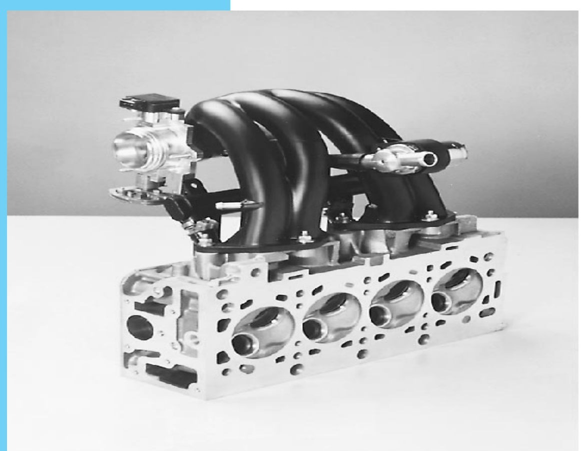
CHAPTER 13
Polymers



A molded engineering polymer serves as a lightweight and cost-effective air-intake manifold for automotive appliations. (Courtesy of Solvay Automotive, Inc., Troy, Michigan.)

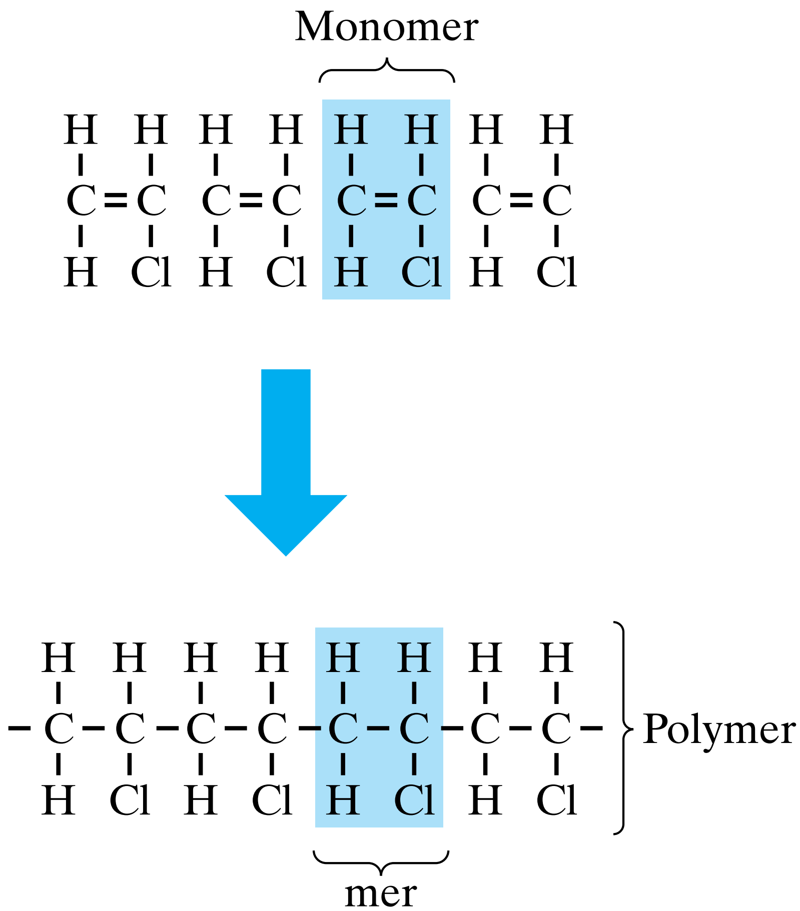


Figure 13-1 *Polymerization is the joining of individual monomers (e.g., vinyl chloride, C_2H_3Cl) to form a polymer [$(C_2H_3Cl)_n$] consisting of many mers (again, C_2H_3Cl).*

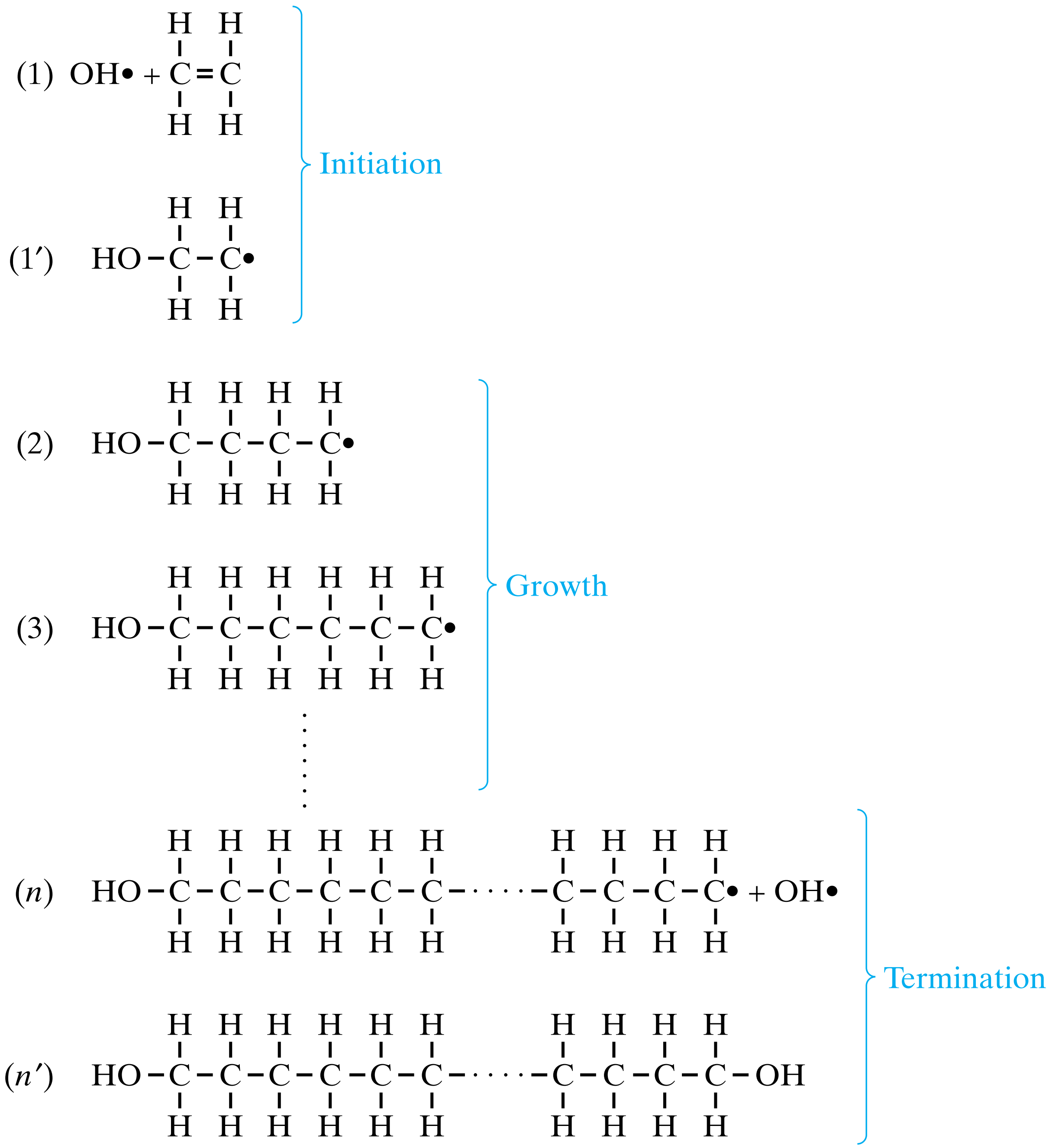


Figure 13-2 *Detailed mechanism of polymerization by a chain growth process (addition polymerization). In this case, a molecule of hydrogen peroxide,* H_2O_2*, provides two hydroxyl radicals, OH•, which serve to initiate and terminate the polymerization of ethylene (*C_2H_4*) to polyethylene* $-(C_2H_4)-_n$*. [The large dot notation (•) represents an unpaired electron. The joining, or pairing, of two such electrons produces a covalent bond, represented by a solid line (—).]*

