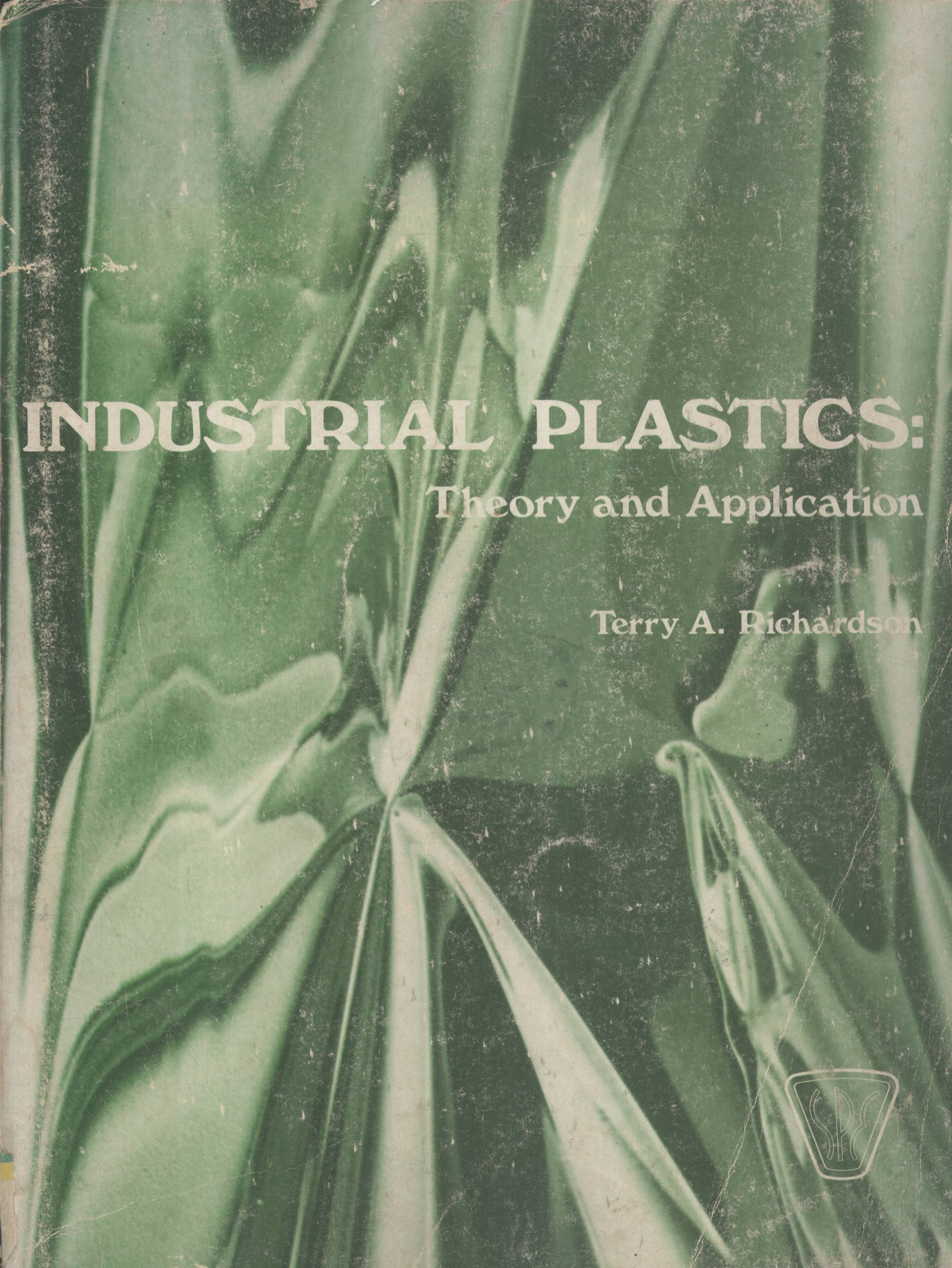

INDUSTRIAL PLASTICS:
Theory and Application

Terry A. Richardson

INDUSTRIAL PLASTICS: Theory and Application

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FOREWORD

One of the purposes of the Society of Plastics Engineers (SPE) is the education of technologists, scientists, and engineers in polymers and plastics. Dr. Terry Richardson, author of INDUSTRIAL PLASTICS: Theory and Application, has been one of the leading educators in plastic technology for many years and his text is an invaluable introduction to plastics. The Society of Plastics Engineers is pleased to sponsor and endorse this edition. We feel this text will attract even more high quality technical people to the rapidly growing and evolving technical discipline of plastics.

The Technical Volumes Committee of SPE has been charged with surveying and evaluating needs for specific technical books since 1956. In that time, it has been the catalyst for publication of more than 50 books dealing with previously undefined, important areas of the plastics industry. The committee works with authors and publishers and reviews the contents of manuscripts to ensure accuracy of the technical material and to determine usefulness to SPE members. This concern with technical accuracy and detail is typical of the way in which the Society deals with its other activities — educational programs, conferences, periodicals, and meetings.

The SPE's 26,000 practicing plastics engineers and technologists are its greatest resource — a resource that has made SPE the largest and most respected worldwide organization of its type.

Again, the Society is enthusiastic in its sponsorship of INDUSTRIAL PLASTICS: Theory and Application by one of the leading educators in plastics education.

James L. Throne, Chairman
Technical Volumes Committee
Society of Plastics Engineers, Inc.
14 Fairfield Drive
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PREFACE

INDUSTRIAL PLASTICS: Theory and Practice is designed to meet the training needs of the plastics industry of today. The purpose of this textlab manual is to present and apply the theory needed in the technology of plastics.

