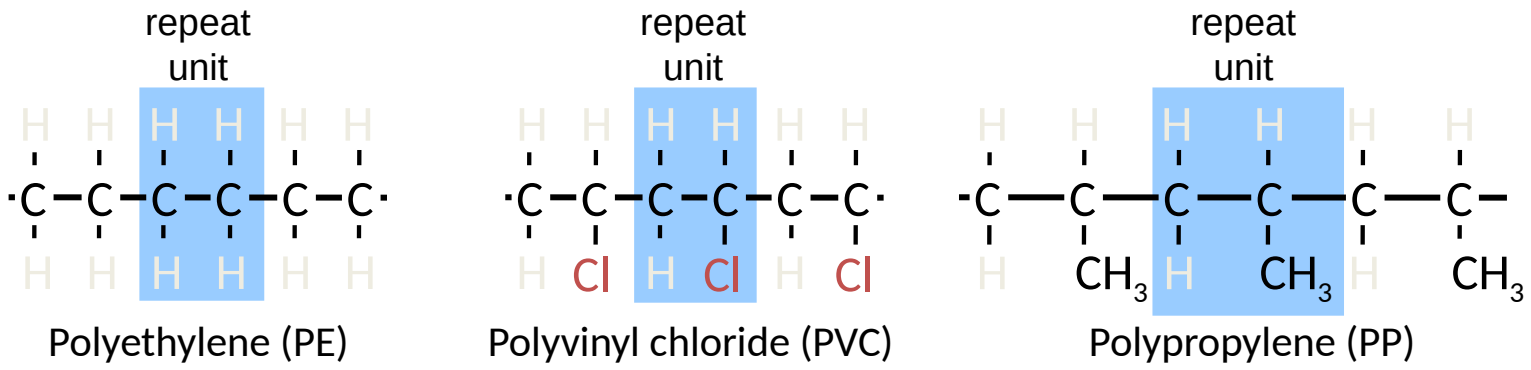

WELCOME TO
OLYMER
PLAN

What is a polymer?

Poly **mer**

many **repeat unit**



Polyethylene (PE) Polyvinyl chloride (PVC) Polypropylene (PP)

Adapted from Fig. 14.2, *Callister 7e.*

Synthetic and Biological Polymers

Polymers: Macromolecules formed by the covalent attachment of a set of small molecules termed monomers.

Polymers are classified as:

(1) Man-made or synthetic polymers that are synthesized in the laboratory;
(2) Biological polymer that are found in nature.

Synthetic polymers: nylon, poly-ethylene, poly-styrene

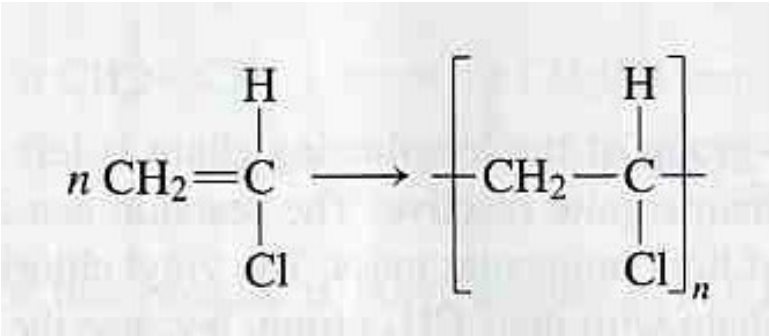
Biological polymers: DNA, proteins, carbohydrates

Methods for making polymers

Addition polymerization and condensation polymerization

Addition polymerization: monomers react to form a polymer without net loss of atoms.

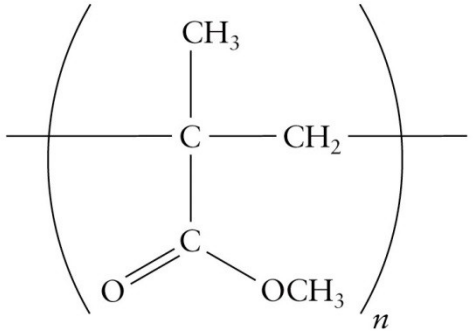
Most common form: free radical chain reaction of ethylenes



n monomers one polymer molecule

Example of addition polymers

TABLE 19.2 Common Addition Polymers

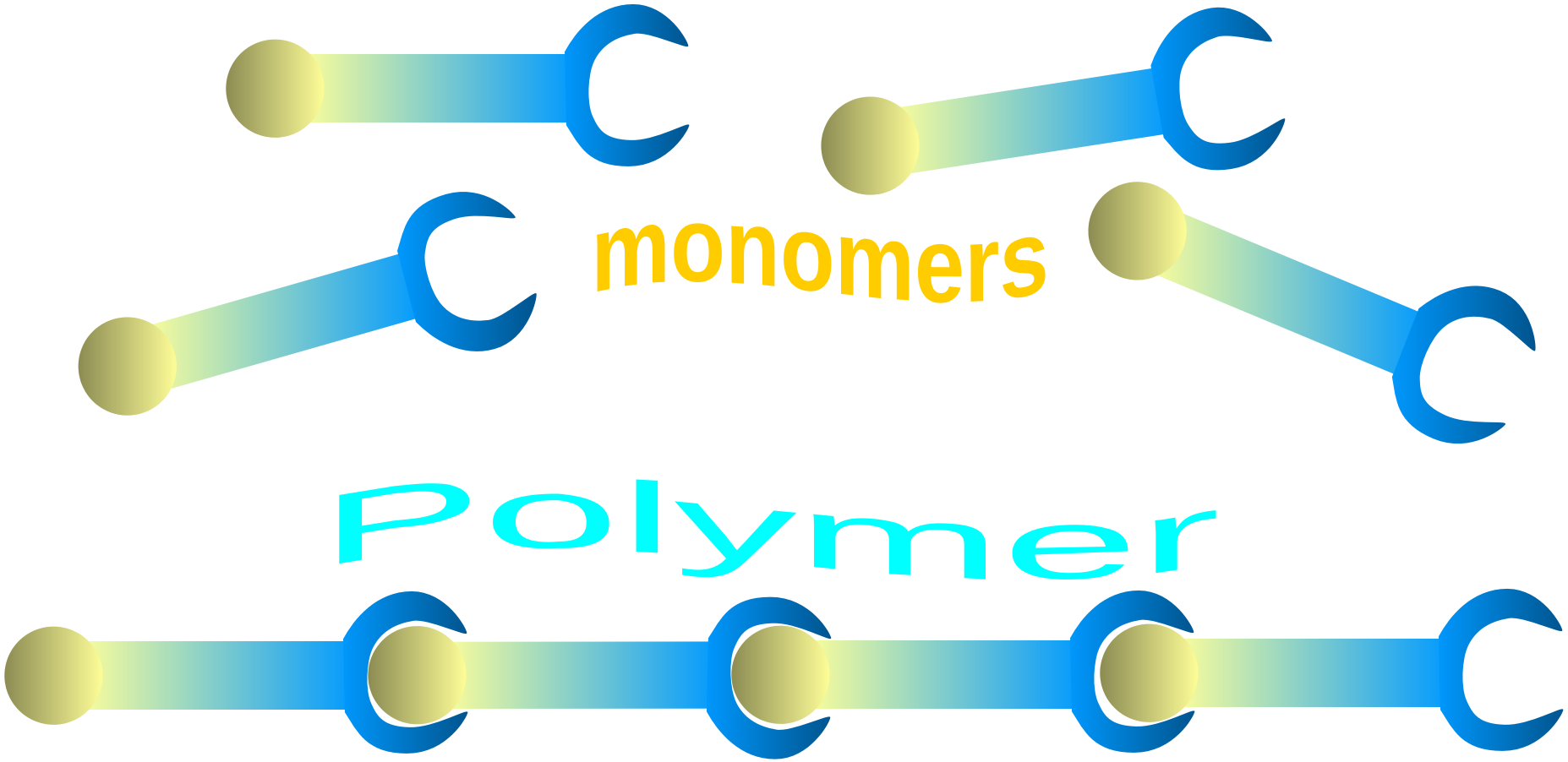
Monomer name	Formula	Polymer formula	Common name
ethene*	$CH_2{=}CH_2$	$-(CH_2{-}CH_2)_n-$	polyethylene
vinyl chloride	$CHCl{=}CH_2$	$-(CHCl{-}CH_2)_n-$	polyvinyl chloride
styrene	$CH(C_6H_5){=}CH_2$	$-(CH(C_6H_5){-}CH_2)_n-$	polystyrene
acrylonitrile	$CH(CN){=}CH_2$	$-(CH(CN){-}CH_2)_n-$	Orlon, Acrilan
propene*	$CH(CH_3){=}CH_2$	$-(CH(CH_3){-}CH_2)_n-$	polypropylene
methyl methacrylate	$CH_3OOCC(CH_3)C{=}CH_2$		Plexiglas, Lucite
tetrafluoroethene*	$CF_2{=}CF_2$	$-(CF_2{-}CF_2)_n-$	Teflon, PTFE†

*The suffix *-ene* is replaced by *-ylene* in the common names of these compounds, hence the names of the corresponding polymers.
†PTFE, polytetrafluoroethylene.

Ancient Polymer History

- Originally many natural polymers were used
  - Wood – Rubber
  - Cotton – Wool
  - Leather – Silk

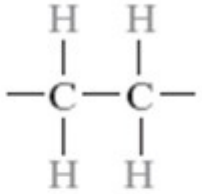
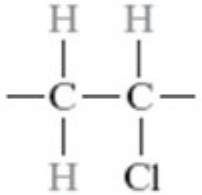
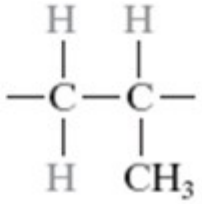
- Oldest known uses of “Modern Polymers”
  - Rubber balls used by Incas
  - Noah used pitch (a natural polymer) for the ark – as had all ancient mariners!