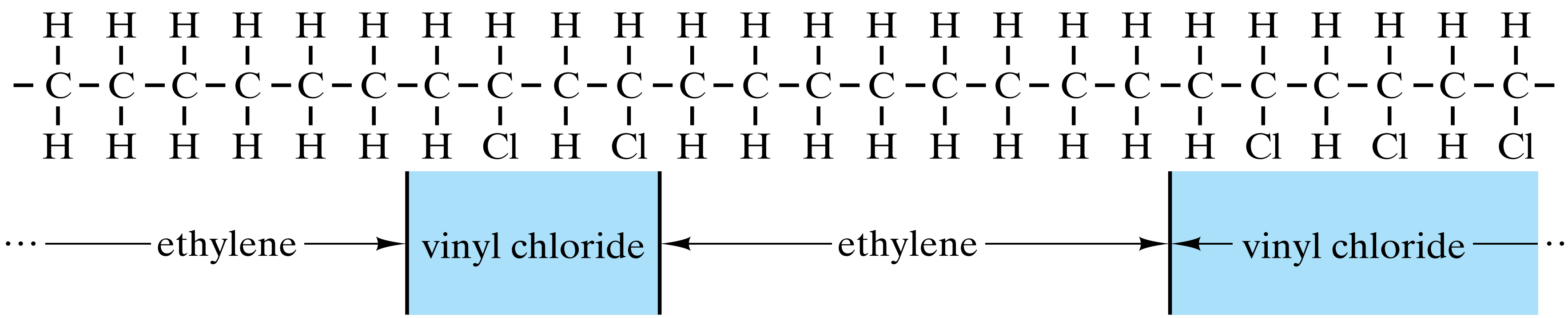


Figure 13-3 *A copolymer of ethylene and vinyl chloride is analogous to a solid-solution metal alloy.*

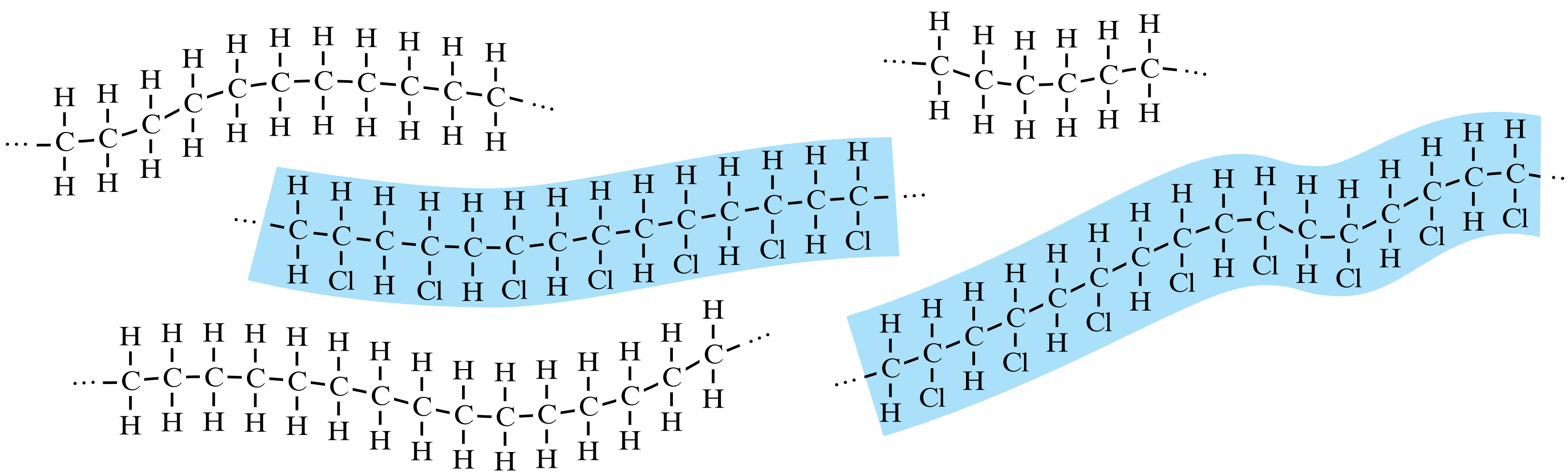


Figure 13-4 *A blend of polyethylene and polyvinyl chloride is analogous to a metal alloy with limited solid solution.*

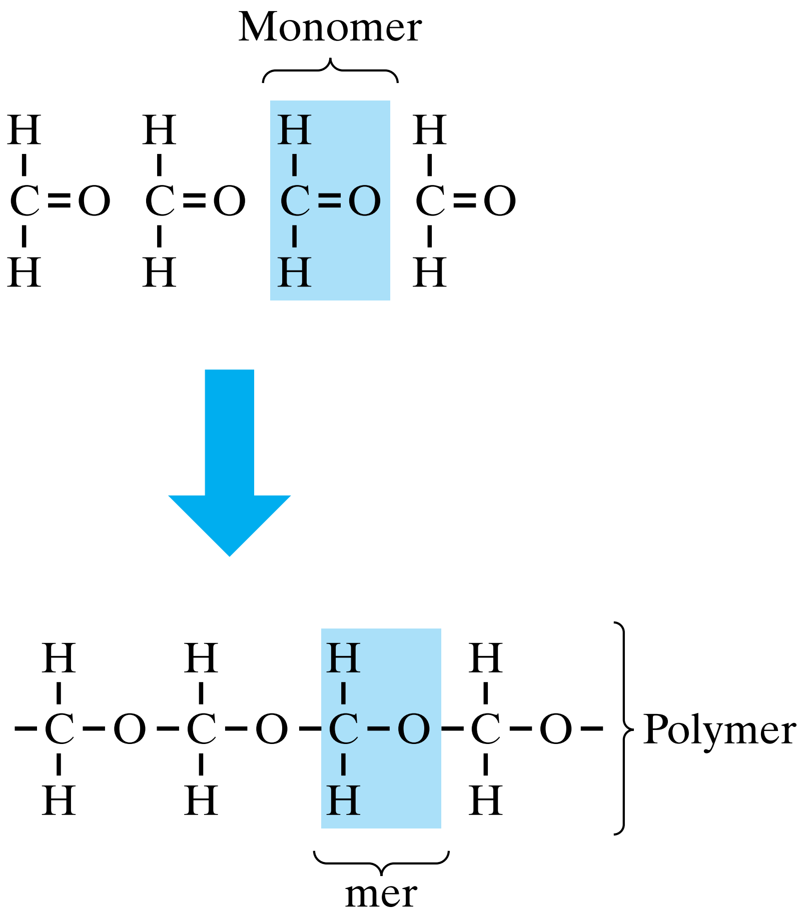


Figure 13-5 *The polymerization of formaldehyde to form polyacetal. (Compare with Figure 13–1.)*

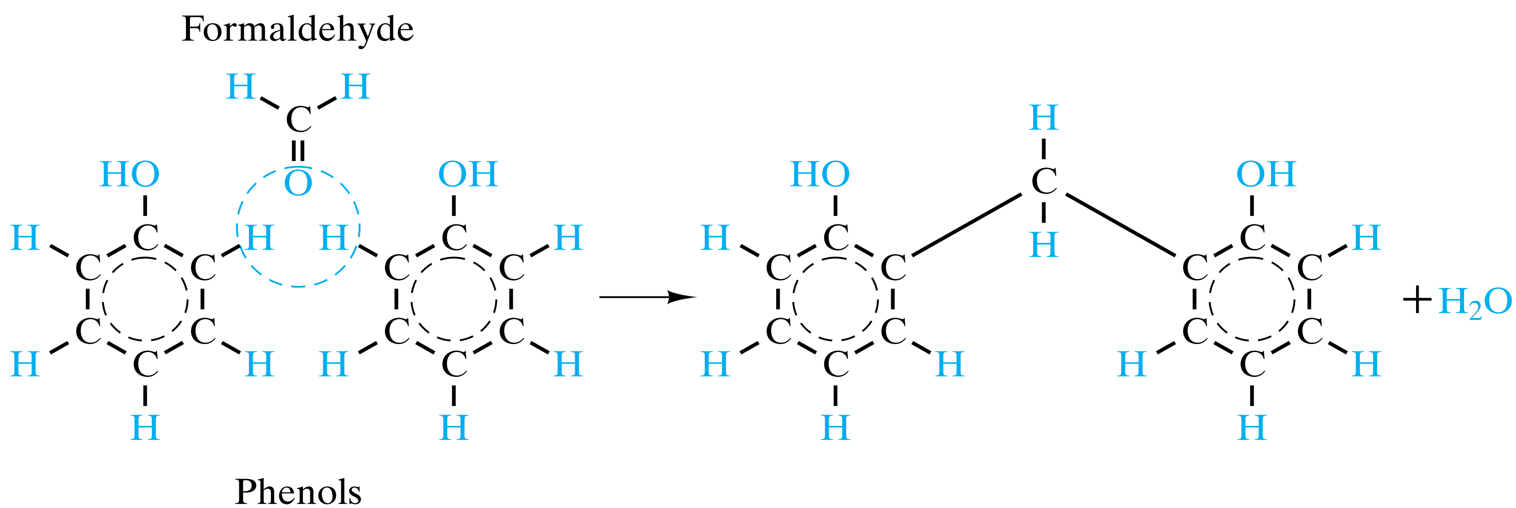


Figure 13-6 *Single, first step in the formation of phenol-formaldehyde by a step growth process (condensation polymerization). A water molecule is the condensation product.*