There are an increasing number of people, in a wide variety of industries, who find a need to know about plastics. Each family of plastics has unique characteristics which are as different from metals, wood, and ceramics as they are different from each other.

The plastics industry has never been stagnant and continues to expand. New materials, processes, and applications are introduced each year. There are not enough qualified technical personnel to meet the needs of this ever expanding industry.

This textlab manual can be used at various levels — at the technician level or to upgrade the level of practicing technicians.

ORGANIZATION

The plastics technology content in INDUSTRIAL PLASTICS: Theory and Practice is covered in a practical rather than a theoretical manner.

The material is organized to enable the reader to reach a basic knowledge of chemistry, properties, testing, designing, processing, fabricating, tooling, and manufacturing plastics. Each chapter may be studied independently and not in the exact order presented. Five appendices are included to reinforce the technical presentations.

FEATURES

Special effort has been made to make INDUSTRIAL PLASTICS an effective learning tool. Chapters are divided into short units of instruction. The text is readable. Language and style have been carefully monitored for easy comprehension. All technical terms are defined and used in context. Textual presentations are illustrated extensively. Within each chapter, there is a series of learning reinforcements and immediate feedback through a vocabulary development program and a "test your knowledge" activity. Theory is reinforced through a series of laboratory activities.

INDUSTRIAL PLASTICS: Theory and Practice is supported by an instructor's manual and key that contains specific teaching suggestions, a test bank, bibliography, source list, and key to the end-of-chapter activities. To assist the instructor, a series of transparency/duplicating masters is provided in the manual. These may be used for a visual presentation on the overhead projector, duplicated for class handouts or for class assignments. This teaching/learning program will provide the reader with a basic understanding of the most versatile and useful materials on earth.

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1

Introduction to Plastics

In this chapter you will see how advances in chemistry and technology have made possible a new industry, and you will learn how that industry—plastics—has changed our lives.

Early humans probably learned about fire from nature. Their earliest tools were stone. Their earliest fuel was wood. Their earliest mode of transportation was on foot.

Early people probably found raw materials—copper, gold, and iron—in the earth. Later, they found methods of processing raw materials. As humans began to industrialize, they needed to make goods that were strong, malleable, durable, and practical. However, materials with all of these properties could not be found in natural form. Synthetic materials, which do not occur naturally, were needed. Over the period of time since humans began to find the materials they needed, many synthetic materials have been developed.

1-1 CHEMISTRY

In the Middle Ages, alchemists tried but failed to produce gold from common metals such as tin, iron, and lead. The modern words *chemistry* and *chemist* are derived from the medieval Latin word *alchimista*.

Chemistry is a science that deals with the composition of matter and how that composition changes. The two broad classes of chemistry are *inorganic* and *organic*. Inorganic chemistry studies matter that is mineral in origin. Organic chemistry deals with matter that contains the element *carbon*. The term organic was used originally to mean compounds of plant or animal origin, but now it includes also many synthetic materials that have been developed through research. One such group of synthetic organic materials is called *plastics*.

1-2 THE AGE OF PLASTICS

What material may be as hard as stone, as transparent as glass, as elastic as rubber? What can be strong yet light, moisture and chemical resistant, and any of a rainbow of colors? The answer, of course, is plastics. According to the Society of the Plastics Industry, Inc. (SPI), production by volume of plastics will surpass that of steel and all other materials combined by the year 2000 (Figs. 1-1 and 1-2). Today may truly be called the *Plastics Age*.

The word plastics comes from the Greek word *plastikos*. It means "to form or fit for molding." The Society of the Plastics Industry has defined plastics as follows:

> Any one of a large and varied group of materials consisting wholly or in part of combinations of carbon with oxygen, nitrogen, hydrogen, and other organic or inorganic elements which, while solid in the finished state, at some stage in its manufacture is made liquid, and thus capable of being formed into various shapes, most usually through the application, either singly or together, of heat and pressure.

Because plastics are closely related to resins, the two are often confused. Resins are gum-like

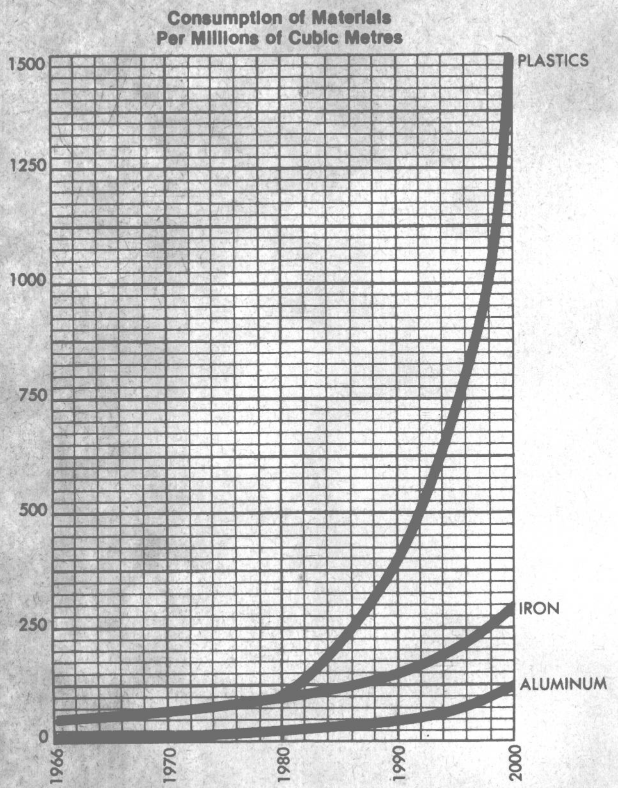


Fig. 1-1. Projected annual world consumption of selected materials through the year 2000. *Based on presentations at the World Chemical Engineering Congress.* (SPI)

solid or semisolid substances used in making such products as paints, varnishes, and plastics.