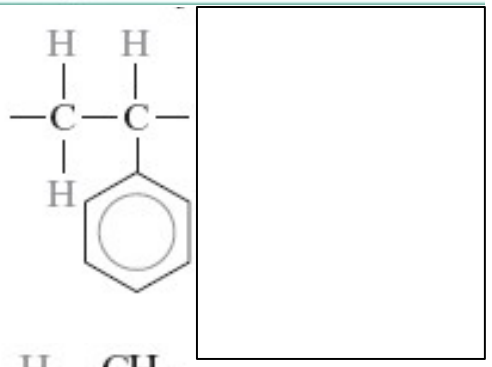
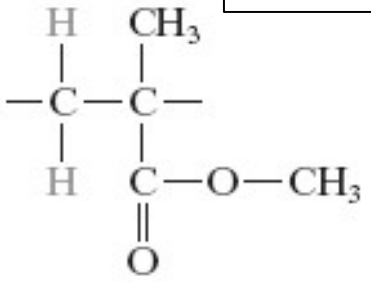
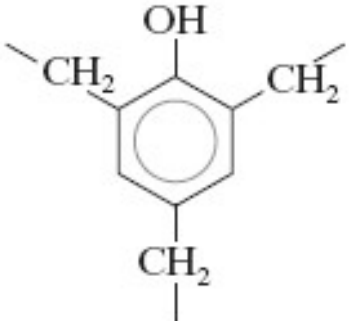


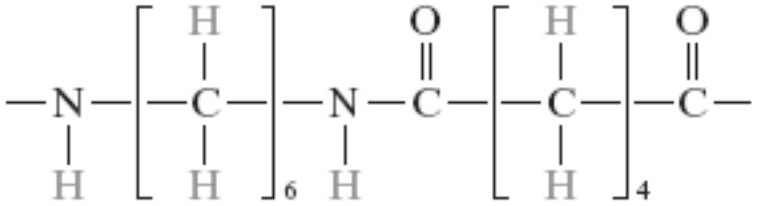
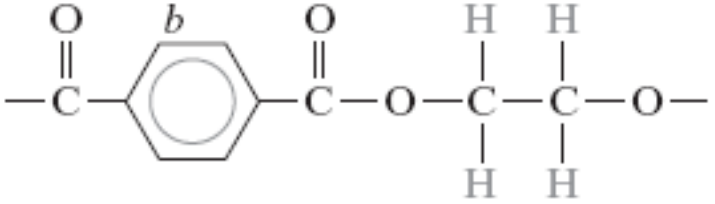
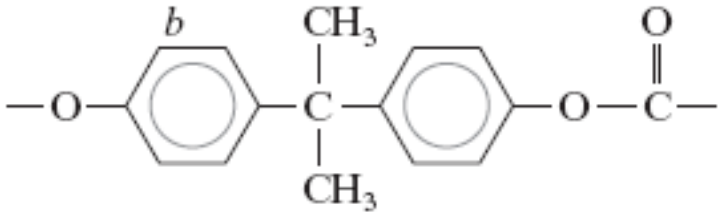
The word, polymer, implies that polymers are constructed from pieces (monomers) that can be easily connected into long chains (polymer). When you look at the above shapes, your mind should see that they could easily fit together.

Bulk or Commodity Polymers

Table 14.3 **A Listing of Repeat Units for Polymeric Materials**

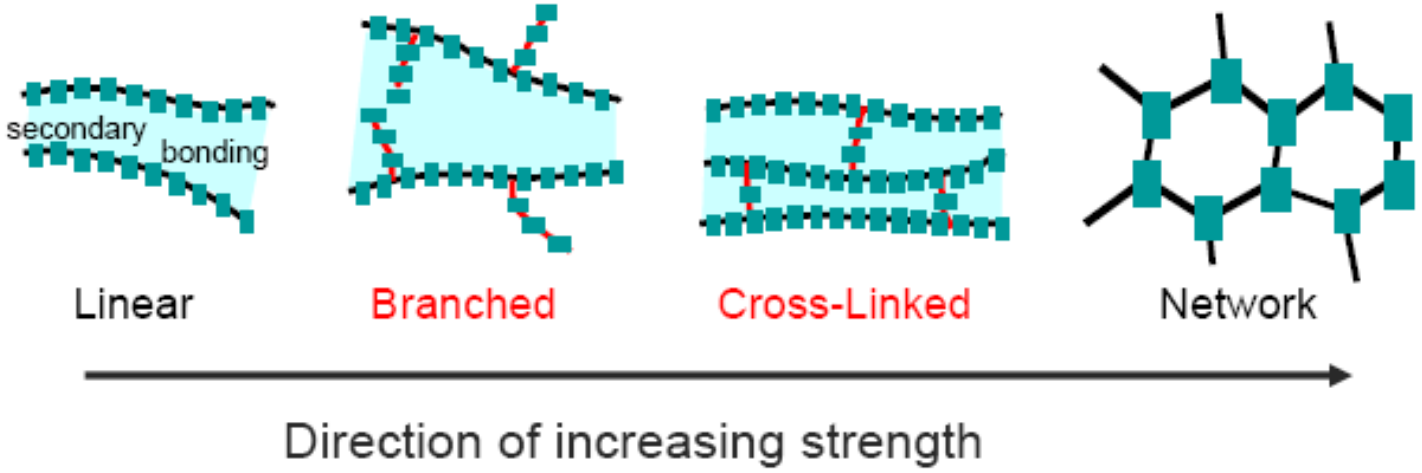
Polymer	*Repeat Unit*
 Polyethylene (PE)	
 Poly(vinyl chloride) (PVC)	
 Polytetrafluoroethylene (PTFE)	
 Polypropylene (PP)	

Polymer	*Repeat Unit*
 Polystyrene (PS)	
 Poly(methyl methacrylate) (PMMA)	
 Phenol-formaldehyde (Bakelite)	

Polymer	*Repeat Unit*
 Poly(hexamethylene adipamide) (nylon 6,6)	
 Poly(ethylene terephthalate) (PET, a polyester)	
 Polycarbonate (PC)	

Molecular Structures

- Covalent chain configurations and strength:

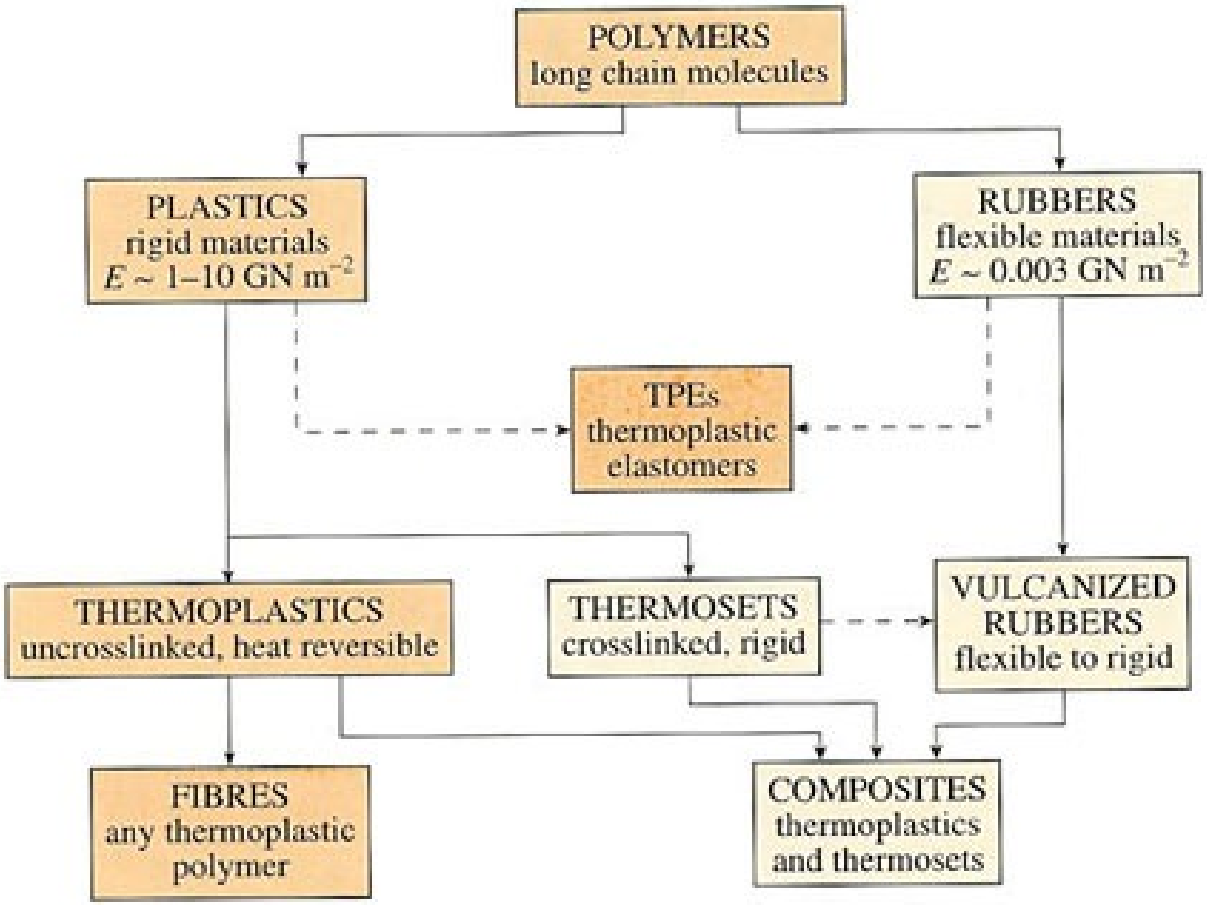


Adapted from Fig. 14.7, *Callister 7e.*

Range of Polymers

- Traditionally, the industry has produced two main types of synthetic polymer – plastics and rubbers.
- Plastics are (generally) rigid materials at service temperatures
- Rubbers are flexible, low modulus materials which exhibit long-range elasticity.

