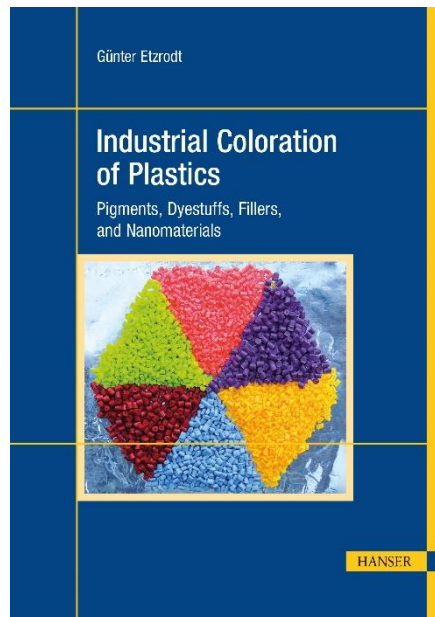


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Günter Etzrodt

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(haftungsbeschränkt)

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1

Introduction

Colors play an important role in our everyday life. We react to colors intellectually, for example, because we have learned to only cross the street when the crossing light is *green* and to wait when it is *red*. But we also react to colors emotionally. The color red is perceived as a warm color and stands for energy and warmth, joy, passion, and love among other things. On the other hand, the color blue belongs to the cold colors and is seen in connection with ice, snow, and cold emotions. *Uniform objects can be supplied to different purposes by different colors.*

This book discusses pigments, dyes, and fillers for plastics and their properties, including the processing method. An indication of the classification at the European Chemical Agency (ECHA) [7] is given in the case of critical toxicological pigment properties. The nano pigments are also discussed in detail.

The present book sets out to convey that knowledge in a straightforward and understandable manner, without compromising scientific objectivity and rigor. Special attention has been given to clear topical division and structuring to facilitate finding pertinent information quickly. That having been said, the gamut of available colorants and fillers is so vast that there would be insufficient space to cover all the materials out there, some of them quite exotic.

Instead, this book concentrates on colorants and fillers in regular current use, with numerous figures and tables to illustrate their properties and applications. All the same, this book cannot claim to be exhaustive in scope. Readers wishing to obtain further information and details will be served by the extensive bibliographic references provided.

This book is intended for anyone who is professionally involved with colorants and fillers used in plastic materials. Beginners and students will gain a comprehensive overview of the field, while experienced developers will find practical details of immediate relevance to solving their everyday problems.

The colorants are listed according to the internationally used Color Index [1]. The chemistry of the respective colorant cannot be recognized from this designation. This knowledge is essential for the colorist because he/she can already recognize

the essential properties of the respective colorant from chemistry. For this reason, the chemistry of individual colorants is consciously dealt with. The formulas are listed and, for organic pigments and dyes, the structural formulas are also presented. Additionally, the CAS (Chemical Abstracts Service) and EC (European Commission) numbers are given, which are useful in everyday business.

As everywhere in daily life, a series of laws and regulations must be followed, also in the coloring of plastics. The number of these regulations has increased significantly in recent years due to intensive toxicological research into the effects of substances on the human organism. Thus, the properties of colorants are being re-evaluated. The consequence can be a limitation or ban on the use of substances. Typical examples of this are the previously widely used cadmium and lead pigments, and several specific azo colorants (keyword “disazodiaryl pigments”). The discussion about nanoparticles, and the methods of how these are to be measured, is not yet complete. The new classifications of pigments as nanoparticles by the ECHA are still in process. Possible carcinogenic potentials of carbon black and titanium dioxide are being discussed.

There have also been significant changes in the economy. Traditional European pigment producers were taken over by other companies or outsourced from groups. The cost pressure has risen sharply: Chinese and Indian pigment manufacturers are entering the market – some with good qualities.

Except for two new inorganic orange pigments, completely new pigment bases have not come onto the market in recent years. Pigment development focuses on improving the pigments’ application properties, such as color strength, dispersibility, temperature resistance, and on variations in the effect pigments. Issues such as thermal management have been added.

This book discusses also the physical basics of color formation, color perception, and color measurement. Since there is already extensive literature in this area [2] [3] [4] [5], this topic is only highlighted selectively.

The processing techniques for plastic coloring and the production of masterbatches and preparations are also described [6].