A resin is not a plastics unless and until the resin has become a "solid in the finished state." Plastics products are often made from resins that are processed and made solid. Both natural and synthetic resin materials are composed of a series of molecules bonded together with some resins having several thousand bonded molecules.

1-3 HISTORY OF PLASTICS

Observations by the Swedish chemicst J. J. Berzelius led, in 1833, to the production of one of the first synthetic compounds containing several thousand molecules.

The term *polymer* was first used by the chemist H. V. Regnault, when, in 1835, he synthesized the plastics vinyl chloride. A polymer is a substance that has large molecules made by joining many small molecules of one or several substances.

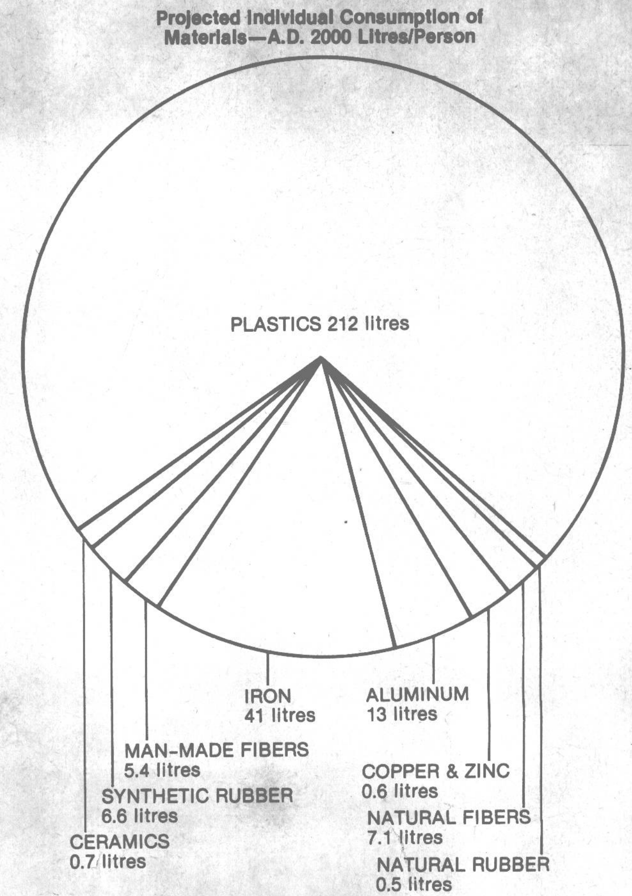


Fig. 1-2. Projected annual consumption of materials, per person, by the year 2000. *Based on presentations at the World Chemical Engineering Congress.* (SPI)

The first known commercial use of polymeric material occurred in 1843, by Dr. George IV William Montgomerie, a Malayan surgeon. He noted that the Malayans used a natural polymer material, *gutta percha,* to make knife handles and whips. Resins collected from the gutta percha trees were sent to England to interested scientists and manufacturers.

Michael Faraday, a pioneer in electricity, found that gutta percha was a good electrical insulator in water and so it was used as insulation for the first transatlantic cable. Modern undersea cables still use plastics for bases, housings, shields, and cores. Figure 1-3 shows an undersea telephone cable amplifier that is designed to work at depths of up to 4 kilometres [2½ miles] and will last for more than 20 years.

In 1862, Alexander Parks of Birmingham, England, displayed a new plastics at the International Exhibition in London. Called *Parkesine,* this plas-

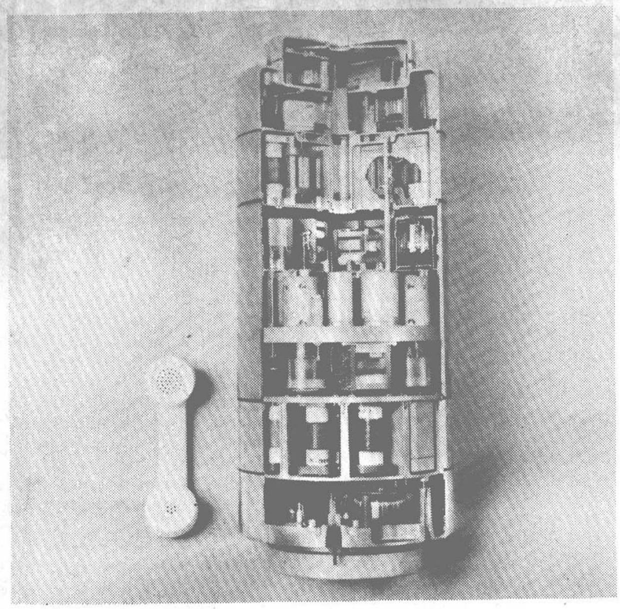


Fig. 1-3. A modern application of plastics in a device intended for continuous use on the ocean floor. (Western Electric)

tics was made from nitrocellulose containing less than 12 percent nitrogen. When the nitrogen content of nitrocellulose, a combination of nitric acid and cellulose, is more than 13 percent, the material is known as *guncotton,* an explosive used in the Civil War and World War I.

John W. Hyatt, a New York printer, began synthetic plastics production in the United States. In 1868, Hyatt responded to an advertisement to find a substitute for gutta percha and for the ivory used for billiard balls. There is no record that Hyatt ever received the reward, but he did succeed in producing a new plastics. Figure 1-4 shows the *Celluloid* billiard ball produced by John Hyatt and his brother, Isaiah.