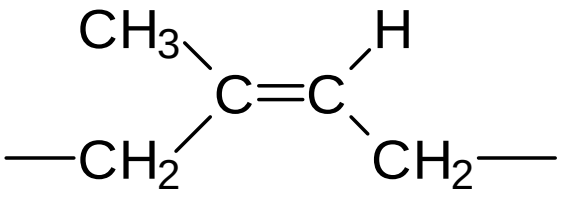
Range of Polymers



Thermoplastics & Thermosetting polymers

- Thermoplastics polymers: soften when heated and harden when cooled and vice versa
- Structure Example: linear, branched:
- Polyethylene, polystyrene, PVC, Poly (ethylene terephthalate)
- Thermosetting polymers: permanently hard (do not soften when heated)
- Made from network polymers: covalent bond resist motion at high temperature prevent.
- Epoxies, phenolics, and some polyester resins.

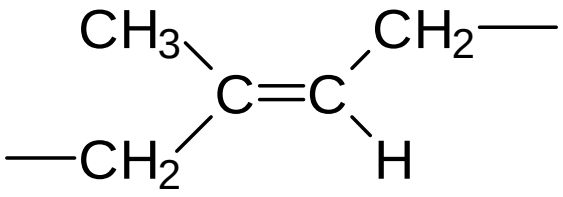
cis/trans Isomerism



cis

cis-isoprene
(natural rubber)

bulky groups on same side of chain

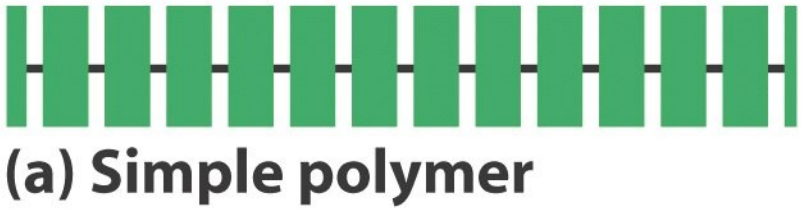


trans

trans-isoprene
(gutta percha)

bulky groups on opposite sides of chain

Important constitutions for synthetic polymers



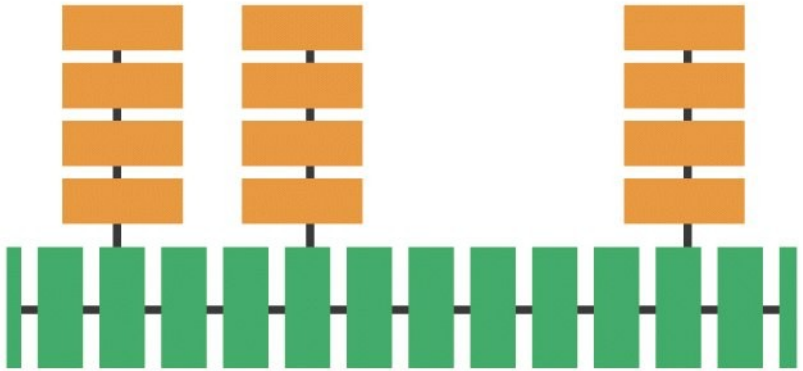
(a) Simple polymer



(b) Alternating copolymer



(c) Block copolymer



(d) Graft copolymer

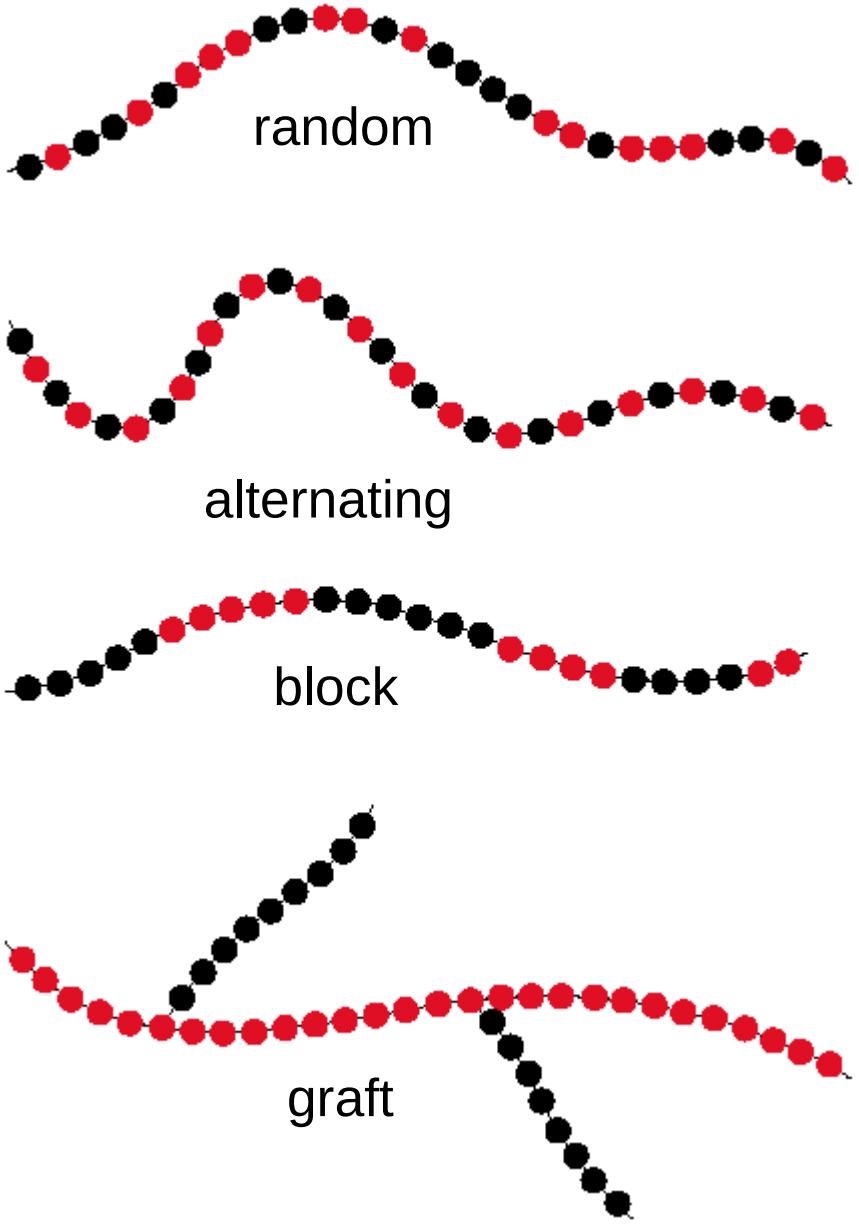
Copolymers

two or more monomers polymerized together

- random – A and B randomly vary in chain
- alternating – A and B alternate in polymer chain
- block – large blocks of A alternate with large blocks of B
- graft – chains of B grafted on to A backbone

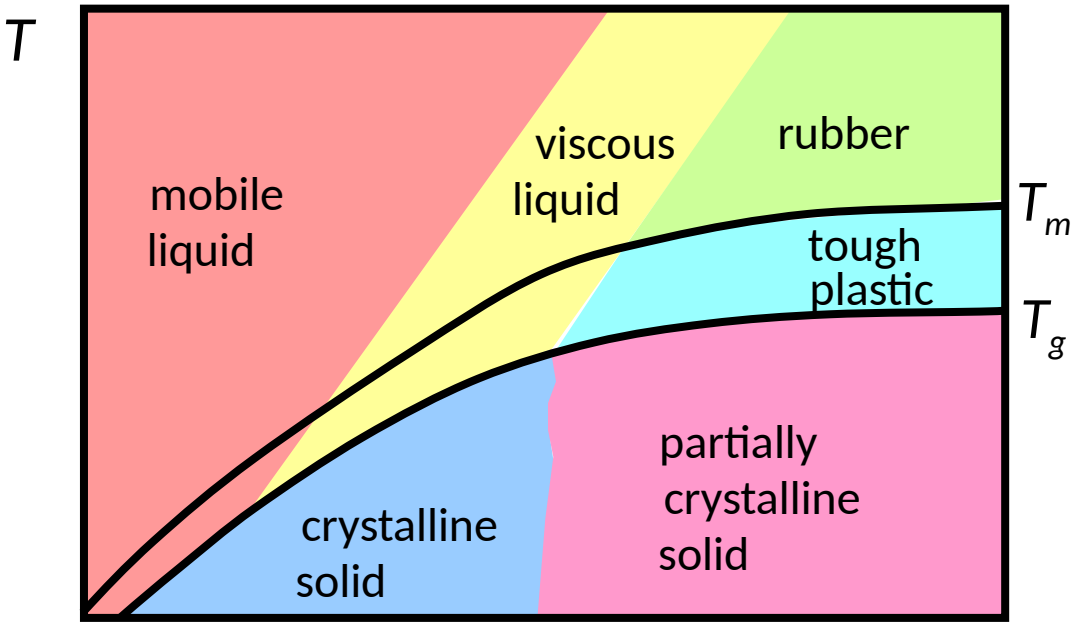
A – **B –**





Thermoplastics vs. Thermosets

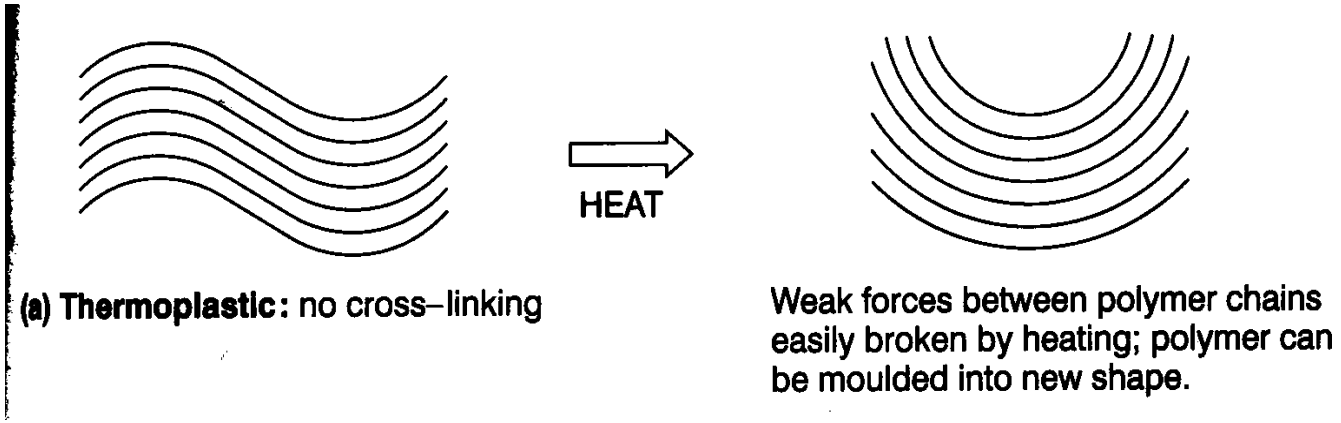
- Thermoplastics:
  -- little crosslinking
  -- ductile
  -- soften w/heating
  -- polyethylene
  polypropylene
  polycarbonate
  polystyrene



Adapted from Fig. 15.19, *Callister 7e*. (Fig. 15.19 is from F.W. Billmeyer, Jr., *Textbook of Polymer Science*, 3rd ed., John Wiley and Sons, Inc., 1984.)