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2

Color and Color Measurement

Countless color variations surround us in everyday life. The term “color” is so evident that it is easy to overlook the role that color plays in everyday life. Although color has a fundamental impact on our lives, our knowledge of “color” and how to use it in a controlled manner is often not sufficient – which can lead to problems when defining or communicating product colors. The assessment often takes place under the influence of personal feelings and experience, making a uniform assessment impossible.

The human eye perceives light in the visible range. However, “light” is not the same as “color”, but, first of all, electromagnetic radiation, which triggers nerve impulses on the retina and which makes “seeing” possible at all. The **spectrally sensitive** sensory cells of the retina transmit their signals to the brain, where this information creates the color impression. So, color is a **sensory impression** in the human brain. Visible light is a small part of existing electromagnetic waves. Different wavelengths are perceived as different colors. Color is, therefore, a perceptual phenomenon that depends on the observer and the conditions under which the color is observed. However, there is no physical quantity for the determination of colors like for length or weight.

Three things are required to perceive colors [1]:

- an object,
- a light source (illuminant), and
- an observer.

The human brain successfully uses the color impression for object tracking and recognition. However, the color of an object changes when the color of the illuminant changes or when the object is against a different colored background.

The energy in the form of light is required to see colors. To better understand the “color” phenomenon, we need to recognize the origin of light. Light comes from a variety of sources and consists of electromagnetic radiation, a form of energy that propagates in a wave motion. All visible light consists of a mixture of colors that are put together in different proportions to form every distinctive visible light. The

way we measure light is spectral energy distribution, in Figure 2.1 the visual color spectrum begins at 400 nm and ends at 700 nm wavelength. Light with wavelength below 400 nm is called ultraviolet (UV), and that above 700 nm is called infrared (IR). The human eye cannot perceive ultraviolet or infrared light.

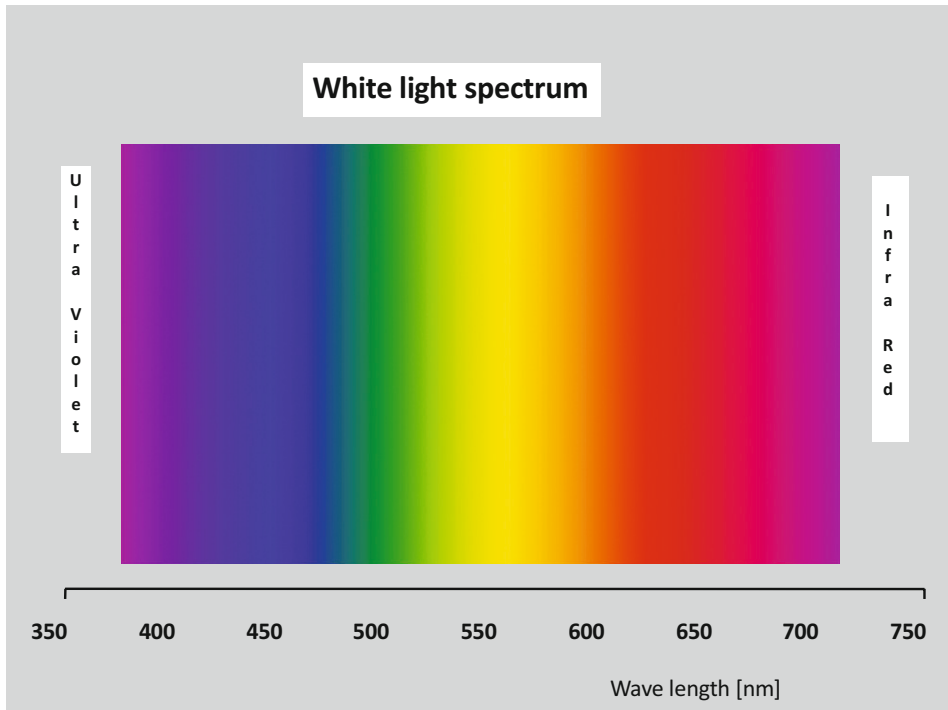


Figure 2.1 White light spectrum

White light consists of a mixture of colors, which are characterized by a specific wavelength range. These are the colors of the spectrum - red, orange, yellow, green, blue, and violet.

Incandescent lamps and luminescence are two ways of generating light. The incandescent lamp generates light from thermal energy. Heating the filament of an incandescent lamp to a sufficiently high temperature will cause it to glow. Luminescence, also known as cold light, is light from other energy sources. It can be generated at room temperature or even lower temperatures. Quantum physics explains luminescence as the movement of electrons from their primary state (lowest energy level) to a state of high energy. When they return to their primary state, the electron releases the energy in the form of a light photon. If the time interval between the two steps is short (a few microseconds), the process is called fluorescence. If the interval is long (a few hours), the process is called phosphorescence.