Hyatt accidentally mixed camphor with some *pyroxylin* (a nitrocellulose with low nitrogen content), and Celluloid resulted. This new, easily molded material was less explosive than previous nitrocellulose plastics.

At the end of the Civil War, there were huge quantities of surplus nitrocellulose. Hyatt and his brother bought a large amount of this surplus to use as raw material and they were granted over 75 United States patents for the production of plastics. An elaborately molded comb and brush produced in the early years of the plastics industry are shown in Figure 1-5.

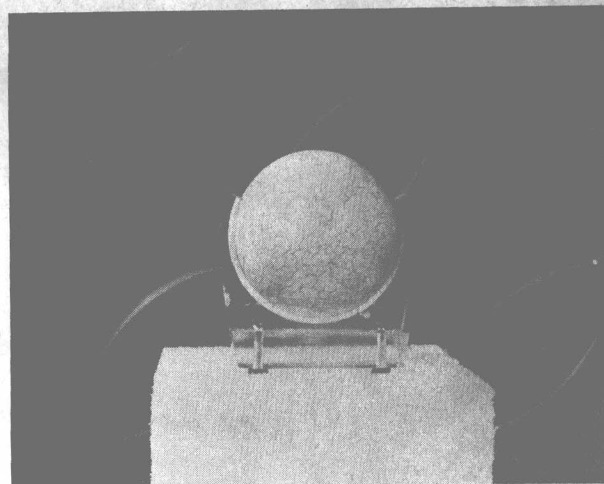


Fig. 1-4. The Hyatt billiard ball, an early Celluloid product. (Celanese Plastic Materials Co.)

Fig. 1-5. A comb and brush produced from Celluloid in 1880. (Celanese Plastic Materials Co.)

In 1897, W. Krische found that protein from milk could be used to make a new plastic material called *casein.* A Bavarian, Adolf Spittler, found that treating the compressed protein sheets with formaldehyde improved their water-resistance. Casein plastics found little favor in the United States, except as adhesives.

Based on the earlier work of a German chemist, Adolf von Baeyer, Leo Hendrik Baekeland of the United States produced a new resin, phenol-formaldehyde, that advanced the commercial use and acceptance of plastics. In 1909, Baekeland secured patents to and began producing plastics products using the trade name *Bakelite*.

Plastics technology developed as new polymers were discovered and new methods of forming and shaping them were devised. New steels for use in molding plastics had to be made. Machinery builders, engineers, educators, salespeople, and others had to learn about this new technology. This education process continues today, as new plastics are introduced (Table 1-1).

1-4 CLASSIFICATION OF POLYMERS

Polymers may be classified by three different systems: *source*, *light penetration*, and *heat reaction*.

Source

When classifying polymers by source, there are three principal categories. These are natural, modified natural, and synthetic polymers (Table 1-2).

Natural Sources of resins include animals, vegetables and minerals. Some common examples are the following:

- *Rosin* is a by-product of turpentine distilling. You may have seen rosin oozing out of pine tree stumps or lumber. It was once widely used in making linoleum and for electrical insulating compounds.
- *Asphalt*, sometimes called pitch, is found in a natural state formed from the decaying remains of plants and animals. Today, most asphalt is a byproduct of the petroleum industry. Asphalt was once used to mold battery cases and electrical insulators.
- *Tar* is obtained by distilling organic materials. Wood, waste fats, petroleum, coal, and peat are sources. Tar is still used on road surfaces, roofs, and in making some color dyes.
- *Amber* is a fossilized resin that formed from the oily sap of ancient coniferous trees. It was once used to mold knife handles and other objects.
- *Copal* is a resin derived from tropical trees. Copal varies from white to brown in color and its resins were once used in paints, linoleum, and varnishes.
- *Lignin* is a resinous binder that surrounds each wood cell. The lignin content of wood varies from 35 to 90 percent depending on the species. Today, most lignin is used as filler for plastics,

Table 1-1. Chronology of Plastics

Date	Material	Example
1868	Cellulose nitrate	Eyeglass frames
1909	Phenol-formaldehyde	Telephone handset
1909	Cold molded	Knobs and handles
1919	Casein	Knitting needles
1926	Alkyd	Electrical bases
1926	Analine-formaldehyde	Terminal boards
1927	Cellulose acetate	Toothbrushes, packaging
1927	Polyvinyl chloride	Raincoats
1929	Urea-formaldehyde	Lighting fixtures
1935	Ethyl cellulose	Flashlight cases
1936	Acrylic	Brush backs, displays
1936	Polyvinyl acetate	Flash bulb lining
1938	Cellulose acetate butyrate	Irrigation pipe
1938	Polystyrene or styrene	Kitchen housewares
1938	Nylon (polyamide)	Gears
1938	Polyvinyl acetal	Safety glass interlayer
1939	Polyvinylidene chloride	Auto seat covers
1939	Melamine-formaldehyde	Tableware
1942	Polyester	Boat hulls
1942	Polyethylene	Squeezable bottles
1943	Fluorocarbon	Industrial gaskets
1943	Silicone	Motor insulation
1945	Cellulose propionate	Automatic pens and pencils
1947	Epoxy	Tools and jigs
1948	Acrylonitrile-butadiene-styrene	Luggage
1949	Allylic	Electrical connectors
1954	Polyurethane or urethane	Foam cushions
1956	Acetal	Automotive parts
1957	Polypropylene	Safety helmets
1957	Polycarbonate	Appliance parts
1959	Chlorinated polyether	Valves and fittings
1962	Phenoxy	Bottles
1962	Polyallomer	Typewriter cases
1964	Ionomer	Skin packages
1964	Polyphenylene oxide	Battery cases
1964	Polyimide	Bearings
1964	Ethylene-vinyl acetate	Heavy-gauge flexible sheeting
1965	Parylene	Insulating coatings
1965	Polysulfone	Electrical and electronic parts
1965	Polymethylpentene	Food bags
1970	Poly(amide-imide)	Films
1970	Thermoplastic polyester	Electrical and electronic parts
1972	Thermoplastic polyimides	Valve seats
1972	Perfluoroalkoxy	Coatings
1972	Polyaryl ether	Recreation helmets
1973	Polyethersulfone	Oven windows
1974	Aromatic polyesters	Circuit boards
1974	Polybutylene	Pipes
1975	Nitrile barrier resins	Packaging
1976	Polyphenylsulfone	Aerospace components