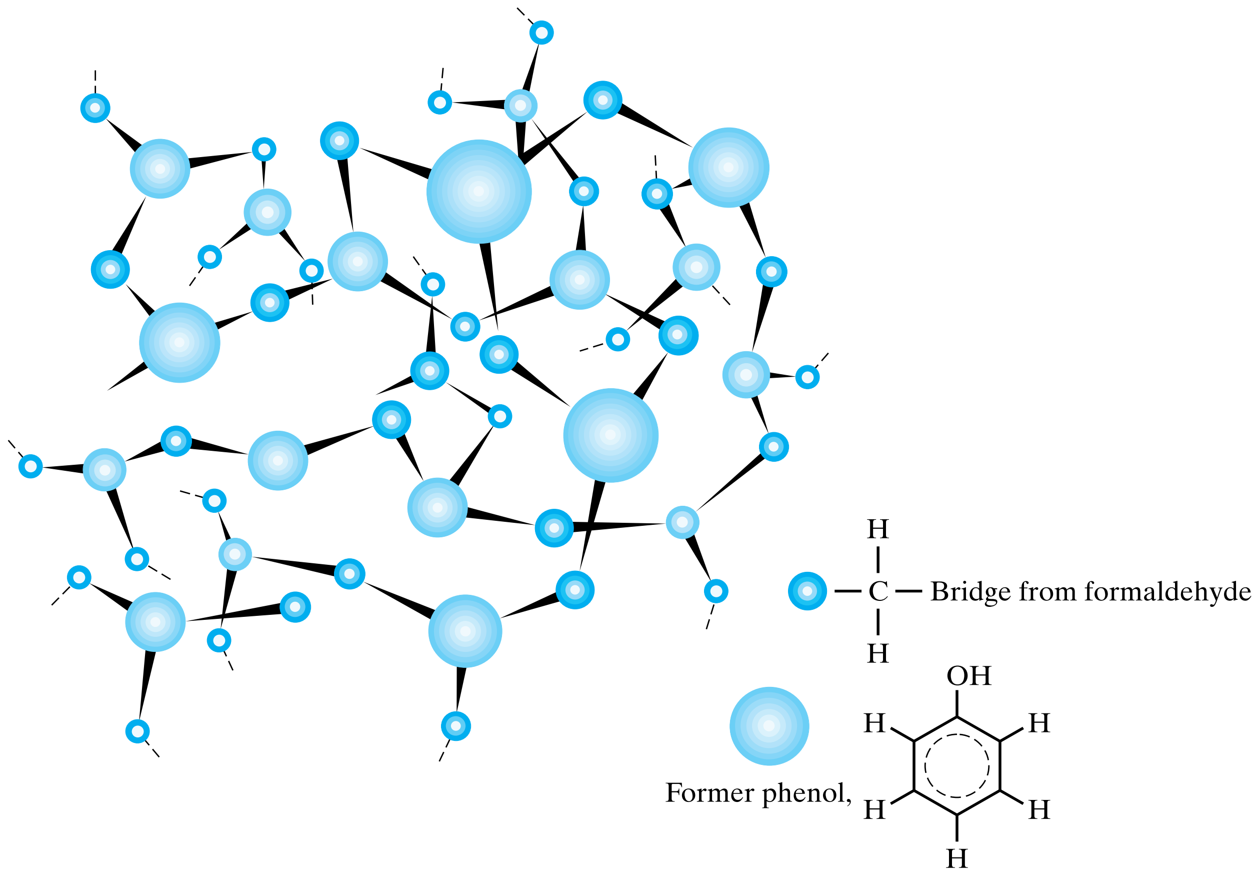
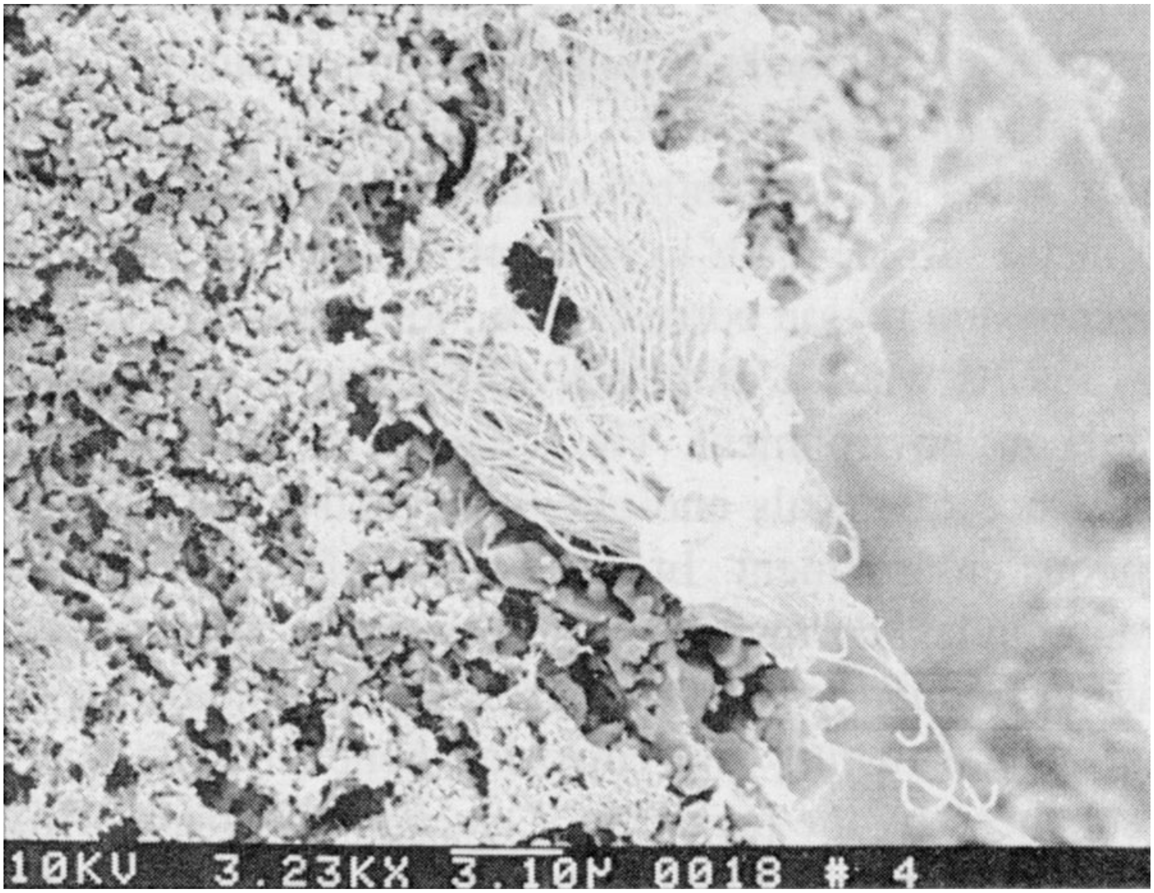
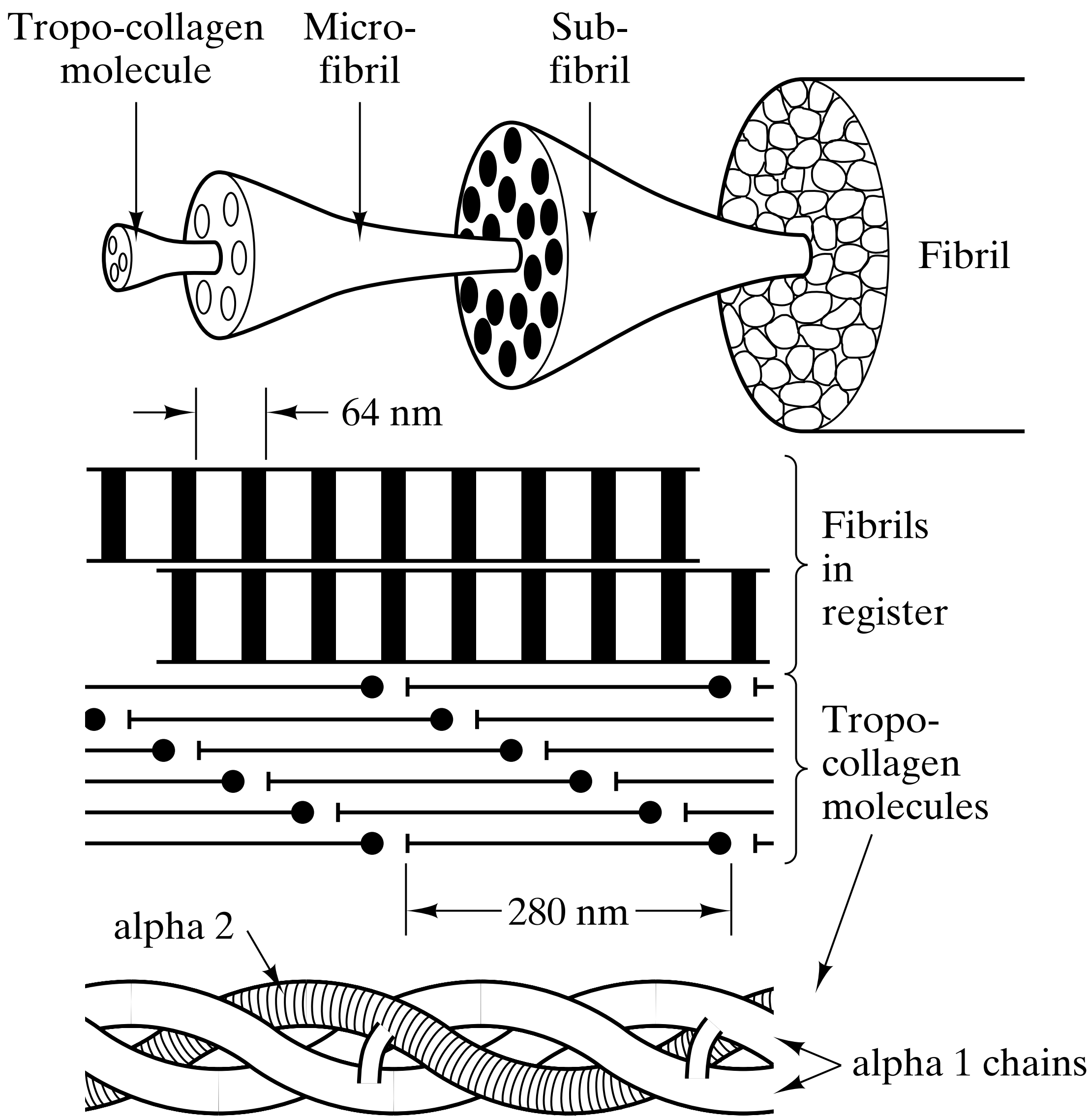