The combination of these wavelengths in the light can change according to the light source. For this reason, colors can look different under the influence of daylight, fluorescent light, or sodium vapor lamps. Natural sunlight varies widely. It can be very blue, especially at noon in northern latitudes. Direct sunlight is usually seen as golden, but at sunset, it can be bright red. Artificial light from sodium vapor lamps is yellow, from mercury vapor lamps blue-green, or from an incandescent lamp more or less yellow.

Several phenomena can occur when the light hits an object. With transparent objects, the electromagnetic waves pass through the object. With colorless objects, the light passes through the objects unchanged. With colored objects, part of the light waves is absorbed. The unabsorbed light waves are perceived as color by the human eye.

With more or less opaque objects, part of the light waves is absorbed, the remaining part is reflected. With a blue object, for example, the red part of the color spectrum is absorbed. The human eye then perceives the reflected blue part as a blue color. The reflection curve of white shows approximately the same intensities near 100% reflection in all wavelengths of the spectrum.

Refraction or scattering means that the light changes direction when it passes from one medium to another, such as from the polymer to a pigment or filler particle in a plastic part. Scattering is influenced by the difference in refractive index between a particle and its surroundings, the particle size, and the wavelength of the light. An opaque color ensures high **scattering**. A translucent color shows a combination of reflection and scattering. Absorption occurs when most of the wavelengths in the visible spectrum are absorbed. Black objects absorb almost all light.

An object appears in a particular color because the light reflected from its surface is made up of precisely the wavelengths combined to produce the observed color. The object absorbs all other wavelengths. For example, a blue object reflects the blue light spectrum but absorbs red, orange, yellow, green, and violet, which are most other wavelengths. A red object reflects the red part of the spectrum, but absorbs most of the orange, yellow, green, blue, and purple.

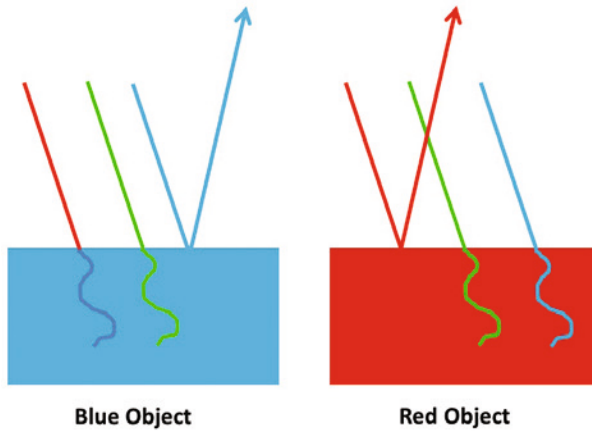


Figure 2.2 Reflection and absorption of colors

Black and white colors are different from other colors in terms of how they reflect and absorb light. A white object reflects almost all colors, while a black object completely absorbs most colors.

Other significant influences on the color of an object are shape and surface effects. For example, an object can be spherical or square, dull or glossy, transparent, opaque, or translucent. It can also appear metallic, pearlescent, fluorescent, or phosphorescent. Viewing angles also affect our color perception.

The human eye is the defining observer of color. An observer almost always bases the acceptance of a color on visual judgment. For this reason, color matching can become very subjective, since the color view varies greatly from person to person. Characteristics such as age, gender, inherited characteristics, and even moods can influence the color vision [2].

■ 2.1 Basics of Color Measurement

People who believe that the eye is the most important observer of color argue that it is possible to judge color purely by referring to color cards through visual adjustment. Since each person perceives the color differently, this method is very subjective and is not suitable for an objective assessment.

In addition to genetic abnormalities, color vision changes with age due to the build-up of yellow macular pigmentation in the eye. For this reason, it is argued that all original colors must be based on physical measurements. However, these

measurements and their interpretation must be closely related to the reactions of the visual observers.

The color control is, therefore, divided into two segments: visual and instrumental. The color measurement method using the CIELAB method, including measurement with a spectrophotometer, is described below [3].

2.1.1 Spectrophotometer

One method for color measurement is the spectrophotometric method. Spectrophotometers measure the spectral characteristics of light and use them to calculate the standard color values based on the CIE normal observer functions. In addition to the numerical results in different color systems, spectrophotometers allow the graphical representation of the spectral properties of the object color. Colors are created by mixing the different wavelengths in certain proportions. A spectrophotometer evaluates the light reflected by the object for different wavelengths or wavelength ranges and can display the results as a graphic.