Table 1-2. Principal Polymer Sources

Category	Source	Origin
Natural	Amber Asphalt Copal Lignin Shellac Tar	Naturally occuring deposits; tree gum, sap, and wood cell binder; insect byproduct
Modified Natural	Casein Cellulose Gelatin Protein Rubber	Animal protein, esters, and regenerated animal protein; Plant and animal protein; natural latex
Synthetic	Agricultural products	Fatty acids, alcohols, formaldehydes, and esters from plants; Glycerin, ureas, alcohols, and formaldehyde from animals
	Coal products	Benzene, toluene, coke, xylene, and naphthalene
	Natural gas products	Acetylene and methane
	Petroleum products	Acetylene, ethylene propylene, butene, benzene, toluene, xylene, and naphthalene

or as an adhesive to bind wood chips together under pressure.

- *Shellac* was the first natural resin to be molded. At one time, large quantities of shellac were molded into phonograph records but today, it is primarily used as a filler, wood finish, and electrical insulation.

Modified Natural Sources of resins include cellulose and protein. *Cellulose* is a major part of all plants, thus, it is readily available as a raw material for plastics.

One of the purest forms of cellulose is cotton linters. These are the short fibers that remain on the cotton seeds after the longer fibers have been separated. Polymers made from linters do not yellow and are very transparent. Another major source of cellulose is wood pulp.

Other cellulose sources are plant wastes and residues, such as straw, cornstalks, corncobs, grass, and weeds. All of these materials have proved useful, but are difficult to collect and process.

Cellulose is a very complex material, and many types of plastics are made from it. There are more than ten basic resins in the cellulose family. The most familiar resins are cellulose acetate, cellulose nitrate, cellulose acetate butyrate, and cellulose propionate.

Another modified natural resin source is *protein*, which comes from milk, soybeans, peanuts, coffee beans, and corn. Casein made from skim milk, is the only protein-derived plastics that has had some commercial success.

There are other protein sources including hair, feathers, bones, and similar wastes. There has been little interest in these sources because collection is not easy and there are not many uses for protein-derived plastics. Most are used for adhesives and coatings. Protein plastics absorb moisture and swell, therefore items made from them may warp and change shape.

Gelatin is a protein mixture made from bones, hoofs, and animal skins. It is used as an odorless, tasteless, and transparent filler in candies, meats, ice cream, and drugs.

A very important polymer, *rubber*, is made from a milky juice called *latex*. When people talk about natural rubber, they are usually referring to elastomers made from the latex of the *Hevea* tree. A mature rubber tree will yield about 1.8 kilograms (kg) or 4 pounds (lb) of rubber per year. A polymer that is chemically like rubber is gutta percha. Gutta percha trees that yield the milky latex for this polymer are found in Malaya, Borneo, and Sumatra.

Although there is still a large market for natural rubber products, synthetic rubbers have largely replaced natural resins for most uses.

Synthetic sources are the most important sources of resins for plastics. Agriculture, petroleum, and coal are the three main sources of chemicals for synthetic plastic materials. The most important of these three is petroleum. As it comes from the earth, petroleum is mainly a mixture of solid, liquid, and gaseous *hydrocarbons* that are almost useless. In refined forms, petroleum is the largest volume product, other than water, dispensed to people in the U. S.

Distilling and refining petroleum by a process called *fractional distillation* yields various crude oil components. These include heavy asphalt and tar, lighter oils, and a gaseous portion including propane, butane, and other hydrocarbons (Fig. 1-6).

Residues collected near the *bottom* of the refining tower include asphalt and thick oils. Lighter fuels (kerosene, diesel fuel, gasoline, and benzene) are extracted near the top of the distilling tower. Light gases (methane, ethylene, propane, and propylene) are byproducts of further refining.

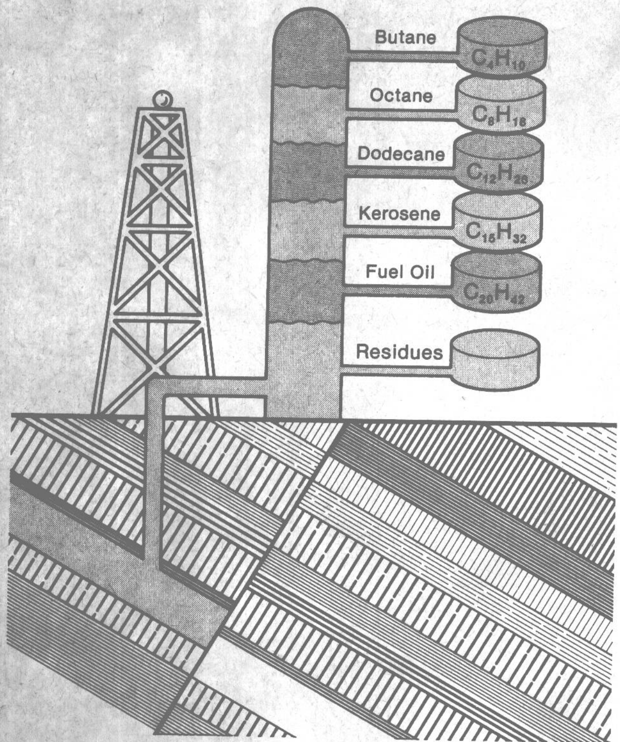


Fig. 1-6. Petroleum is found in deposits deep underground. In a fractionating tower, the material is vaporized by heating. Different products are drawn off at various points.