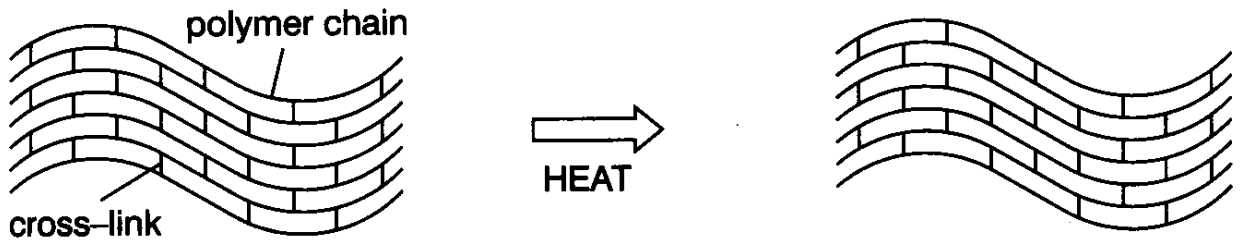
- Thermosets:
  -- large crosslinking
  (10 to 50% of mers)
  -- hard and brittle
  -- do NOT soften w/heating
  -- vulcanized rubber, epoxies,
  polyester resin, phenolic resin

Thermoplastics (80%)



- No cross links between chains.
- Weak attractive forces between chains broken by *warming*.
- Change shape - can be remoulded.
- Weak forces reform in new shape when cold.

Thermosets



(b) Thermoset: extensive cross–linking

Strong covalent bonds between polymer chains cannot be easily broken; polymer keeps shape on heating.

- Extensive cross-linking formed by covalent bonds.
- Bonds prevent chains moving relative to each other.
- What will the properties of this type of plastic be like?

Longer chains make stronger polymers.

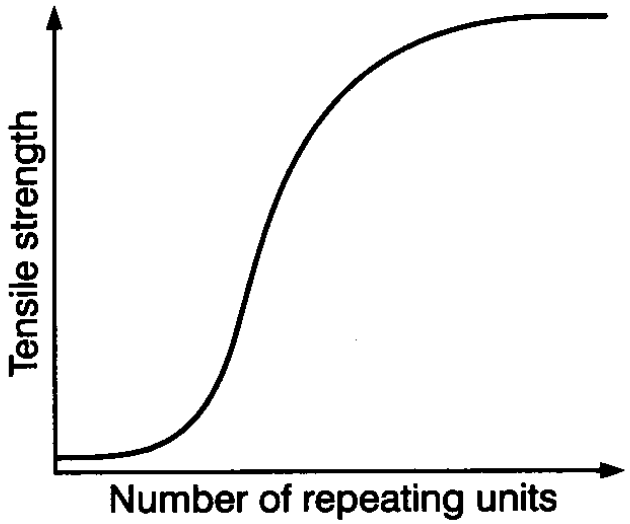


Figure 31 The relationship between tensile strength and chain length for a polymer.

- Critical length needed before strength increases.
- Hydrocarbon polymers average of 100 repeating units necessary but only 40 for nylons.
- Tensile strength measures the forces needed to snap a polymer.
- More tangles + more touching!!!

Polymer Additives

Improve mechanical properties, processability, durability, etc.

- Fillers
  - Added to improve tensile strength & abrasion resistance, toughness & decrease cost
  - ex: carbon black, silica gel, wood flour, glass, limestone, talc, etc.

- Plasticizers
  - Added to reduce the glass transition temperature T_g
  - commonly added to PVC - otherwise it is brittle

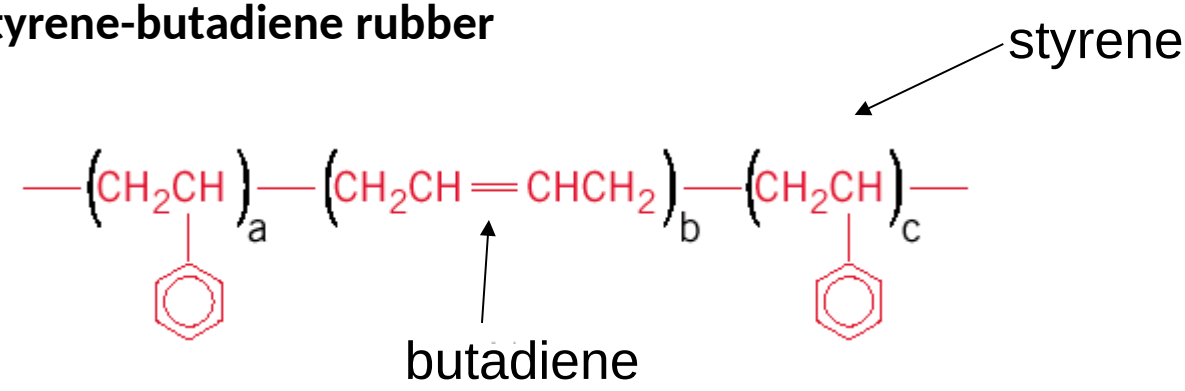
Polymer Additives

- Stabilizers
  - Antioxidants
  - UV protectants
- Lubricants
  - Added to allow easier processing
  - “slides” through dies easier – ex: Na stearate
- Colorants
  - Dyes or pigments
- Flame Retardants
  - Cl/F & B

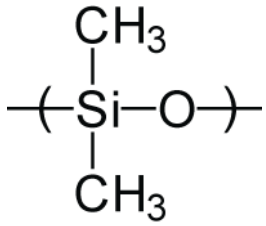
Polymer Types: Elastomers

Elastomers – rubber

- **Crosslinked materials**
  - **Natural rubber**
  - **Synthetic rubber and thermoplastic elastomers**
    - **SBR- styrene-butadiene rubber**



- Silicone rubber



Processing of Plastics

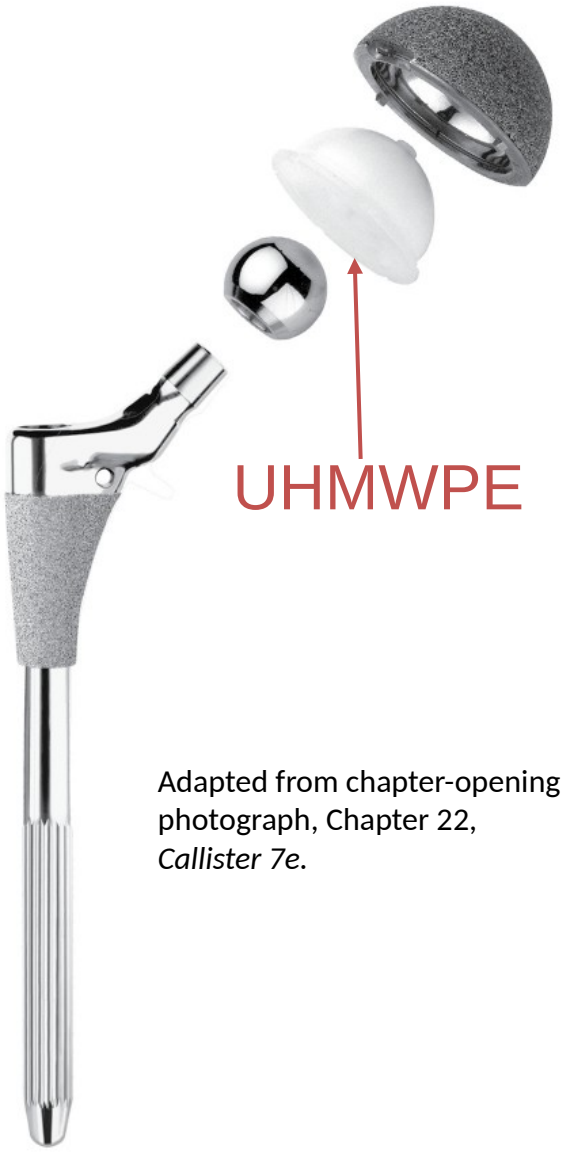
- Thermoplastic –
  - can be reversibly cooled & reheated, i.e. recycled
  - heat till soft, shape as desired, then cool
  - ex: polyethylene, polypropylene, polystyrene, etc.
- Thermoset
  - when heated forms a network
  - degrades (not melts) when heated
  - mold the prepolymer then allow further reaction
  - ex: urethane, epoxy

TABLE 12.10

The Relationship of Processing, Molecular Structure, and Mechanical Behavior for Polymers

Category	Processing technique	Molecular structure	Mechanical effect
Thermoplastic polymers	Addition agent	Branching	Increased strength and stiffness
	Vulcanization	Cross-linking	Increased strength and stiffness
	Crystallization	Increased crystallinity	Increased strength and stiffness
	Plasticizer	Decreased molecular weight	Decreased strength and stiffness
	Filler	Restricted chain mobility	Increased strength and stiffness
Thermosetting polymers	Setting at elevated temperatures	Network formation	Rigid (remaining upon cooling)

