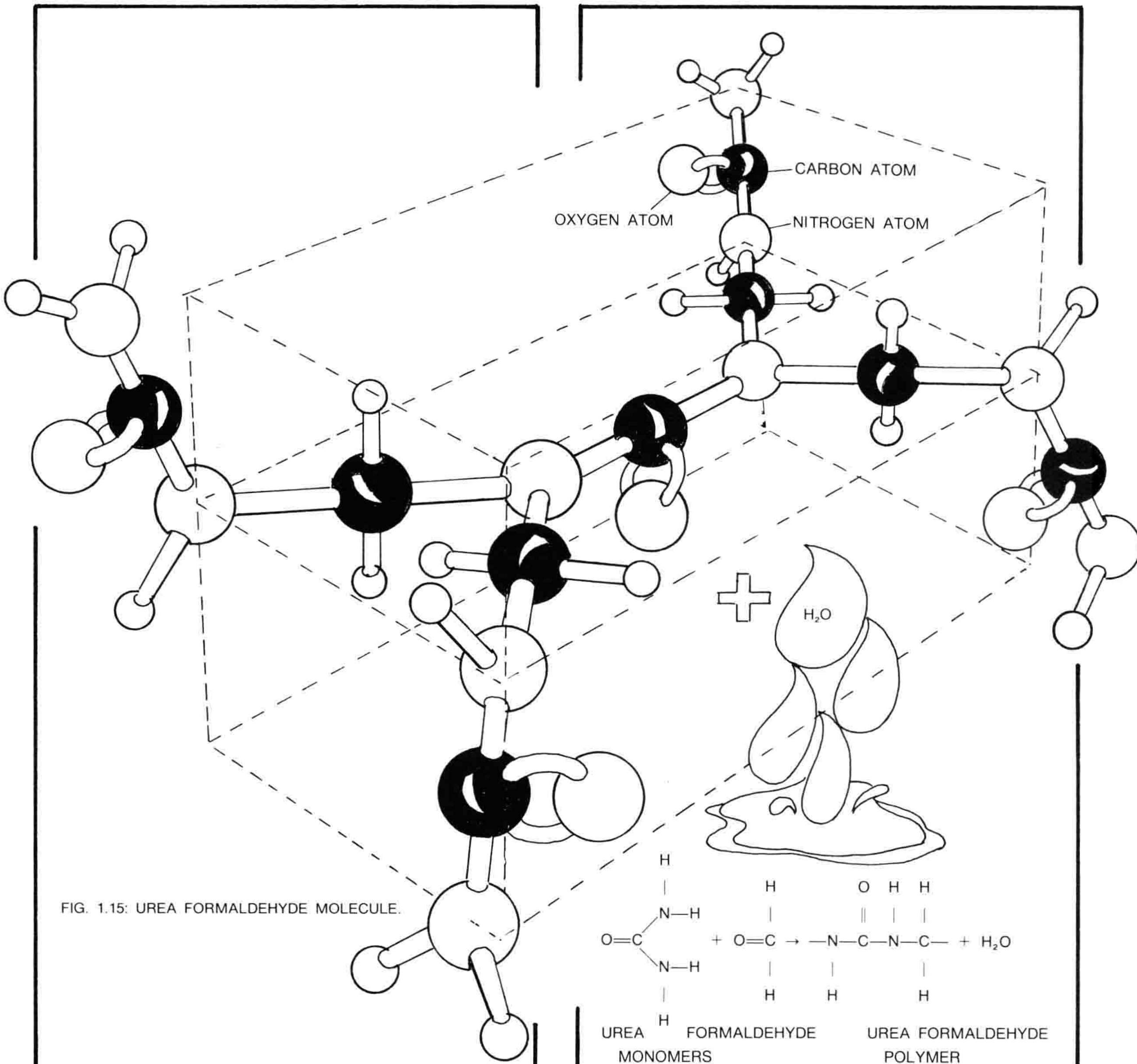


FIG. 1.15: UREA FORMALDEHYDE MOLECULE.

FIG. 1.16: FORMULA FOR UREA FORMALDEHYDE.