By varying the proportions of hydrocarbons, salt, chlorine, formaldehyde, nitrogen, and other chemicals, chemists create a great variety of polymers. Hydrocarbons, of course, are the building blocks of polymers. Hydrocarbons also may come from agricultural products, such as cottonseed, linseed, soybean, lard, and safflower. Methane and other gases may come from sewage sludge and crushed coal.

The human race is draining the world's reserves of oil and coal. Soon, we will have to turn to other hydrocarbon sources to produce polymers, thus farm and human waste products will have to be used more than they are today.

Plastics technologists are also working on the secrets of *photosynthesis*. Photosynthesis, the process by which plants convert light and carbon dioxide into sugar may lead to new ways of producing simple organic chemicals. Bacteria or small plants may ferment sugar to produce alcohol, a raw substance for making many plastics.

Light Penetration

Because many plastics possess unique optical properties they are often classified relative to light penetration. The following optical properties summarize this classification.

- *Opaque* —Light will not pass through. Cannot be seen through.
- *Transparent* —Light will pass through. Can be seen through.
- *Translucent* —Light will pass through. Cannot be seen through.
- *Luminescent* —(a) *flourescent*: emits light only when electrons are being excited, usually transparent; (b) *phosphorescent*: gives off light energy more slowly than it takes on light, translucent.

See the further discussion of optical properties in Chapter 4.

Heat Reaction

All plastics fall into two broad categories with regard to their reaction to heating. They are either thermoplastic or thermosetting.

Thermoplastic materials become soft when heated and solid when cooled to room temperature. This softening and setting may be repeated many times. It is something like melting and cooling wax. When cooled, the plastics become firm.

The most useful members of the thermoplastic group are acrylics, cellulosics, polyamide, polystyrene, polyethylene, fluoroplastics, polyvinyls, polycarbonate, and polysulfone. See Chapter 7 for a complete discussion of thermoplastics materials.

Thermosetting materials may not be reheated and softened again. Once the structural framework is set, these plastics cannot be reformed. A simplified analogy is that hardening a thermosetting plastics is like baking a cake or boiling an egg.

Useful members of the thermosetting group include aminos, casein, epoxies, phenolics, polyesters, silicones, and polyurethanes. See Chapter 8 for a complete discussion of thermosetting plastics materials.

A list of ten general advantages and disadvantages of plastics follows. It is included to show positive and negative aspects of plastics in general. For example, not all plastics are difficult to repair, nor do all deteriorate easily. Cost factors may be considered an advantage in many plastics products.

Advantages of plastics

1. Chemical resistance
2. Good thermal insulating properties
3. Good electrical insulating properties
4. Good strength-to-mass ratio
5. Lightness in mass (weight)
6. Ease of processing
7. Available in a variety of forms
8. Capable of being foamed or made flexible
9. Available as transparent, translucent, or opaque
10. Available in wide range of colors

Disadvantages of plastics

1. Dimensional instability
2. Limited useful thermal range
3. Fragility (may break, crack, or scratch easily)
4. Flammability (many burn easily)
5. Incapable of absorbing moisture
6. Non-degradability (some do not decompose)
7. Subject to attack by chemicals (deteriorate)
8. Odors or chemical fumes in processing
9. Difficulty of repair
10. Cost

1-5 MODERN INDUSTRIAL PLASTICS

The first commercial plastics, *Celluloid,* was developed about 100 years ago, but in recent decades, explosive growth and diversification have occurred in the industry. Since World War II, the plastics industry has been growing at a rate double that of other industries. Compare the modern plastics plant shown in Figure 1-7 with the first plastics plant, shown in Figure 1-8.

Plastics are widely used in everyday living—at home, on the job, and even at the frontiers of space. From housewares to exotic aerospace applications, plastics are replacing more traditional materials (Fig. 1-9). The volume of plastics consumed in the United States is expected to exceed the volume of metals consumed in 1983 (Fig. 1-10).

Although most people think of plastics as housewares or toys, their biggest growth areas are elsewhere (Fig. 1-11). Construction is the number one market for plastics, despite limited acceptance by labor unions and the public. Electronics now uses about 1 000 000 tonnes [1 102 000 short tons] of plastics, worth three billion dollars, in the manufacture of components. The growing use of plastics in transportation is most evident in the automobile industry. The packaging industry has long been a high volume user of plastics and that trend continues to grow.

1-6 DESIGNING WITH PLASTICS

Plastics have helped produce new designs in both the automotive and aerospace industries. Many plastics are stronger and lighter than the metallic parts they replace. Plastics have also been considered as primary construction material and molded and shaped into new parts for vehicles. With increasing demands for emission control and fuel economy, plastics are an important automotive design element. Reducing mass is one of the most efficient ways of increasing fuel economy.

Because plastics materials are easily processed, they have become the perfect substitutes for other materials. Often better results may be gained by using plastics as the original design material rather than as a substitute material. Many of the early uses of plastics were failures because plastics products were designed with little regard for the properties and limitations of the material. A lack of structural design knowledge is a problem even today, because plastics are not sufficiently understood by some designers, engineers, and technicians.