Figure 13-7 *After several reaction steps like that in Figure 13–6, polyfunctional mers form a three-dimensional network molecular structure. (From L. H. Van Vlack,* Elements of Materials Science and Engineering, *4th Ed., Addison-Wesley Publishing Co., Inc., Reading, Mass., 1980.)*



A fibrous bundle of natural collagen is shown attached to the surface of synthetic hydroxyapatite granules in a bioceramic implant. (From J.P. McIntyre, J.F. Shackelford, M.W. Chapman, and R.R. Pool, Bull. Amer. Ceram. Soc. 70 1499 (1991))



Schematic illustration of the polymeric structure of collagen in bone. (From R.B. Martin, "Bone as a Ceramic Composite Material," in Bioceramics—Applications of Ceramic and Glass Materials in Medicine, Ed. J.F. Shackelford, Trans Tech Publications, Switzerland, 1999)

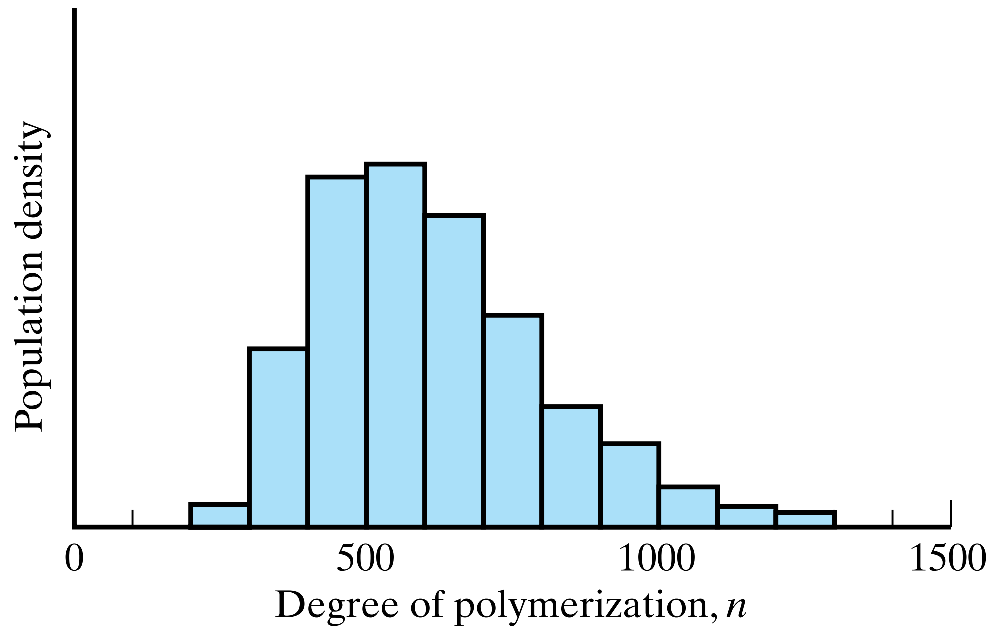


Figure 13-8 *Statistical distribution of molecular lengths in a given polymer as indicated by n, the degree of polymerization.*

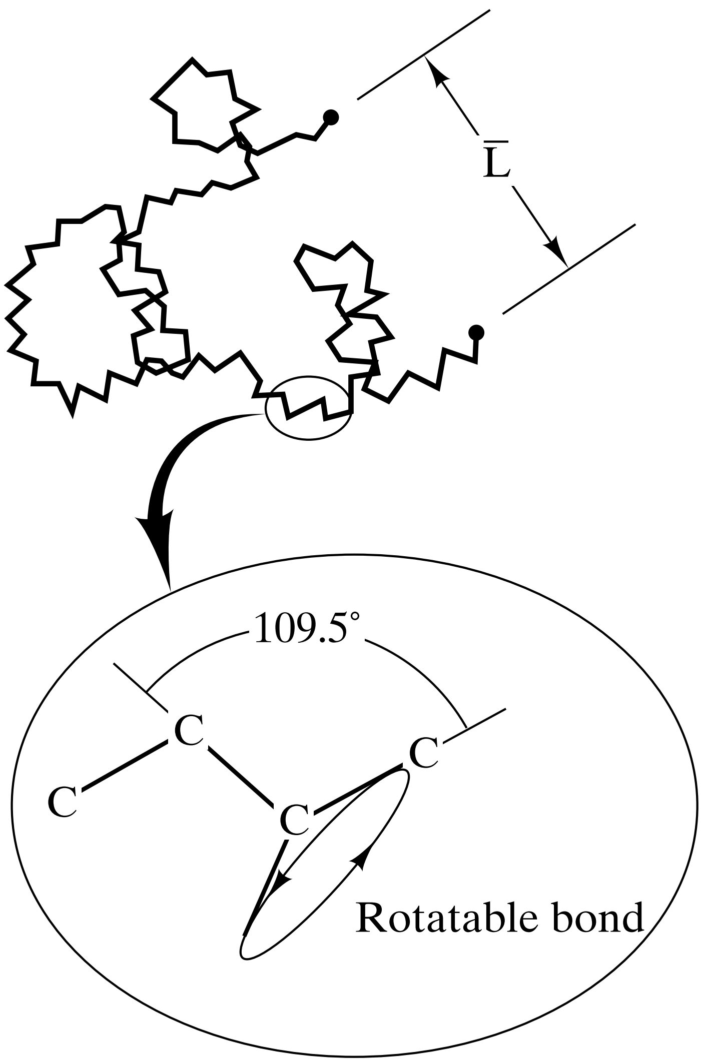


Figure 13-9 *The length of kinked molecular chain is given by Equation 13.4, due to the free rotation of the C—C—C bond angle of 109.5°.*