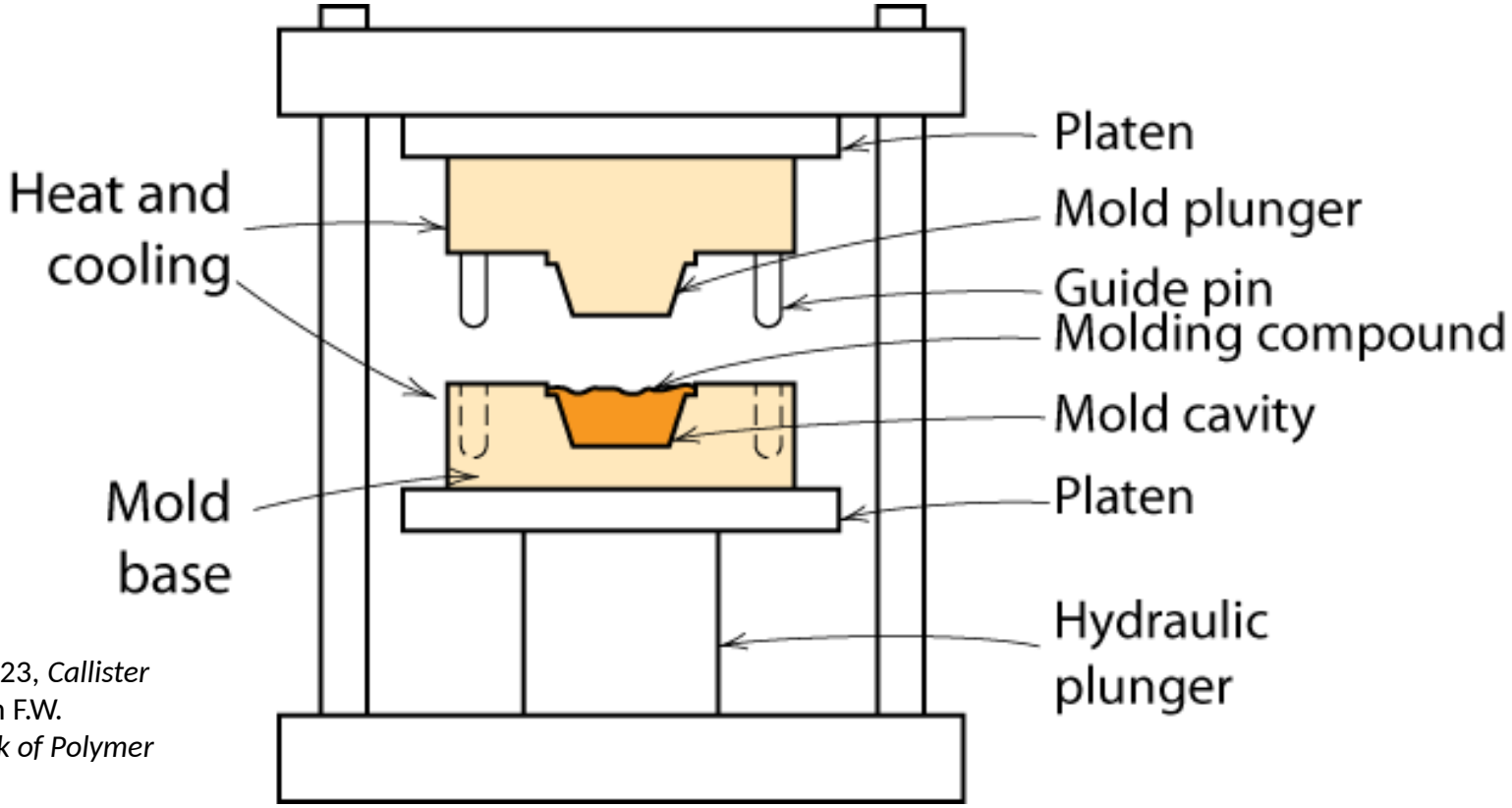
- Ultrahigh molecular weight polyethylene (UHMWPE)
  - Molecular weight
    ca. 4×10^6 g/mol
  - Excellent properties for variety of applications
    - bullet-proof vest, golf ball covers, hip joints, etc.



Adapted from chapter-opening photograph, Chapter 22, *Callister 7e*.

Processing Plastics - Molding

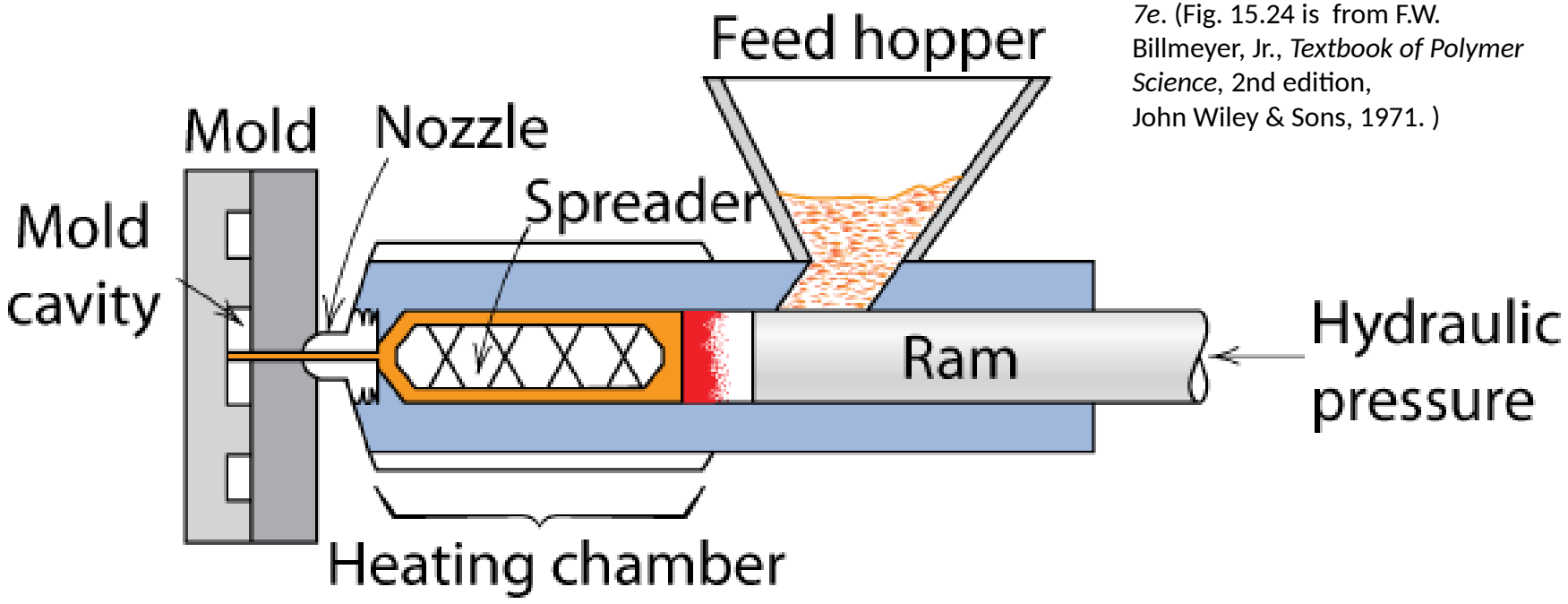
- **Compression and transfer molding**
  - **thermoplastic or thermoset**



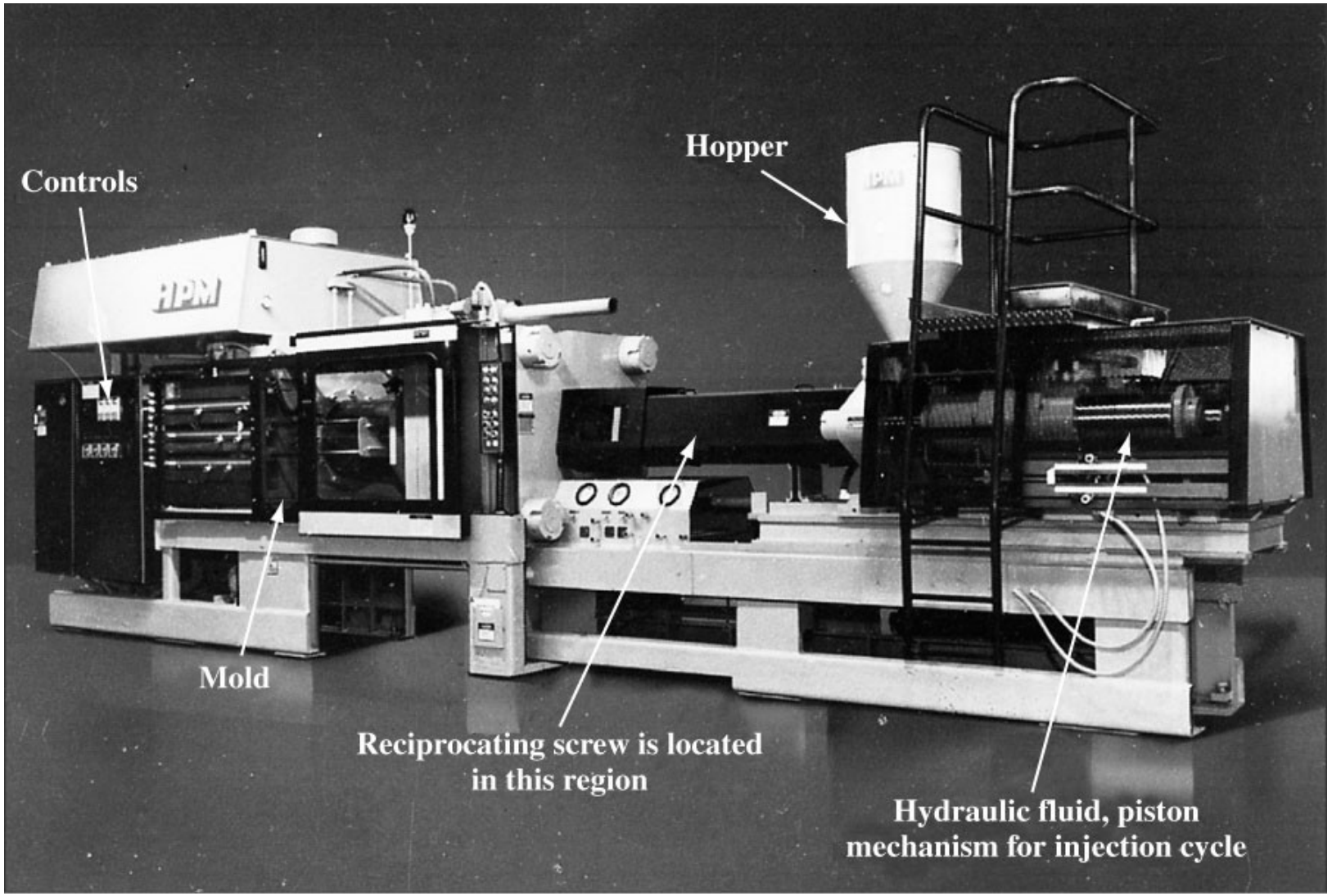
Adapted from Fig. 15.23, *Callister 7e*. (Fig. 15.23 is from F.W. Billmeyer, Jr., *Textbook of Polymer Science*, 3rd ed., John Wiley & Sons, 1984.)