For the measurement, the visible spectrum is broken down into small, narrowly defined wavelength ranges, each of which is evaluated by another segment of the sensor (e.g., 39 segments). With this method, the smallest color differences can be determined, which remain hidden from the human eye.

2.1.2 CIELAB Method

The Commission Internationale de l'Eclairage (CIE) has set certain standard values that are used worldwide for color measurement.

The CIELAB system, which is widely used today, consists of the Cartesian coordinates a^* , b^* (hue), and L^* (lightness). Each color can be represented by the L^* , a^* , and b^* values. In certain cases, the polar coordinates L^* , C^* (chroma, chromaticity), and h° (hue angle) are also used.

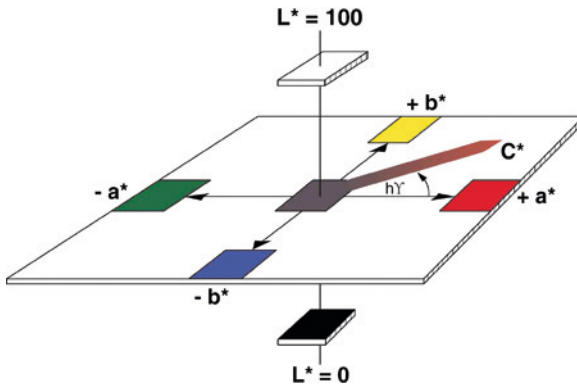


Figure 2.3 CIELAB coordinate system [1]

The Following Points Must Be Taken into Account when Measuring Color:

- Is the measuring device calibrated (“adjusted”), white/black standard clean?
- Are the values of the current standard correct?
- Has the measuring device been calibrated with a colorful reference sample?
- ISO 9001 requires test equipment monitoring!
- Is the sample translucent? => Background!
- Is the sample/background fluorescent?
- Edge effects with thick plastic samples must be taken into account!
- Should the pigmentation or the visual appearance of the **plastic article** be characterized?
- Is the sample matt/glossy?

The Following Must Be Taken into Account when Evaluating the Color:

- Which light source/standard observer is available?
- Which geometry of the measurement/gauge device is used?
- $L a b$ or $L^* a^* b^*$?
- DE^* or, e.g., DE (CMC)?
- Color strength calculation: which method (“equality criterion”)?
- Hiding power: which method?

2.1.3 Influences of Sample Quality and Temperature during Color Measurement [3]

Powder/Granules

When measuring powders with a spectrophotometer, the measured value depends on the compaction and the surface. In order to avoid mistakes, some points have to be considered. The containers (e.g., glass cuvettes) must always be of the same type, the fill level and compaction of the powder must be constant, and the surface smooth and comparable. If the grain size is large, it is recommended to use a spectrophotometer with a large measuring aperture. The measurement surface is averaged with the result of reproducible measurement values.

Semi-Transparent Materials

For semi-transparent materials, the light partly passes through the layer and is more or less reflected by the background. It must be taken into account that the background can have a major influence on the measurement result. This influence can be minimized by increasing the layer thickness. An opaque white background material also ensures constant results.

Materials with a Surface Structure

Surfaces with structure and patterns lead to poorly reproducible measurement results with a small measuring aperture. Therefore, the largest possible **measuring orifice** should be used. The measurement accuracy can be significantly increased by multiple measurements at different locations on the surface and subsequent averaging.

Influence of Temperature

With some materials, a change in temperature also results in a change in color. This phenomenon is called thermochroism. To carry out accurate color measurements, the sample and measuring device must have a constant, defined temperature, ideally by storing them in a room with a constant climate.

Sample Preparation

- The preparation will influence the results!
- The sample should be uniform and homogeneous, without visible particles, air bubbles, or fingerprints.
- The sample to be measured must be of uniform thickness in the case of translucent and transparent samples.
- The backing must be specified in this case and must be uniform as well.

- The samples should be as flat as possible.
- In the case of transparent and translucent samples, the edge loss must be considered.
- The measurement direction must keep constant in case of dichroism.
- Measurements should be done at room temperature – thermochromism.
- Better to start with new instead of using old samples (aging).