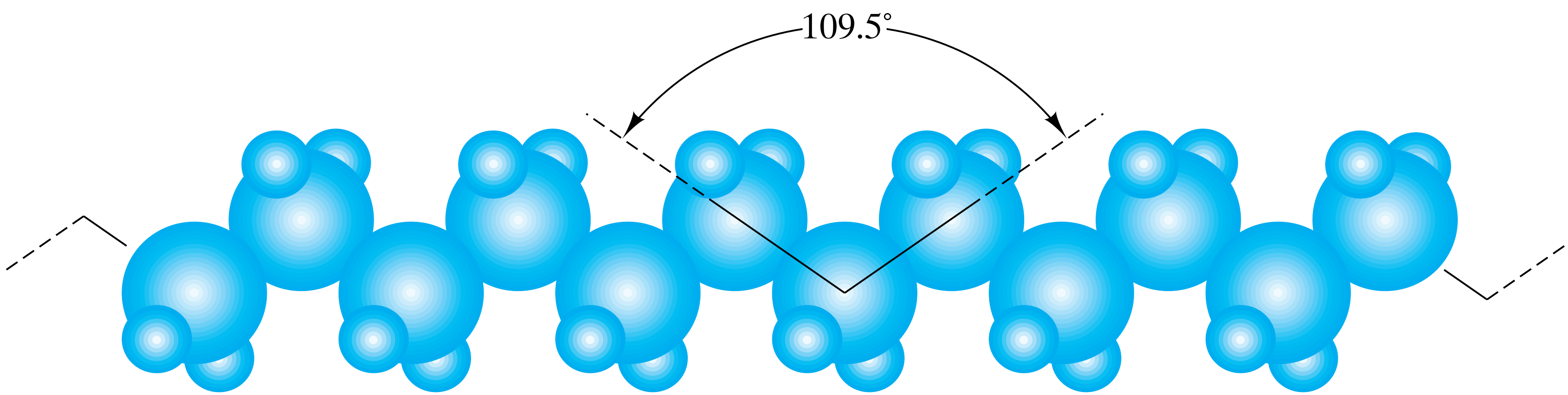


Figure 13-10 *"Sawtooth" geometry of a fully extended molecule. The relative sizes of carbon and hydrogen atoms are shown in the polyethylene configuration.*

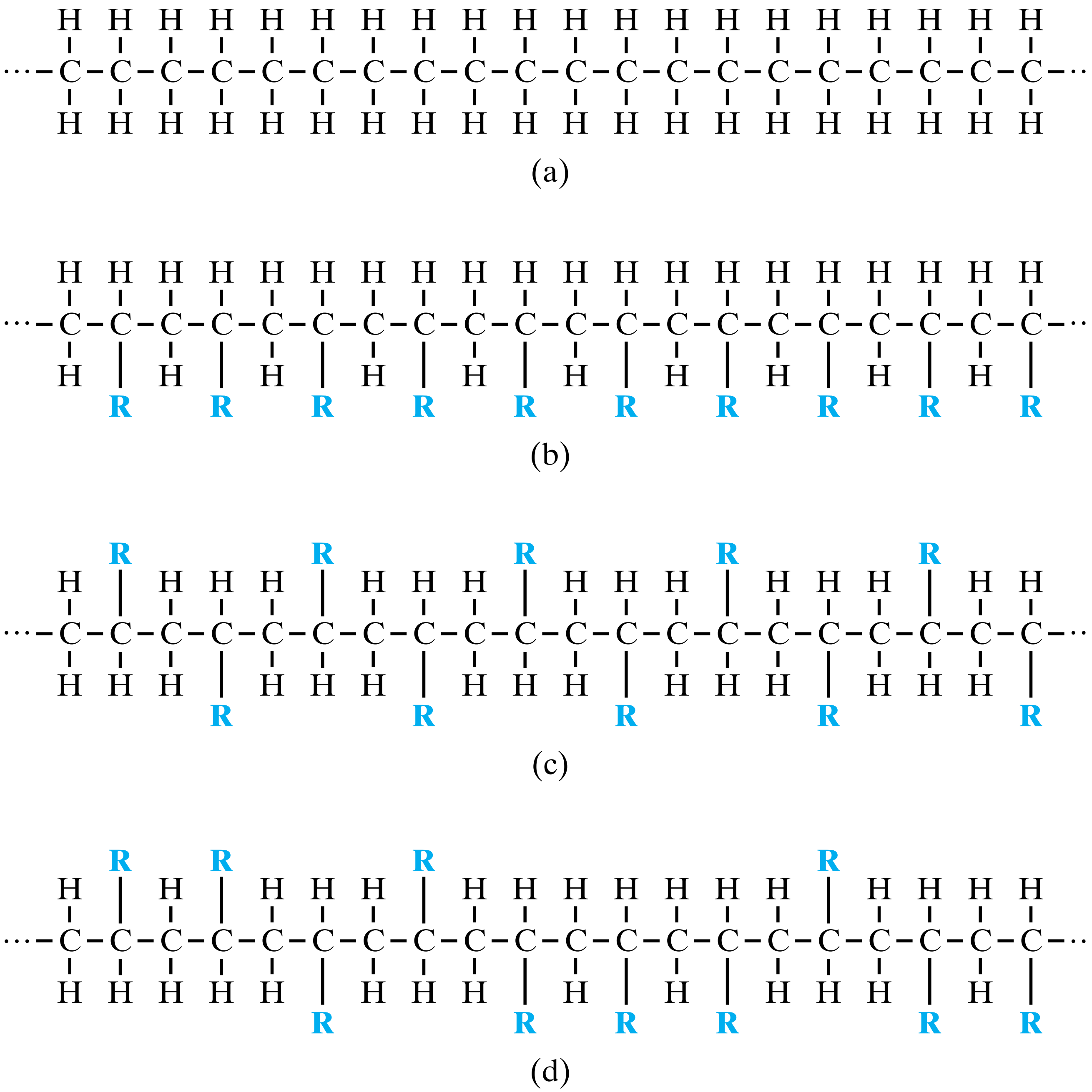


Figure 13-11 *(a) The symmetrical polyethylene molecule. (b) A less symmetrical molecule is produced by replacing one H in each mer with a large side group, R. The isotactic structure has all R along one side. (c) The syndiotactic structure has the R groups regularly alternating on opposite sides. (d) The least symmetrical structure is the atactic, in which the side groups irregularly alternate on opposite sides. Increasing irregularity decreases crystallinity while increasing rigidity and melting point. When R* $= CH_3$*, parts (b)–(d) illustrate various forms of polypropylene. (One might note that these schematic illustrations can be thought of as "top views" of the more pictorial representations of Figure 13–10.)*