PROJECTS AND ACTIVITIES

(1) Find a steel ruler, a wooden ruler and a plastic ruler of similar size. They are samples of three different materials. Devise some tests to show how the materials differ. Write down a list of the properties of each material. Then using this information decide which materials are most suitable for making:
 (a) a writing instrument;
 (b) a bath toy;
 (c) a door handle;
 (d) a pair of scissors;
 (e) a bottle to contain hair shampoo;
 (f) a garden chair.

(2) Some materials that occur naturally show thermoplastics properties when heated (hair, bone, horn, tar and pitch for example). Can you describe how we use these properties and find any examples of uses for these materials?

(3) Look around your home and find an example of a product with variations made from different materials (a coathanger, for example). Collect three versions made in different ways from different materials. Draw them in detail and discuss their structural, practical and visual qualities.

(4) Why are van de Waals forces important in thermoplastics materials and what effect does heat have on them?

(5) In the kitchen you will find storage containers made entirely from plastics materials. Cooking pots and pans are made from glass, metal and ceramics but not plastics. Why is this?

(6) Can you find out how many parts of the human body can be replaced with plastics materials? Why are plastics suitable for replacement parts? Draw a chart of a human figure, identify where the replacement parts are used and label them with the names of the plastics.

(7) Plastics are used as substitute materials for some natural materials. Can you find and make a display of some examples of plastic that look and perhaps feel like (a) leather, (b) bone, (c) ivory, (d) marble, (e) string, (f) silk, (g) fur, (h) wool, (i) wood, (j) chrome metal. Discuss in class whether it is good practice to make plastics look like natural materials.

(8) Some people claim that plastics packaging has increased the litter problem in this country. Is it because plastics do not rot easily that the problem arises or is it for another reason? See if you can find out anything about **bio-degradable** plastics (plastics that rot and breakdown by the action of bacteria and weather). Would these materials solve the litter problem or would other problems occur?

(9) Take several pieces of different 'rigid' plastics materials, each 110 mm long, 20 mm wide and 3 mm thick. Clamp them firmly to the end of a bench, leaving 100 mm of each sticking out. Suspend a 10 g weight from each and measure the amount of deflection (sag) that takes place. Leave them in position with their weights for two weeks and measure the deflection every day. Draw a graph for each material. This will show you the property of creep. At the end of the period examine and record any permanent 'set' that the materials have taken. How important is this in designing plastics products?

(10) Can you find the following names of plastics materials in the word search below? (Letters can be used more than once.)

ACRYLIC
ACRYLONITRILE BUTADIENE STYRENE
CELLULOSE ACETATE BUTYRATE
EPOXY
MELAMINE FORMALDEHYDE
POLYAMIDE
POLYCARBONATE
POLYESTER
POLYETHENE
POLYPROPYLENE
POLYSTYRENE
POLYURETHANE
POLYVINYLCHLORIDE
PHENOL FORMALDEHYDE
UREA FORMALDEHYDE

E	F	O	R	M	A	L	D	E	H	Y	D	E	O	P
N	J	E	L	I	R	T	I	N	O	L	Y	R	C	A
I	E	B	P	O	L	Y	U	R	E	T	H	A	N	E
M	D	U	R	E	S	O	L	U	L	L	E	C	Y	N
A	I	T	E	A	C	E	T	A	T	E	B	A	L	E
L	M	A	T	Y	E	P	O	X	Y	K	U	R	O	L
E	A	D	S	P	O	L	E	L	Y	V	T	B	P	Y
M	Y	I	E	L	L	E	N	T	L	I	Y	O	H	P
A	L	E	Y	X	P	O	L	Y	O	N	R	N	E	O
C	O	N	E	N	E	H	T	E	P	Y	A	A	N	R
R	P	E	S	T	Y	R	E	N	E	L	T	T	O	P
Y	U	S	E	D	I	R	O	L	H	C	E	E	L	Y
L	R	E	D	Y	H	E	D	L	A	M	R	O	F	L
I	E	E	E	N	E	R	Y	T	S	Y	L	O	P	O
C	A	F	O	R	M	A	L	D	E	H	Y	D	E	P