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■ 3.1 History of Development

The scientific and technical development of plastics began in 1838 with the discovery of polyvinyl chloride (PVC) by Victor Regnault. The name of this new working area was established by Ernst Richard Escales in 1911 with the first publication of the magazine *Kunststoffe*. Hermann Staudinger introduced the term “macromolecule” in 1922. Table 3.1 gives a brief historical overview of the most important development steps in the field of plastics research and technology. The most important synthetic plastics are listed in Table 3.3.

Polymers consist of chain molecules that are synthesized by linking of smaller components, the monomers. These can be of natural origins, such as cellulose, or are produced by chemical syntheses, such as polystyrene. *The properties of polymers are based both on the length of the molecular chains and on the chemical structure. The principle of building long molecular chains applies to both natural and synthetic polymers.* The molecular structures are shown exemplarily with the two structural formulas shown in Figure 3.1 and Figure 3.2.

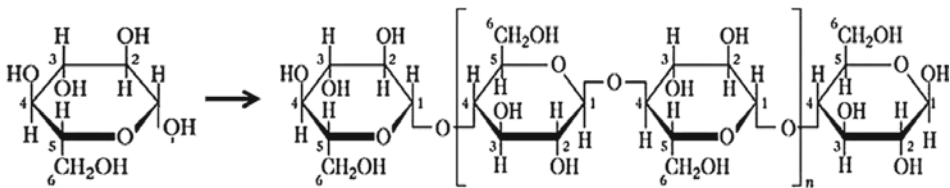


Figure 3.1 Cellulose is made from a monosaccharide

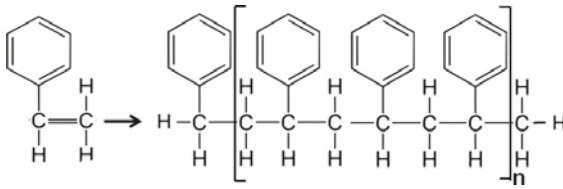


Figure 3.2 Polystyrene is made from styrene monomer through polymerization

When it comes to bonding monomers, a distinction is made between condensation and addition polymerization. The number of repeating units in a macromolecule is called the degree of polymerization.

Depending on the type of repeating unit, the polymers can be called homopolymers, which are built up from only one type of repeating. The incorporation of chemically different monomers leads to copolymers. If two different monomers are present, alternating, random, or block-like structures are obtained. *Besides linear chains, there are also branched and cross-linked systems. The diversity of polymer materials is based on these different molecular architectures.*

Plastics can be divided into two important groups: thermoplastics that can be deformed by heat and thermosets that cannot be deformed by heat. The major difference is based on the behavior of the plastic during the forming process.

When a thermoplastic is heated and pressed into a mold, there is no chemical reaction involved. After the polymer has cooled and hardened in the mold, it could be brought back into a new shape by reheating it without changing the characteristics of the plastic noticeably.

Thermosets, on the other hand, change chemically as they are brought into their final shape. They react in a polycondensation reaction and form a network similar to a spatial grid. This hardening through structural changes in the molecule is irreversible. Once a thermoset has been molded, it cannot be changed.

Figure 3.3 gives an overview of the synthetic polymers:

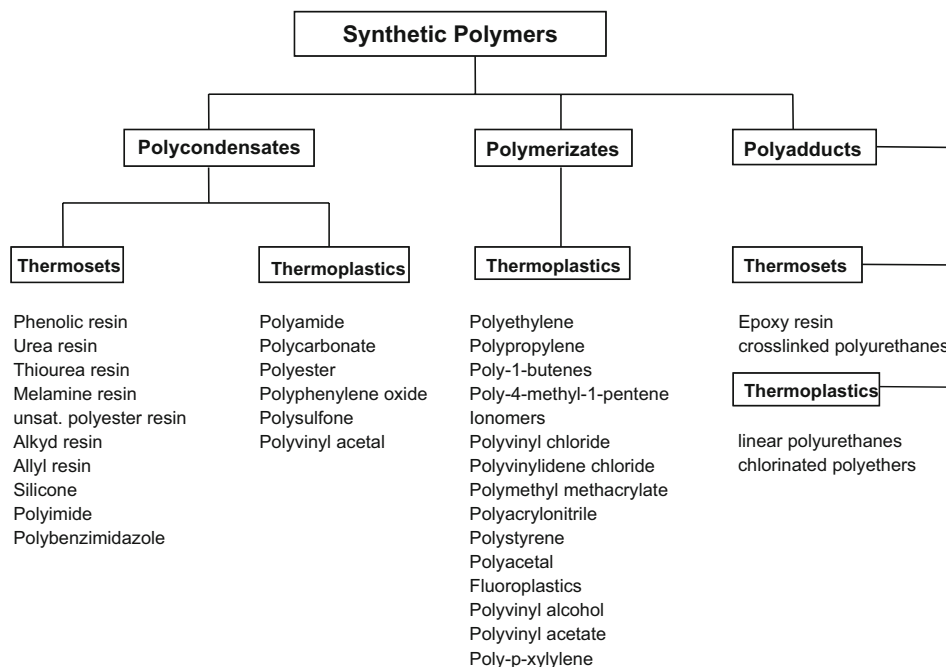


Figure 3.3 Synthetic polymers

Table 3.1 The History of the Development of Plastics

Year	Discoverer	Discovery
1838	Victor Regnault	Laboratory scale polyvinyl chloride
1839	Charles Nelson Goodyear	Crosslink-ability of rubber with sulfur
1846 to 1900		Development of cellulosic plastics
1901	Otto Röhm	First work on acrylic acid and acrylic acid esters
1912	General Electric	Patenting of the first alkyd resins
1928	Otto Röhm	Production of polymethyl methacrylate
1928	Erich Konrad	Development of Buna S, the first all-purpose synthetic rubber
1928	Heinz Hopf	Technical production of caprolactam
1930 to 1933	IG-Farbenindustrie	Start of production of polystyrene, polyacrylonitrile, polyisobutylene, polyvinyl chloride, and polyethylene oxide
1933	Eric W. Fawcett and Reginald O. Gibson	High-pressure polymerization of ethylene to produce LDPE

Year	Discoverer	Discovery
1933 to 1939	ICI	Elaboration of the technical basis for the large-scale production of polyethylene
1935 to 1938	Wallace Hume Carothers Du Pont	Production of the first polyamide 66 (Nylon), production of Nylon begins
1938	Paul Schlack IG-Farbenindustrie	Production of the first polyamide 6 (Perlon), Start of production of Perlon
1940	Otto Bayer	Process for the production of polyurethane
1946	John R. Winfield and James T. Dickson	Discovery of saturated polyester as a fiber raw material, production at ICI and Du Pont
1946	US-Rubber Co.	First ABS plastics
1953	Karl Ziegler	Low-pressure polymerization of ethylene with organometallic catalysts
1953	Hermann Schnell	Discovery of polycarbonates
1957	Hoechst AG	Start of production of polypropylene
1965	Shell	Block copolymers made from styrene and polyolefins
1967	Dynamit Nobel AG	Technical production of crystal-clear polyamide
1973	Dynamit Nobel AG	Production of polyvinylidene fluoride begins
From 1973		Development of special plastics such as polyaryl ethers, polyaryl sulfones, polyphenylene sulfide, polyether sulfone, polyetherimide, polyimide sulfone and, above all, thermoplastic copolymers

■ 3.2 Thermoplastic Polymers

In plastics processing, thermoplastic polymers play the most considerable economic role, as they can be melted and deformed at higher temperatures without significant decomposition. Although they have most of the required material properties after their production, coloring is advantageous for many purposes or is necessary for identification. The thermoplastic polymers show the following properties:

Table 3.2 Properties of Thermoplastic Polymers

Natural state	<ul style="list-style-type: none"> ▪ Transparent to beige opaque ▪ Material properties largely available
Coloring	Depending on the use, advantageous to absolutely necessary (e.g., electrical cables)
Typical characteristics	<ul style="list-style-type: none"> ▪ Highly viscous consistency above the softening point ▪ Decrease in viscosity up to the decomposition point ▪ Hardening after cooling
Thermoplasticity	Is used to process plastics through injection molding, extrusion, blow molding and welding
Damage	With every machining process, the material is damaged to a greater or lesser extent

Under unfavorable processing conditions, crystallization effects can occur after the reshaping of polymers. Crystallization nuclei can also be pigments. This can change the shape of the finished plastic article (“warpage”). The consequence can be, for example, that beverage crates can no longer be stacked or that the lid of garbage cans no longer fits on the can.

The thermoplasticity of plastics is used to process them by injection molding, extrusion, blow molding, or welding.