Plastics are known by many names, some of which are hard to pronounce. For this reason, manufacturers use trade names for their brands of resin, knowing these names are easier for consumers to pronounce and remember. For example, *Acrylite, Lucite,* and *Plexiglas* are trade names for polymethyl methacrylate, resins manufactured by three different companies. *Acrylic* is used as the common name. (See Appendixes B and C.)

1-7 EXTENT OF THE PLASTICS INDUSTRY

What is the extent of the plastics industry? With each passing day, it becomes increasingly dif-

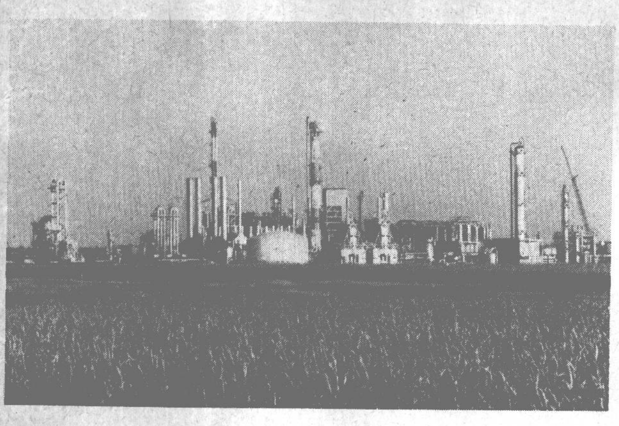


Fig. 1-7. A modern plant for manufacturing plastics. (Chemplex Company)

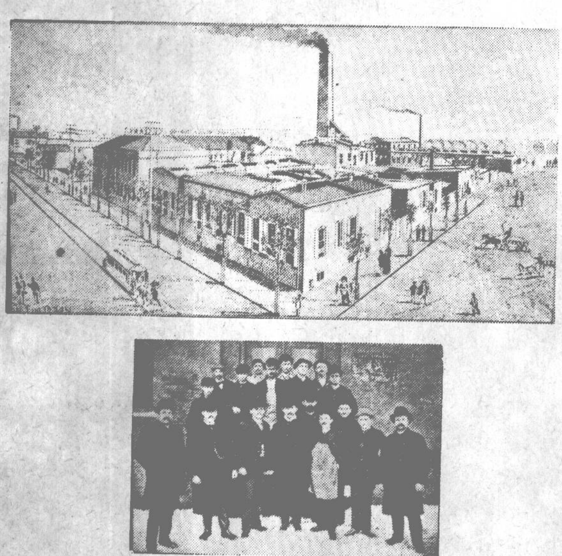


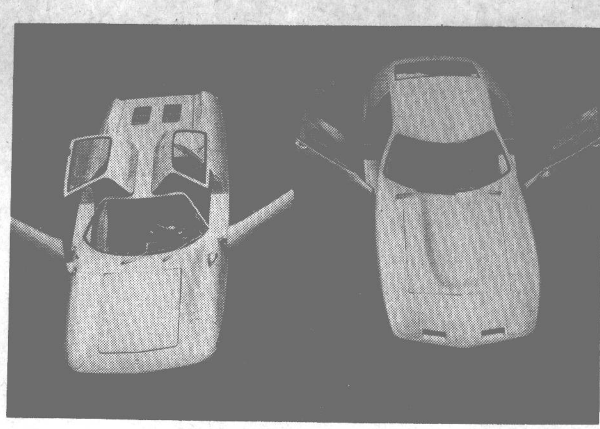
Fig. 1-8. The first plastics plant in the United States, with some of the personnel. (Celanese Plastic Materials Co.)

ficult to define plastics as a discrete industry. Plastics are products of companies in practically every industry including steel, paper, chemicals, petroleum, and electronics, to name only a few.

The plastics industry may be divided into three large categories that sometimes overlap:

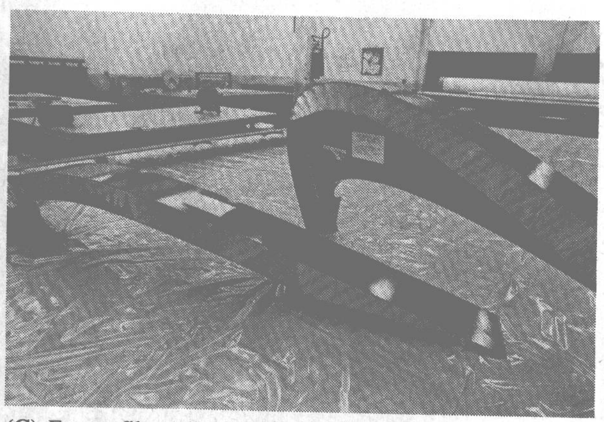
1. The material manufacturer who produces the basic plastics resins from chemical sources
2. The processor who converts the basic plastics into solid shapes
3. The fabricator and the finisher who further fashions and decorates the plastics.

In Figure 1-12, a simple flow chart of the polymer industry is shown. There may be additional



(A) Autos with bodies and trim of plastics. (Borg-Warner Chemicals)

(B) Solid vinyl siding doesn't rot or peel, and requires no painting. (Bird & Sons, Inc.)



(C) Epoxy film adhesive bonding is used for the leading edge of wing slats for the military C-5A cargo plane. (Lockheed-Georgia)

Fig. 1-9. Diverse uses of plastics.