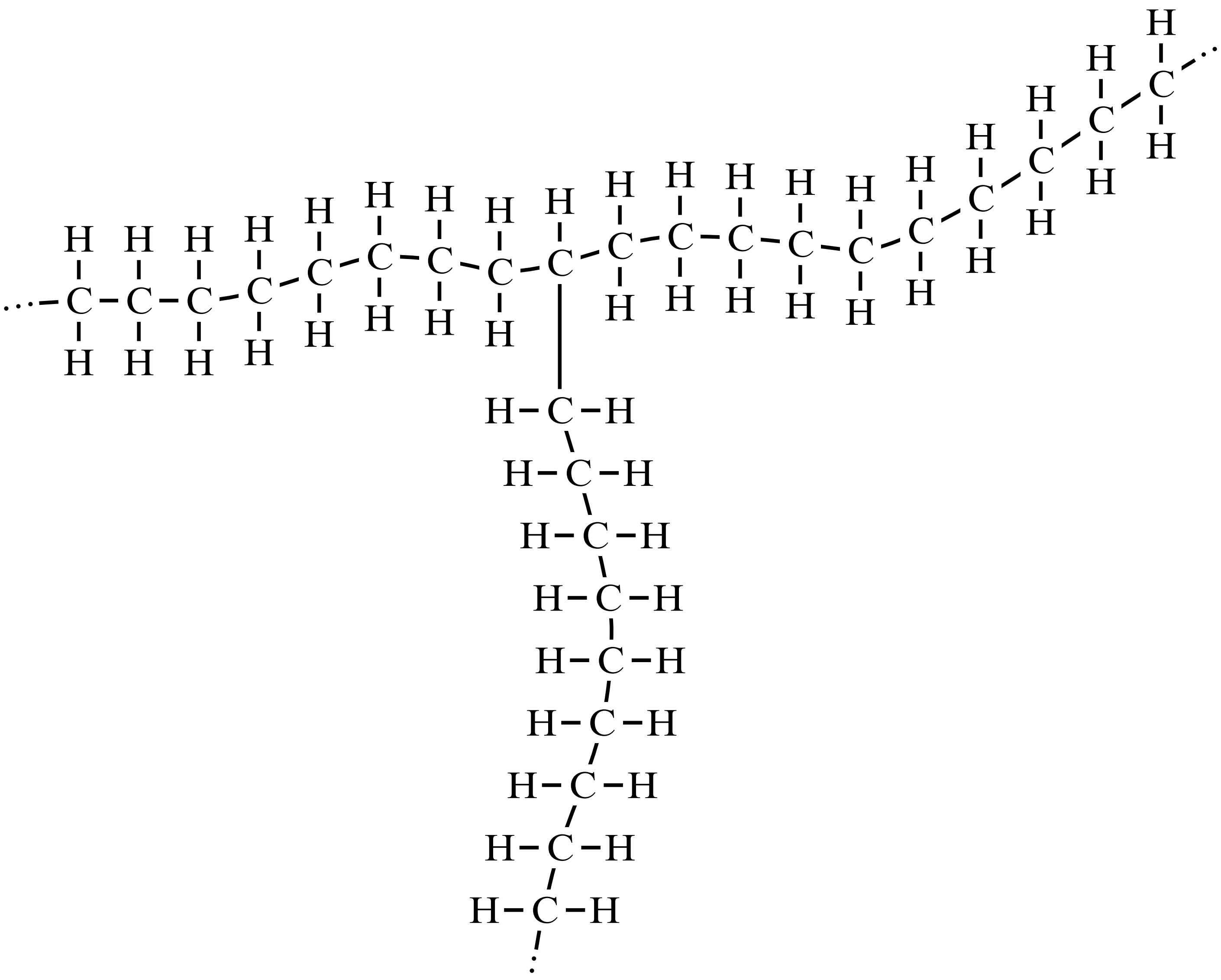
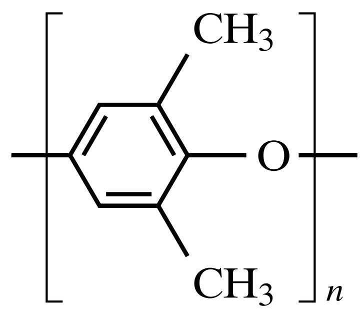


Figure 13-12 *Branching involves adding a polymeric molecule to the side of the main molecular chain.*


CH3
O
CH3
n

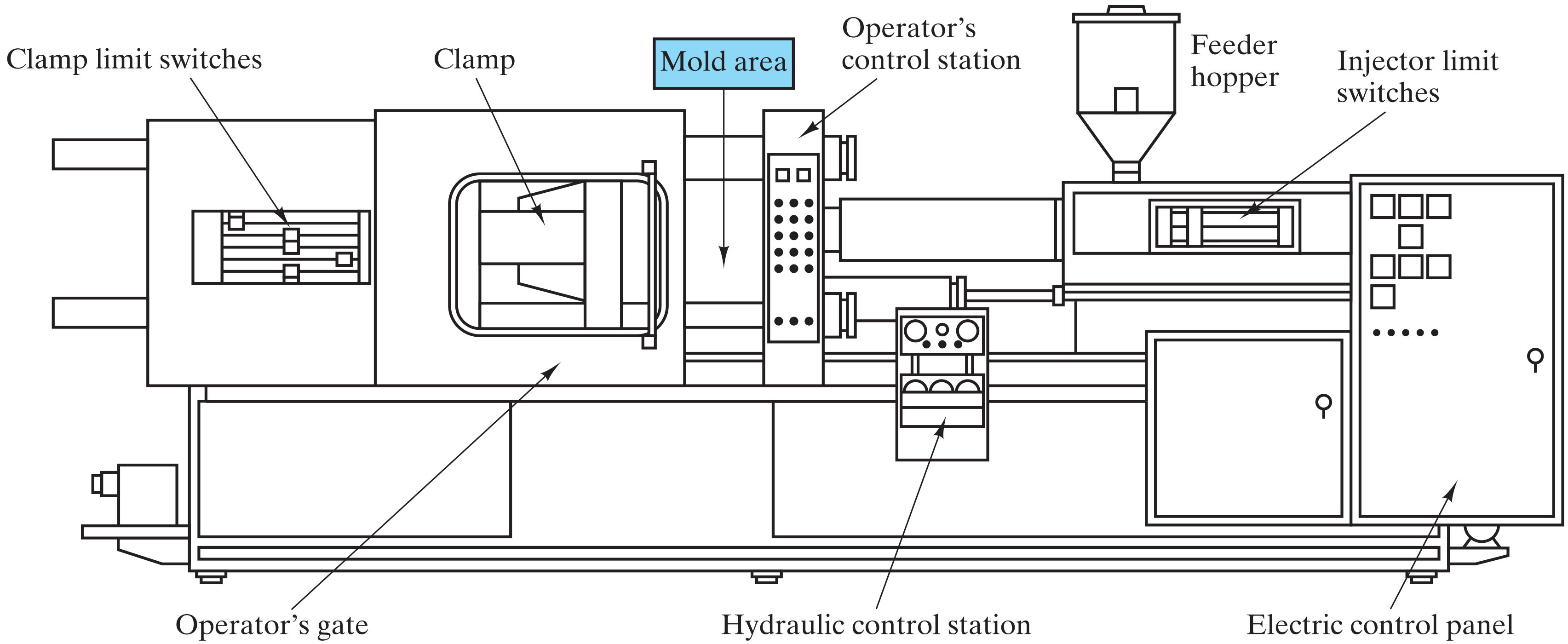


Figure 13-13 *Injection molding of a thermoplastic polymer. (After Modern Plastics Encyclopedia, 1981–82, Vol. 58, No. 10A, McGraw-Hill Book Company, New York, October 1981.)*