Processing Plastics - Molding

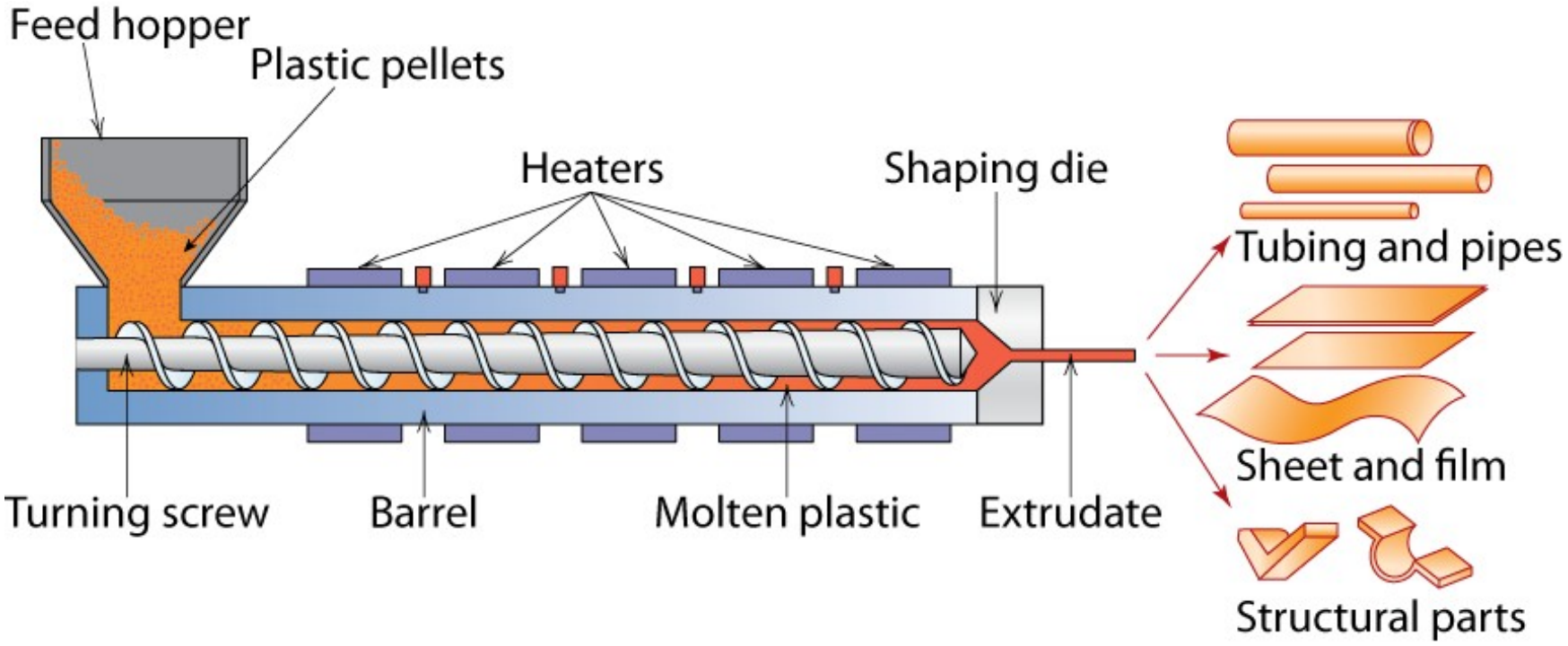
- Injection molding
  - thermoplastic & some thermosets



Adapted from Fig. 15.24, *Callister 7e*. (Fig. 15.24 is from F.W. Billmeyer, Jr., *Textbook of Polymer Science*, 2nd edition, John Wiley & Sons, 1971.)

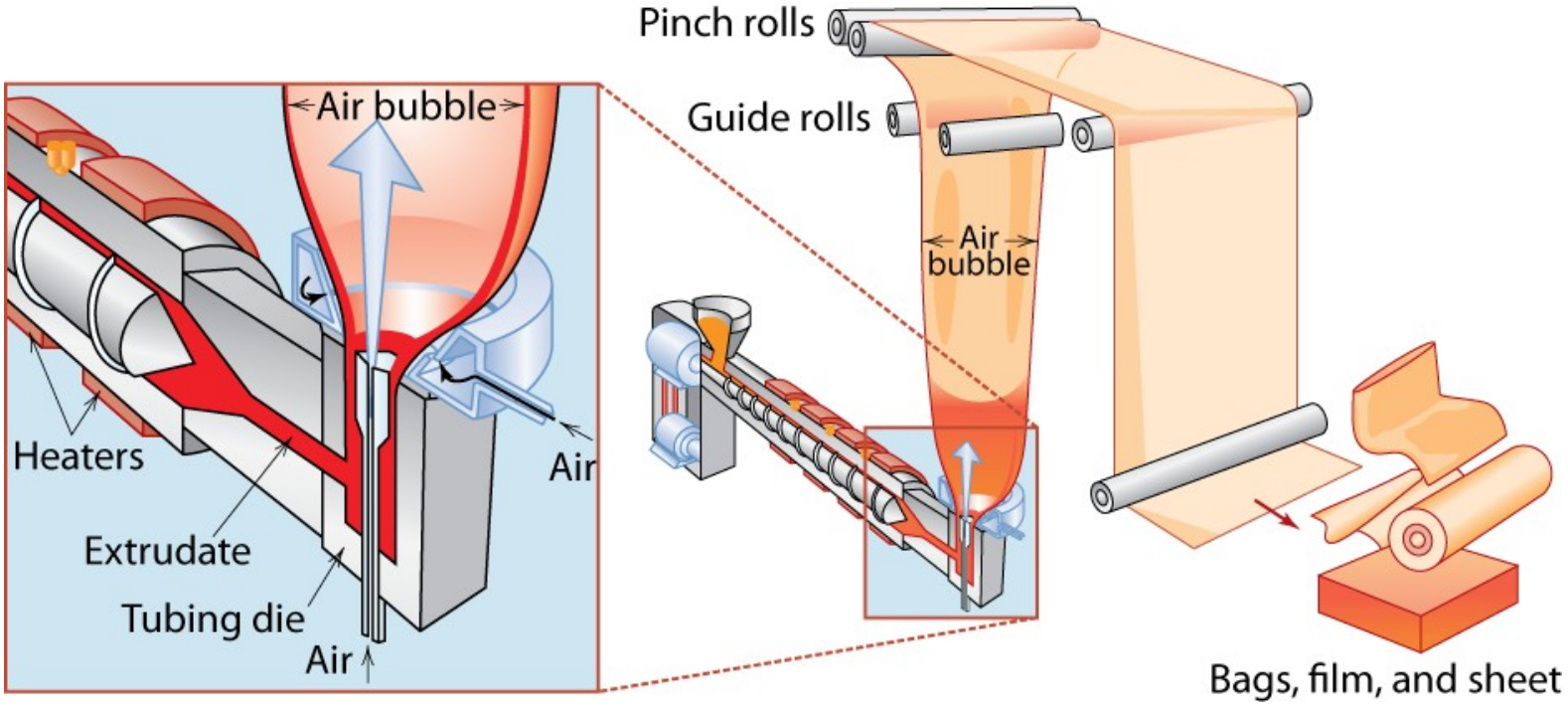

Controls
Hopper
HPM
Mold
Reciprocating screw is located
in this region
Hydraulic fluid, piston
mechanism for injection cycle

Processing Plastics – Extrusion



Adapted from Fig. 15.25, *Callister 7e*. (Fig. 15.25 is from *Encyclopædia Britannica*, 1997.)

Blown-Film Extrusion



(from *Encyclopædia Britannica*, 1997.)

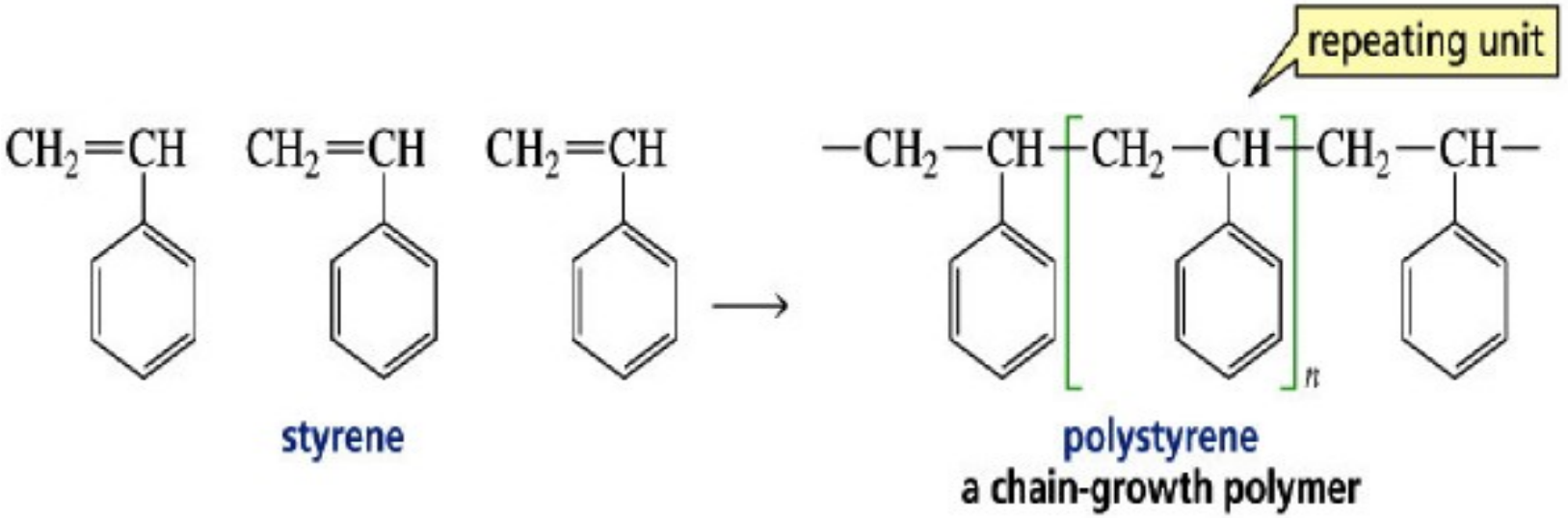
Synthesis of Polymers

Synthesis of Polymers

- **There are a number different methods of preparing polymers from suitable monomers, these are**
  - **step-growth (or condensation) polymerisation**
  - **addition polymerisation**
  - **insertion polymerisation.**