The *advantages* of polymer materials are:

- low specific weight
- high resistance to corrosion and rotting
- high electrical insulation properties
- thermal insulation and sound insulation
- easy shaping
- ideal material for mass production because of its economic processability
- easy to color, print, and metalize
- wide range of inexpensive raw materials

These favorable properties are offset by the following *disadvantages*:

- usually low mechanical strength
- low heat resistance
- deterioration of the physical properties under the action of light and heat
- most polymers are flammable
- expensive waste disposal
- uneconomical reparability
- limited dimensional accuracy, a tendency to post-shrinkage and creep

3.2.1 Chemical Composition and Material Properties

3.2.1.1 Polyvinyl Chloride

Polyvinyl chloride (PVC) is produced on an industrial scale using emulsion, suspension, and bulk polymerization processes. PVC is flame-retardant and very resistant to chemicals. Its softening point is between 75 °C and 80 °C. Processing is relatively easy by calendaring, extrusion, and blow molding, whereby the PVC usually needs to be stabilized, e.g. by environmentally friendly calcium-zinc stabilizers. For injection molding, PVC with low molar mass (low K-value, easy flowing) must be used.

PVC can be produced as PVC-u (unplasticized), PVC-p (plasticized), a copolymer of vinyl chloride with vinyl acetate, and as an impact-resistant molding compound by mixing PVC with rubber-like components. PVC-u can be bonded and welded and is processed into pipes, fittings, window frames, and façade coverings, among others. PVC-p is used as a base material for films, floor coverings, hoses, cable insulation, artificial leather, or similar things, and is particularly suitable for high-frequency welding.

3.2.1.2 Polyolefins

Polyolefins are all polymers made from olefins, such as polyethylene, polypropylene, polybutene-1 and polyisobutylene. They have good mechanical properties, are easy to process, resistant to chemicals, and versatile, and have a good price-performance ratio.

3.2.1.2.1 Polyethylene

Polyethylene is produced by polymerizing ethylene using various processes. Its properties are mainly determined by the molar mass, the molar mass distribution, and the degree of branching. The density and the melting point increase with the crystalline portion of the polyethylene, whereby the lower the degree of branching of the molecular chains, the higher this portion is. The traded polyethylene is differentiated according to its density in LDPE, LLDPE, and HDPE, whereby the overall density ranges between 0.91 g/cm³ and 0.97 g/cm³.

Low-density polyethylenes can be manufactured in high-pressure processes (LDPE) or low-pressure processes (LLDPE). The use of metallocene catalysts in recent years has brought about a further improvement in the product properties in both process variants.

3.2.1.2.2 Polypropylene

Most of the polypropylene (PP) is produced by the gas phase process using metallocene catalysts, which are tailored to the desired product properties. PP is used in the packaging sector (films), in the textile sector for fibers and tapes and the industrial sector (vehicle construction, electrical engineering/electronics, semi-finished products). There is a large number of PP products on the market that differ in their flowability, transparency, scratch resistance, flexural modulus, flexibility, weather resistance, heat resistance, rigidity, hardness, toughness, and melting point, among other things. Highly crystalline PP products (HCPP) close the gap between unreinforced PP and PP reinforced with mineral fibers or platelets.

3.2.1.3 Styrene Polymers and Copolymers

Polystyrene (PS) is the thermoplastic polymer of styrene ($C_6H_5-CHCH_2$) and is technically predominantly polymerized by free radicals in suspension. PS is crystal clear, stiff, quite brittle, and resistant to acids, alkalis, alcohol, and mineral oil, but not resistant to, or soluble in, most solvents. It is inexpensive, easy to process, and versatile. To improve the brittleness, the impact resistance, and the light sensitivity of the standard PS, before the polymerization, the styrene is added to a solution of polybutadiene. Since the two polymers are immiscible, a polystyrene phase is formed when the reaction is carried out appropriately, in which small particles of the grafted rubber are embedded. The amount of rubber used, as well as the structure and size of the particles of the graft polymer, are decisive for the mechanical properties of impact-resistant polystyrene (HIPS, High-Impact PS).

Another change in properties can be achieved by copolymerizing styrene with acrylonitrile (SAN), with acrylonitrile and butadiene (ABS), or with acrylonitrile and acrylic ester (ASA). SAN has high strength and hardness, as well as excellent heat resistance. ABS is particularly impact-resistant, but due to the butadiene content only has limited aging resistance. ASA is also particularly impact-resistant, but more weather-resistant than ABS. The products are used in household and consumer goods as well as in sophisticated technical parts.