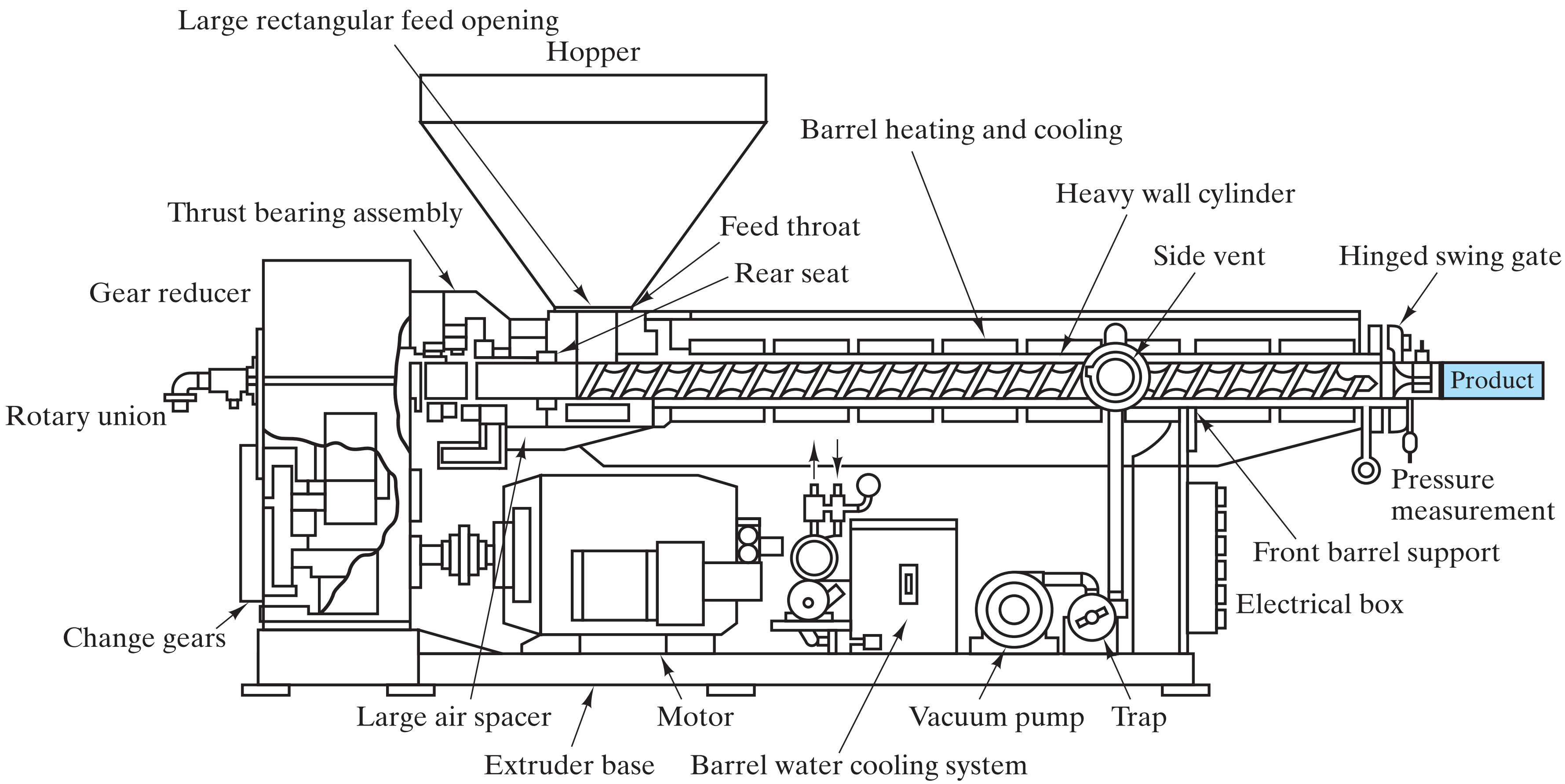


Figure 13-14 *Extrusion molding of a thermoplastic polymer. (After* Modern Plastics Encyclopedia, 1981–82, *Vol. 58, No. 10A, McGraw-Hill Book Company, New York, October 1981.)*

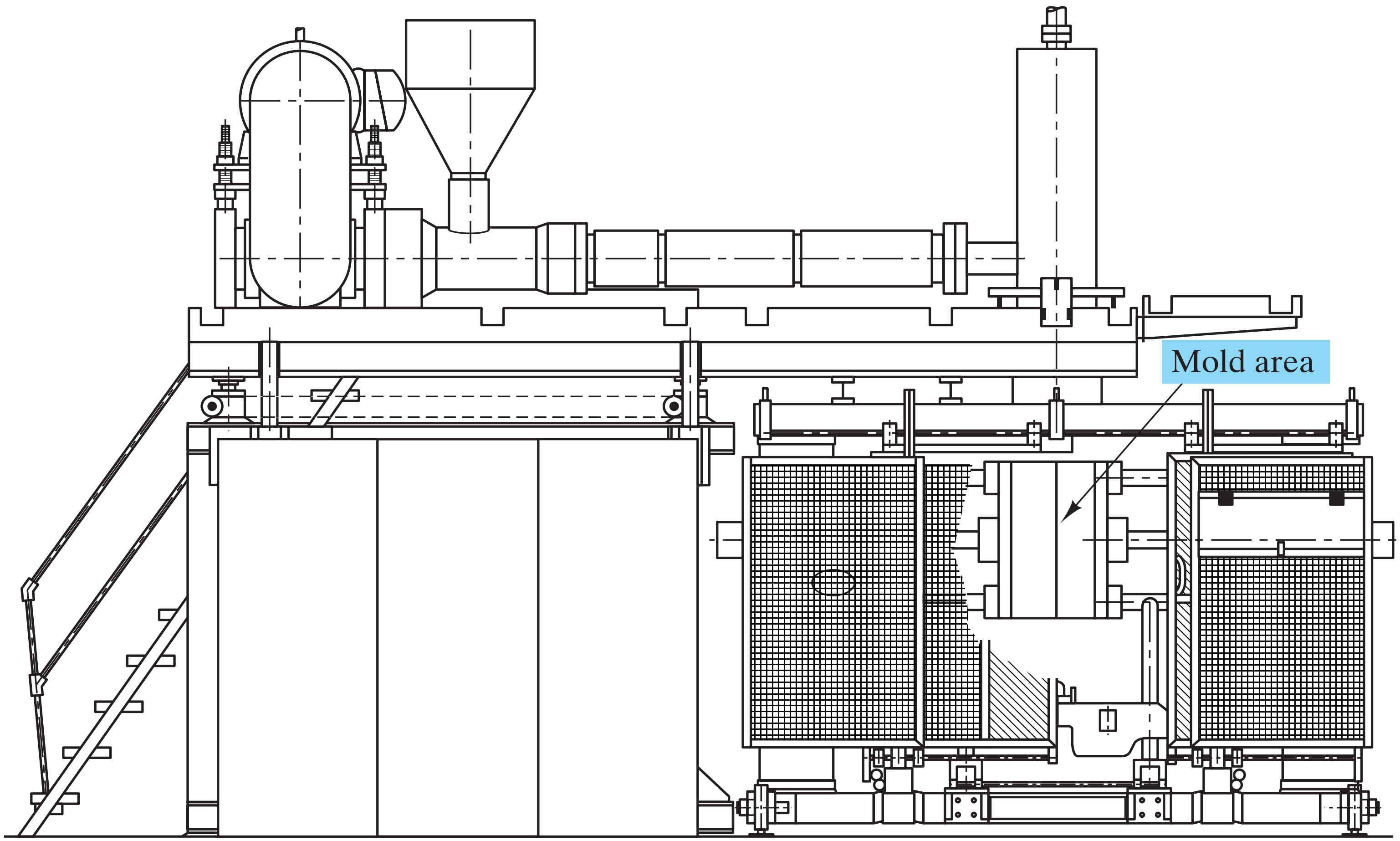


Figure 13-15 *Blow molding of a thermoplastic polymer. The specific shaping operation is similar to the glass container process of Figure 12–3. (After a Krupp-Kautex design.)*

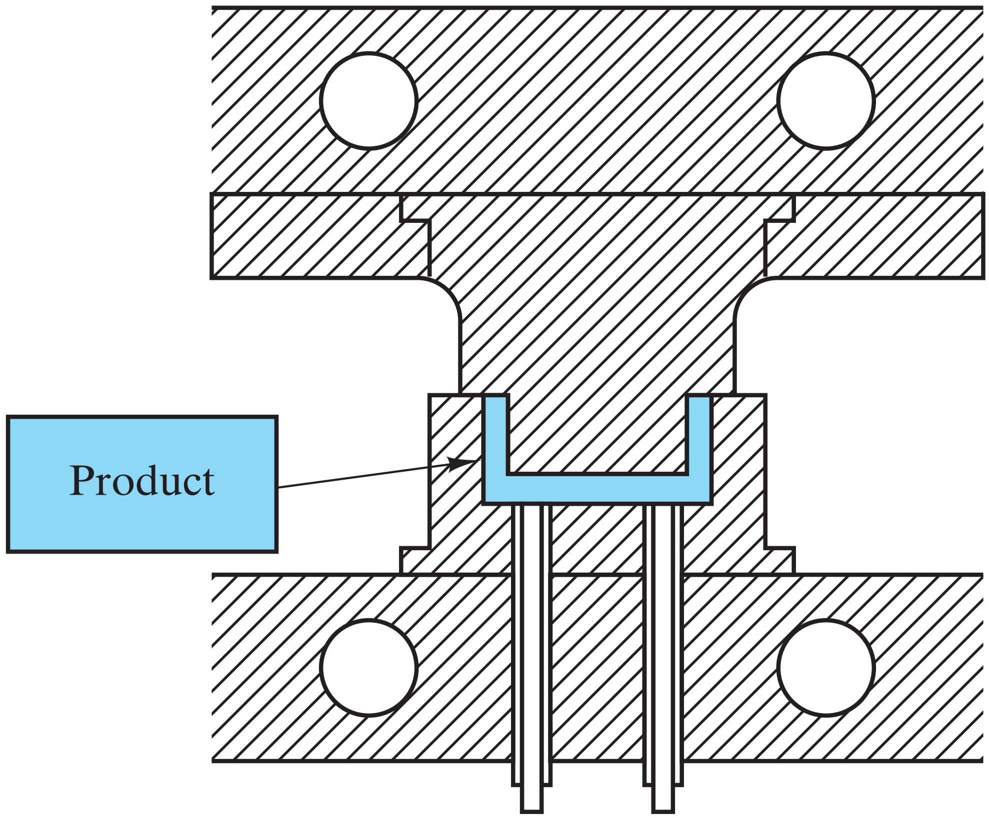


Figure 13-16 *Compression molding of a thermosetting polymer. (After Modern Plastics Encyclopedia, 1981–82, Vol. 58, No. 10A, McGraw-Hill Book Company, New York, October 1981.)*