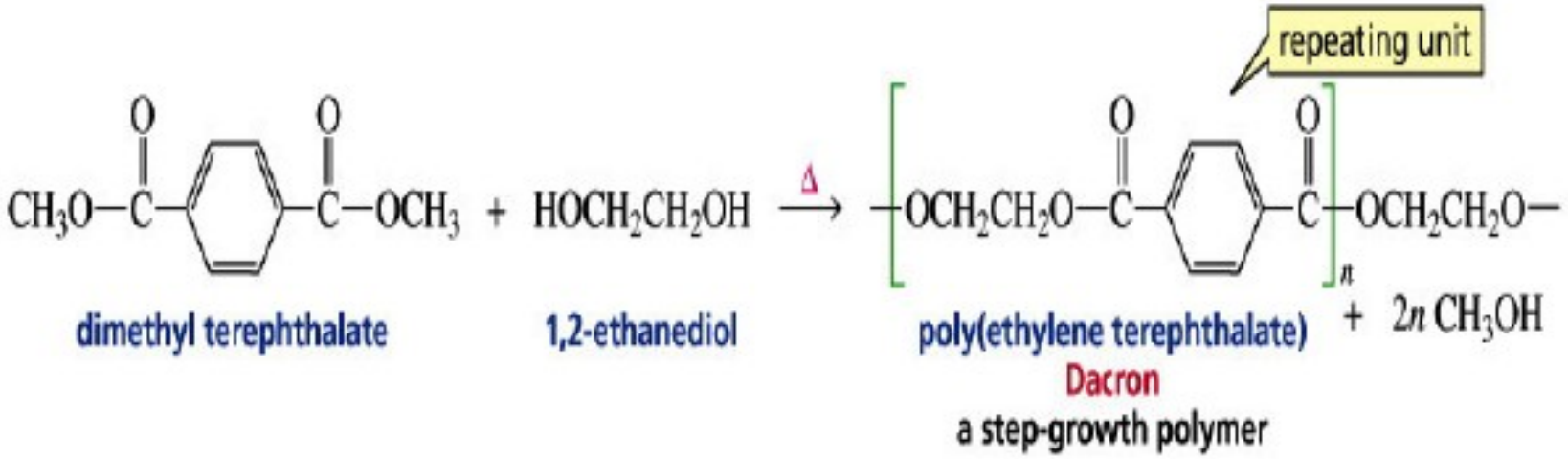
Types of Polymerization

- Chain-growth polymers, also known as addition polymers, are made by chain reactions



Types of Polymerization

- Step-growth polymers, also called condensation polymers, are made by combining two molecules by removing a small molecule

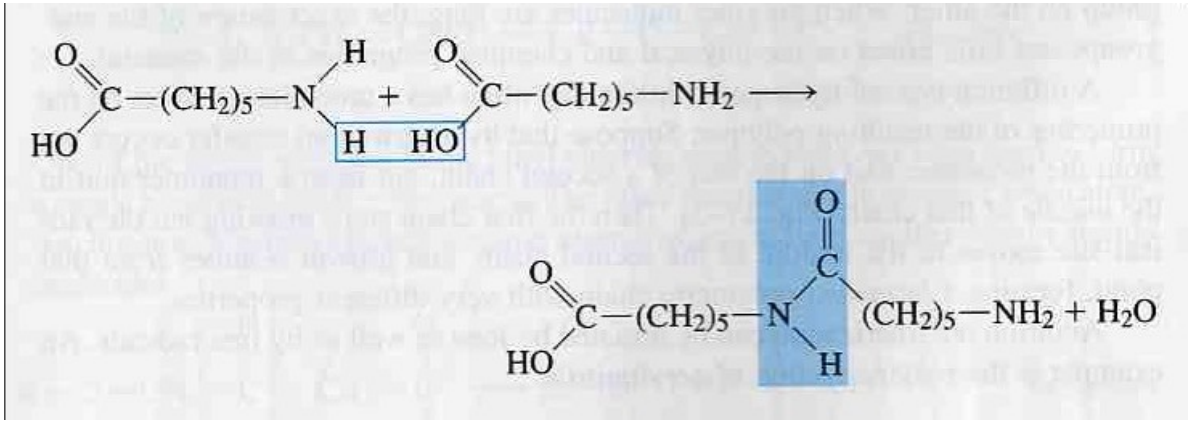


Condensation polymerization

Condensation polymerization: the polymer grows from monomers by splitting off a small molecule such as water or carbon dioxide.

Example: formation of amide links and loss of water

Monomers



First unit of polymer + H_2O

In the 1967 movie, "The Graduate",

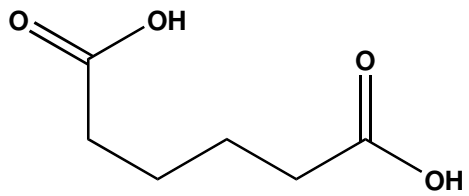
a smug Los Angeles businessman takes aside the baby-faced Dustin Hoffman and declares,

"I just want to say one word to you -- just one word -- 'plastics.' "

In 2005 we can replace 'plastics' with another word: 'synthetic polymers'

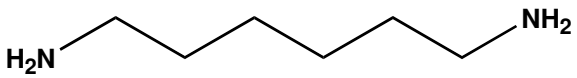
Rembember from GChem?

Nylon is a condensation polymer made of the monomers adipic acid and hexamethylene diamine.



adipic acid

+



hexamethylene diamine

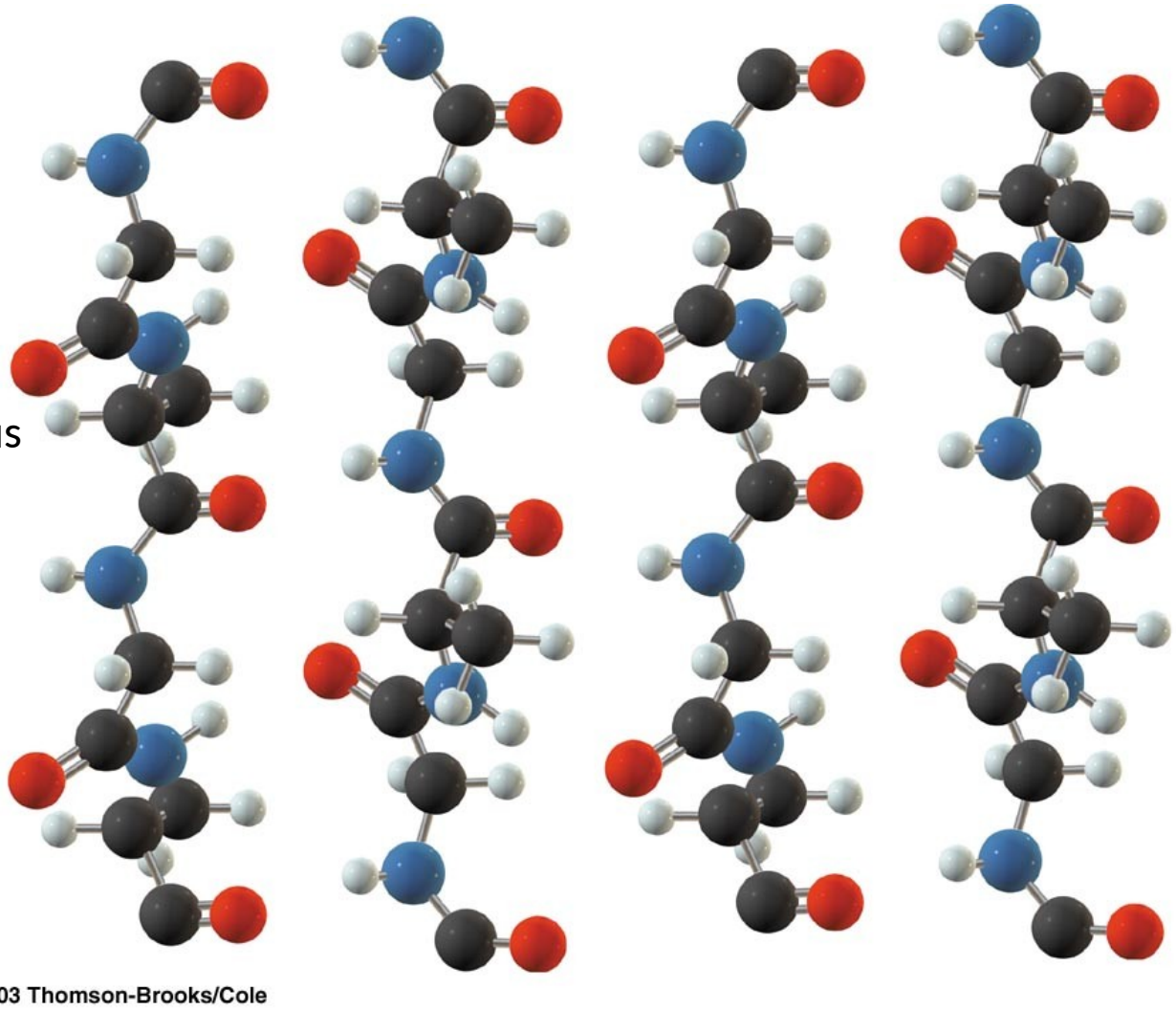
nylon

They're nylons, Be

Hydrogen bonds between chains

Supramolecular
Structure of nylon

Intermolecular hydrogen bonds give nylon enormous tensile strength



© 2003 Thomson-Brooks/Cole

Biopolymers

Nucleic acid polymers (DNA, RNA)