3.2.1.4 Acrylic Resins

Acrylic resins are the collective name for polymers of acrylic acid and methacrylic acid, as well as the corresponding nitriles, esters, amides, and similar. The best-known type of acrylic resin is thermoplastic poly(methyl methacrylate) (PMMA). It is produced using free radical polymerization in bulk, solution, suspension, and emulsion processes. Methacrylates have a wide range of properties. The excellent light transmission, combined with low weight and high flexibility in processing, as well as particularly excellent weather resistance, contributes significantly to the fact that this material can be used in many ways, e.g., in building glazing, the illu-

minated advertising sector, and automotive engineering. In addition to standard PMMA, impact-resistant molding compounds are also produced.

3.2.1.5 Polyamide

Silk and wool are natural polyamides (PA) while technical thermoplastic PAs are best known as “Nylon” (PA 66) and as “Perlon” (PA 6). PAs are designated according to the number of carbon atoms in their monomers: PA 6 = polycaprolactam; PA 66 = polycondensation product of hexamethylenediamine and adipic acid (DIN 16773 T1). PAs are semi-crystalline, and conventional PAs melt between 200 °C and 260 °C. The narrow melting and solidification range is also characteristic. Polyamides are mainly processed into fibers and used for technical parts in the electrical industry and vehicle construction. The impact strength is increased by adding elastomers; glass fibers and mineral fillers increase strength and reduce thermal expansion. PAs are resistant to alkalis, many solvents, fuels, and oil, but are attacked by acids. Partly aromatic polyamides (PPA) are suitable for the highest mechanical, thermal, and environmental stress.

3.2.1.6 Polycarbonate

Polycarbonates (PC) are linear thermoplastic polyesters and polycondensation products of carbonic acid with diols, e.g., dioxydiphenylalkanes. Starting products are bisphenol A (2,2-bis(4-hydroxyphenyl)propane) and phosgene. PCs are very translucent, mechanically stable, heat-resistant, and have excellent electrical insulation properties. In addition to areas of application in electrical engineering and the automotive sector (headlights), considerable quantities are processed into laser-optically readable data carriers (e.g., CDs). For technical applications in the automotive sector, PCs are also processed into blends (e.g., ASA/PC or ABS/PC).

3.2.1.7 Other Thermoplastics

Since a detailed treatment of all plastics would go beyond the scope of this book, a few more important plastics should be mentioned at this point:

- ABS – acrylonitrile-butadiene-styrene copolymers
- ASA – acrylonitrile-styrene-acrylic ester
- SAN – styrene-acrylonitrile copolymers
- PET – polyethylene terephthalate
- PBT – polybutylene terephthalate
- POM – polyoxymethylene
- PUR – polyurethane

Table 3.3 Uses of Commercially Available Plastics

PE (polyethylene)	<ul style="list-style-type: none"> ▪ Films (carrier bags, sacks, etc.) ▪ Hollow bodies ▪ Bottle crates ▪ Toys ▪ Cables ▪ Pipes
PP (polypropylene)	<ul style="list-style-type: none"> ▪ Household items (mixing bowls) ▪ Toys ▪ Bottle crates ▪ Stretched woven tapes (bags, nets) ▪ Fibers
PS (polystyrene)	<ul style="list-style-type: none"> ▪ Electrical industry (spools, light covers, tape and film reels) ▪ Household items (stay-fresh cups, party dishes, refrigerators) ▪ Toys ▪ Office supplies ▪ Parts without much mechanical stress
SB (styrene butadiene)	<ul style="list-style-type: none"> ▪ Electrical industry (TV rear panels, junction boxes, phone housings) ▪ Coat hangers ▪ Thermoformed packaging for dairy products ▪ Packaging for eggs ▪ Drinking cups for vending machines ▪ Machine housings ▪ Toys
SAN (styrene acrylic nitrile)	<ul style="list-style-type: none"> ▪ Electrical industry (covers, household machines) ▪ Containers, coffee filters ▪ Headlight housings ▪ Indicator and taillight covers
ABS (acrylic butadiene styrene)	<ul style="list-style-type: none"> ▪ Machine housings ▪ Vacuum cleaner housings, food processors, telephone housings ▪ Automotive industry (front spoilers, radiator grilles, glove boxes)
ASA (acrylonitrile styrene acrylic rubber)	<ul style="list-style-type: none"> ▪ Traffic lights ▪ Information signs ▪ Hot water drainage pipes ▪ Garden furniture, boat hulls
PPO (polyphenylene oxide)	<ul style="list-style-type: none"> ▪ High-temperature-resistant plastic parts (> 200 °C)
PA (polyamide)	<ul style="list-style-type: none"> ▪ Fibers ▪ Technical articles (gears, bobbins) ▪ Machine housings

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