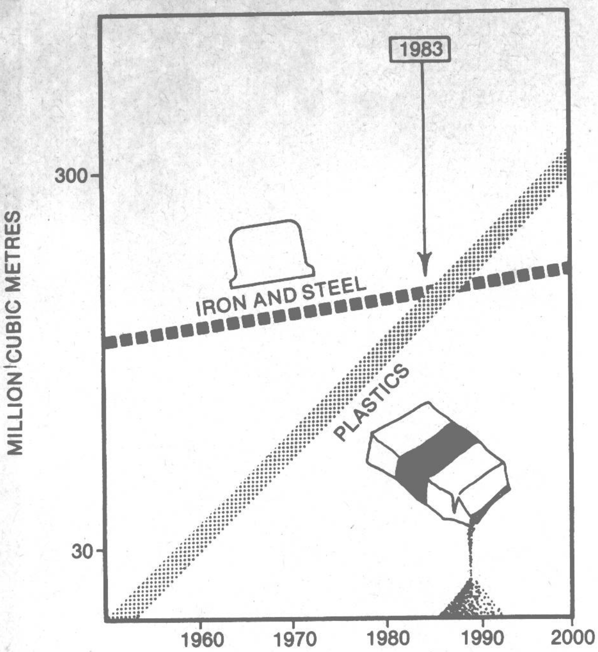


Fig. 1-10. World consumption of iron and steel and of plastics, through the year 2000. From the pamphlet *The Need For Plastics Education*. (SPI/SPE)

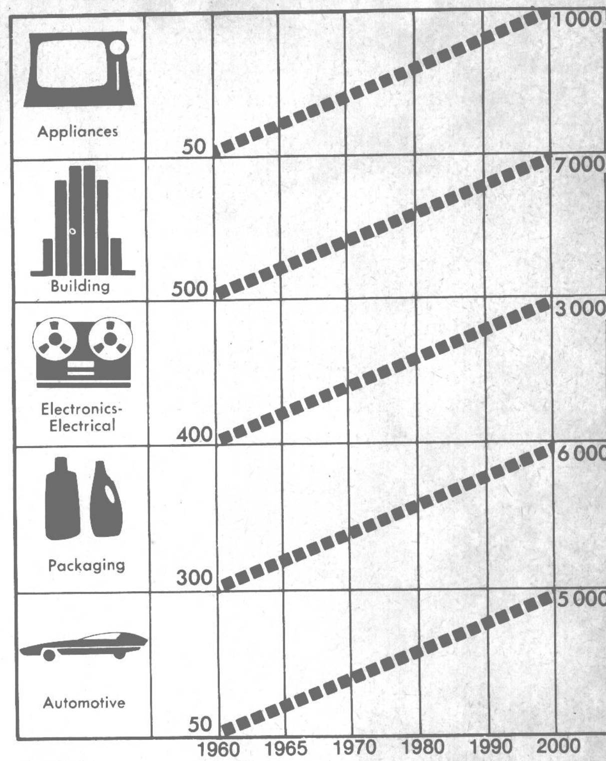


Fig. 1-11. Estimated consumption of plastics by selected industries through the year 2000, in thousands of metric tonnes.

connecting lines between the polymer industry, processing industry, and fabrication industry. Also, a connecting line could be drawn to the waste and recycle stage. There are waste products in all stages. Plastics and other chemicals are recycled in each stage. Recycling is more economical by saving energy and material resources.

Odor, noise, and, in processing, radiation pollution are among problems that affect the plastics industry. Pollutants have been given increased attention because of their effect on people and the

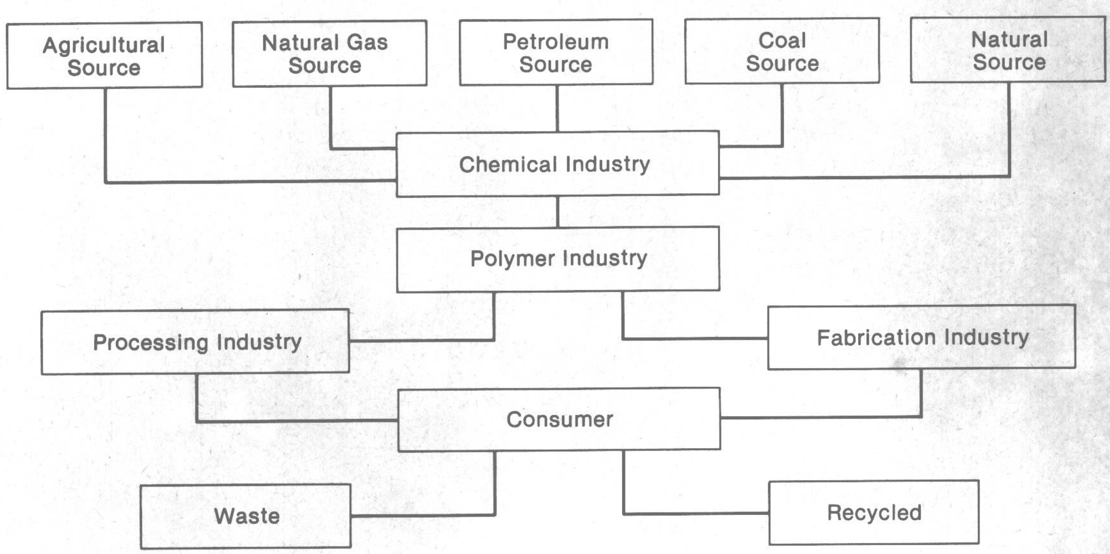


Fig. 1-12. Flow chart of the polymer industry.

environment. These effects can involve a remarkable range of problems including chemical, physical, social, physiological, and even psychological damage. The plastics industry must apply the knowledge and technology at hand to solve these problems.

Vocabulary

The following vocabulary words are found in this chapter. Look up the definition of any of these words you do not understand in the glossary, Appendix A.

Celluloid
Elastomer
Gutta percha
Inert gases
Lac
Latex
Nitrocellulose
Plastics
Polymer
Resin
Shellac
Synthetic
Technology
Trade name