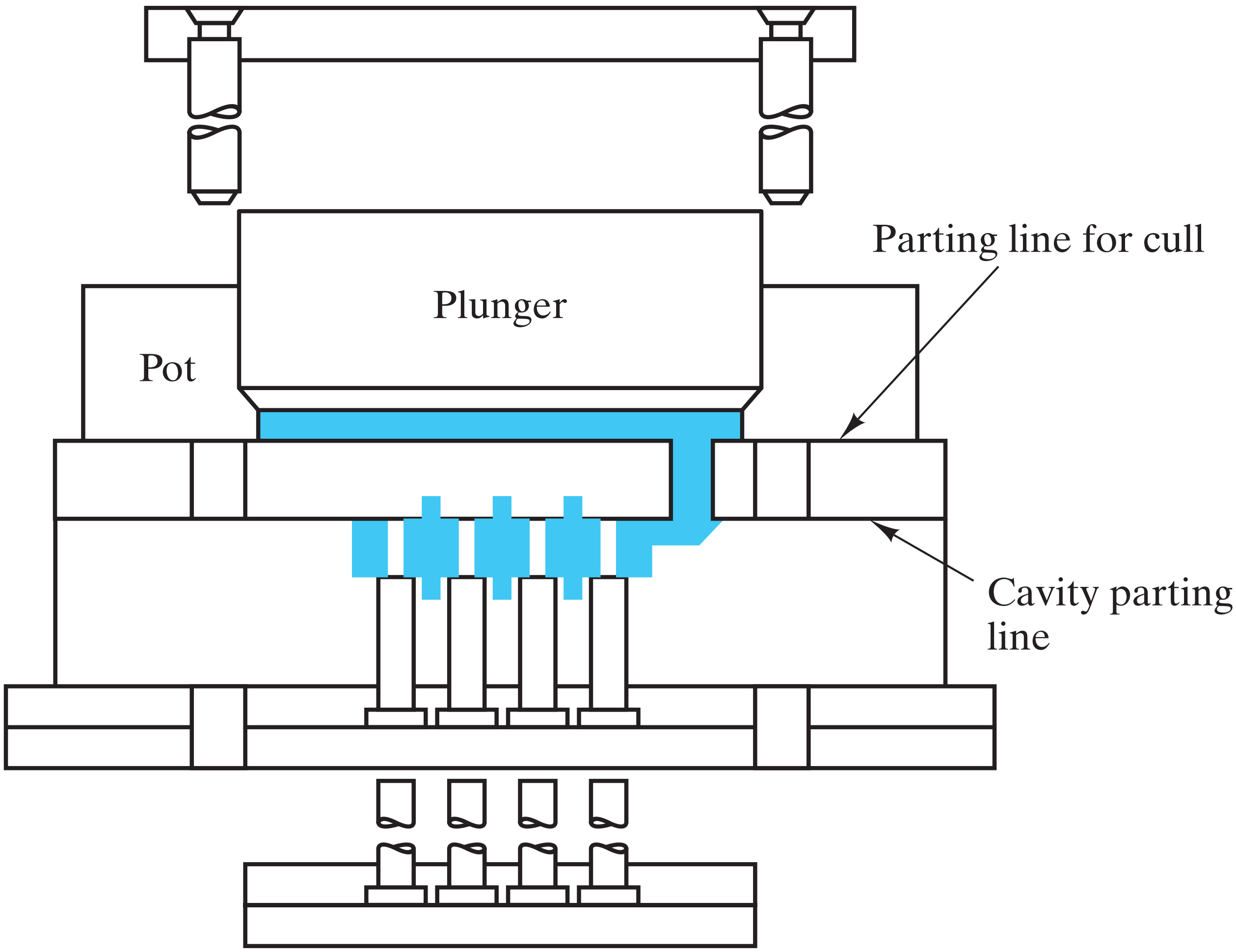


Figure 13-17 *Transfer molding of a thermosetting polymer. (After* Modern Plastics Encyclopedia, 1981–82, *Vol. 58, No. 10A, McGraw-Hill Book Company, New York, October 1981.)*

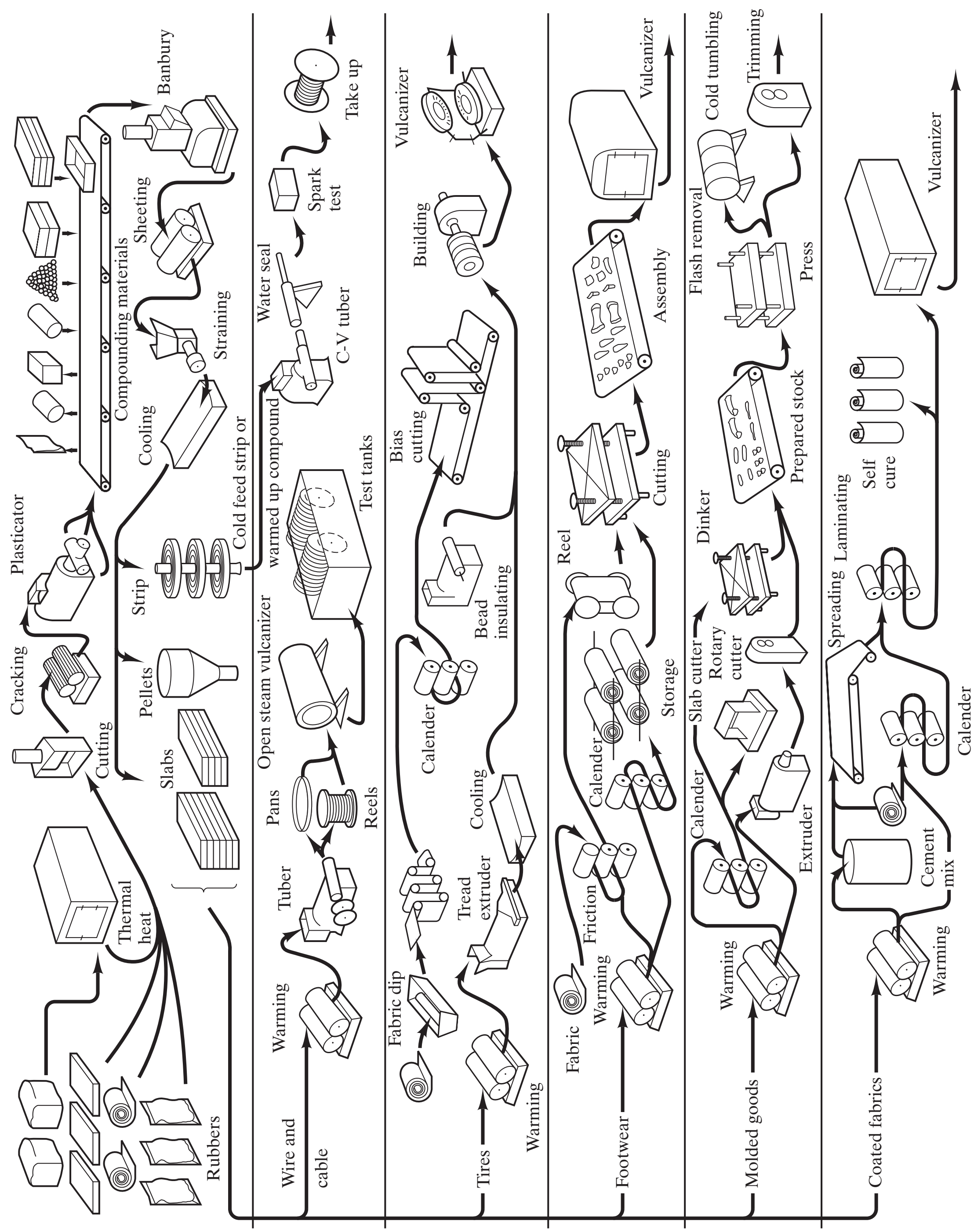


Figure 13-18 *Typical flow diagram for the manufacturing of various common rubber goods. (From the Vanderbilt Rubber Handbook, R. T. Vanderbilt Co., Norwalk, Conn., 1978.)*