Amino acids polymers (Proteins)

Sugar polymers (Carbohydrates)

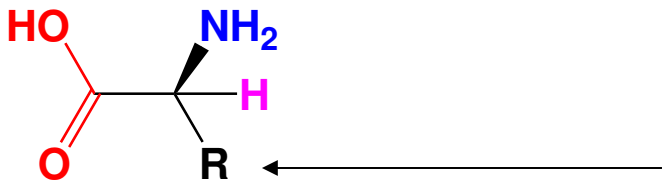
Genetic information for the cell: DNA

Structural strength and catalysis: Proteins

Energy source: Carbohydrates

Proteins: amino acid monomers

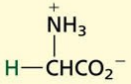
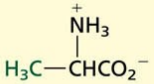
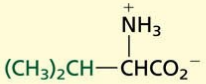
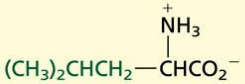
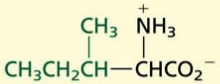
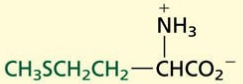
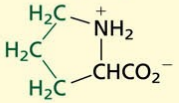
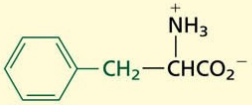
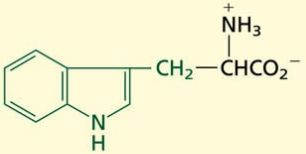
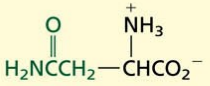
The basic structure of an amino acid monomer



The difference between amino acids is the R group

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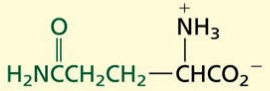
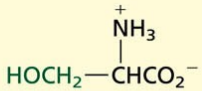
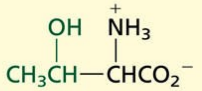
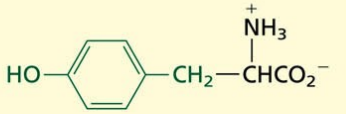
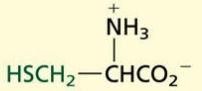
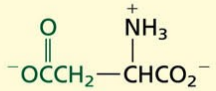
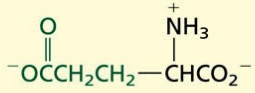
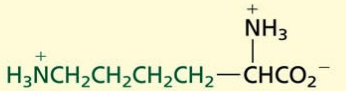
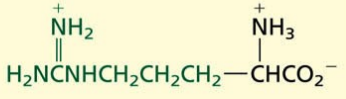
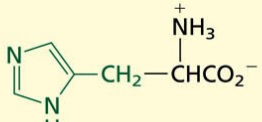
TABLE 27.1 α-Amino Acids Found in Proteins

Name	Abbreviation	Structural formula*
Amino acids with nonpolar side chains		
Glycine	Gly (G)	
Alanine	Ala (A)	
Valine†	Val (V)	
Leucine†	Leu (L)	
Isoleucine†	Ile (I)	
Methionine†	Met (M)	
Proline	Pro (P)	
Phenylalanine†	Phe (F)	
Tryptophan†	Trp (W)	
Amino acids with polar but nonionized side chains		
Asparagine	Asn (N)	

*All amino acids are shown in the form present in greatest concentration at pH 7.
†An essential amino acid, which must be present in the diet of animals to ensure normal growth.

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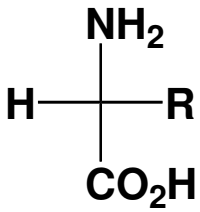
TABLE 27.1 α-Amino Acids Found in Proteins *(Continued)*

Name	Abbreviation	Structural formula*
Amino acids with polar but nonionized side chains		
Glutamine	Gln (Q)	
Serine	Ser (S)	
Threonine†	Thr (T)	
Tyrosine	Tyr (Y)	
Cysteine	Cys (C)	
Amino acids with acidic side chains		
Aspartic acid	Asp (D)	
Glutamic acid	Glu (E)	
Amino acids with basic side chains		
Lysine†	Lys (K)	
Arginine†	Arg (R)	
Histidine†	His (H)	

Proteins: condensation polymers

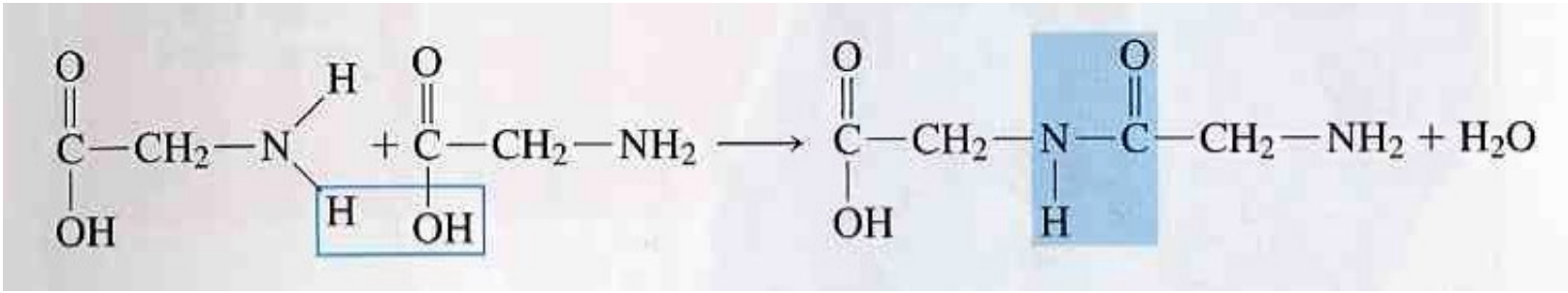
Formed by condensation polymerization of amino acids

Monomers: 20 essential amino acids



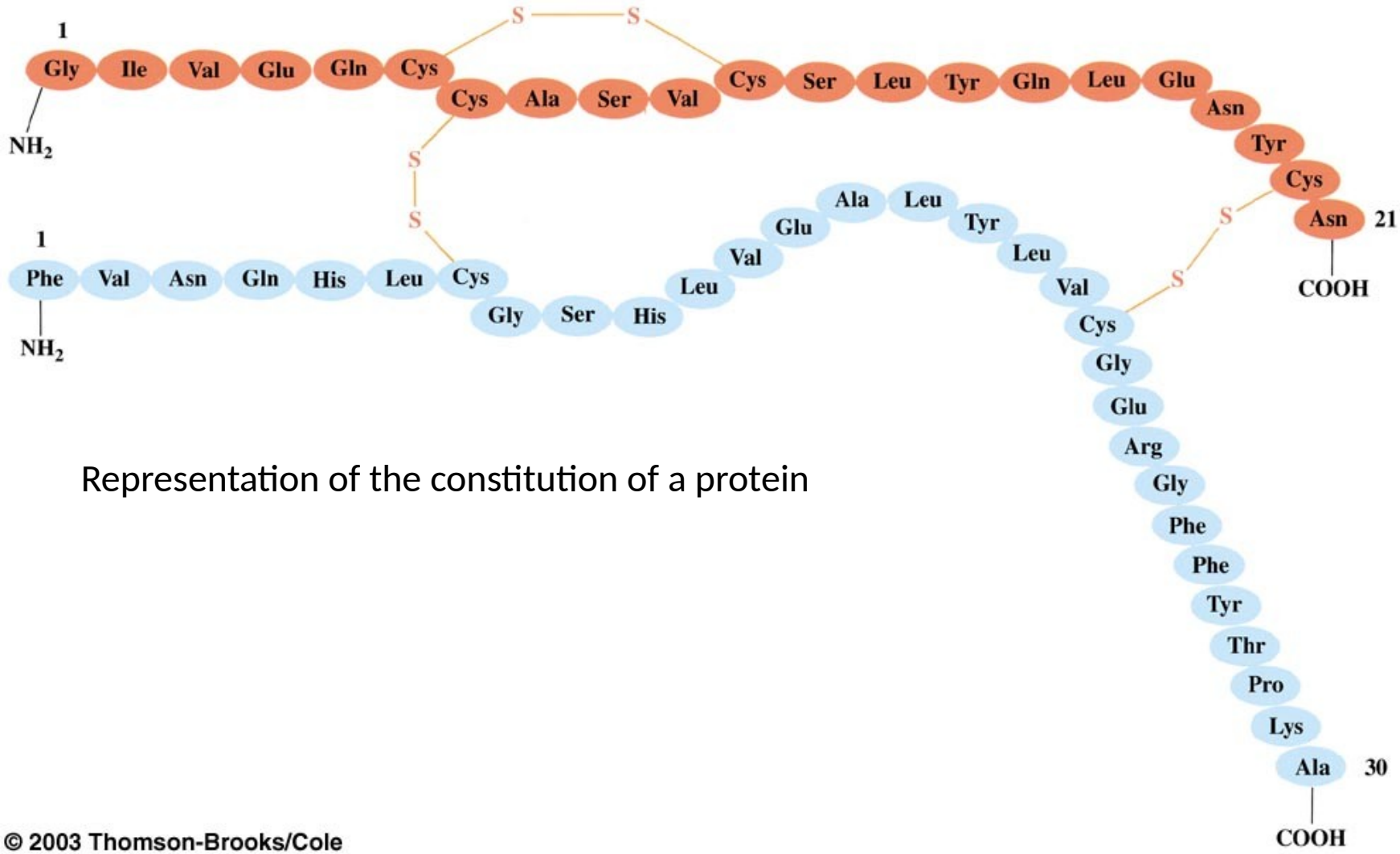
General structure of an amino acid

R is the only variable group



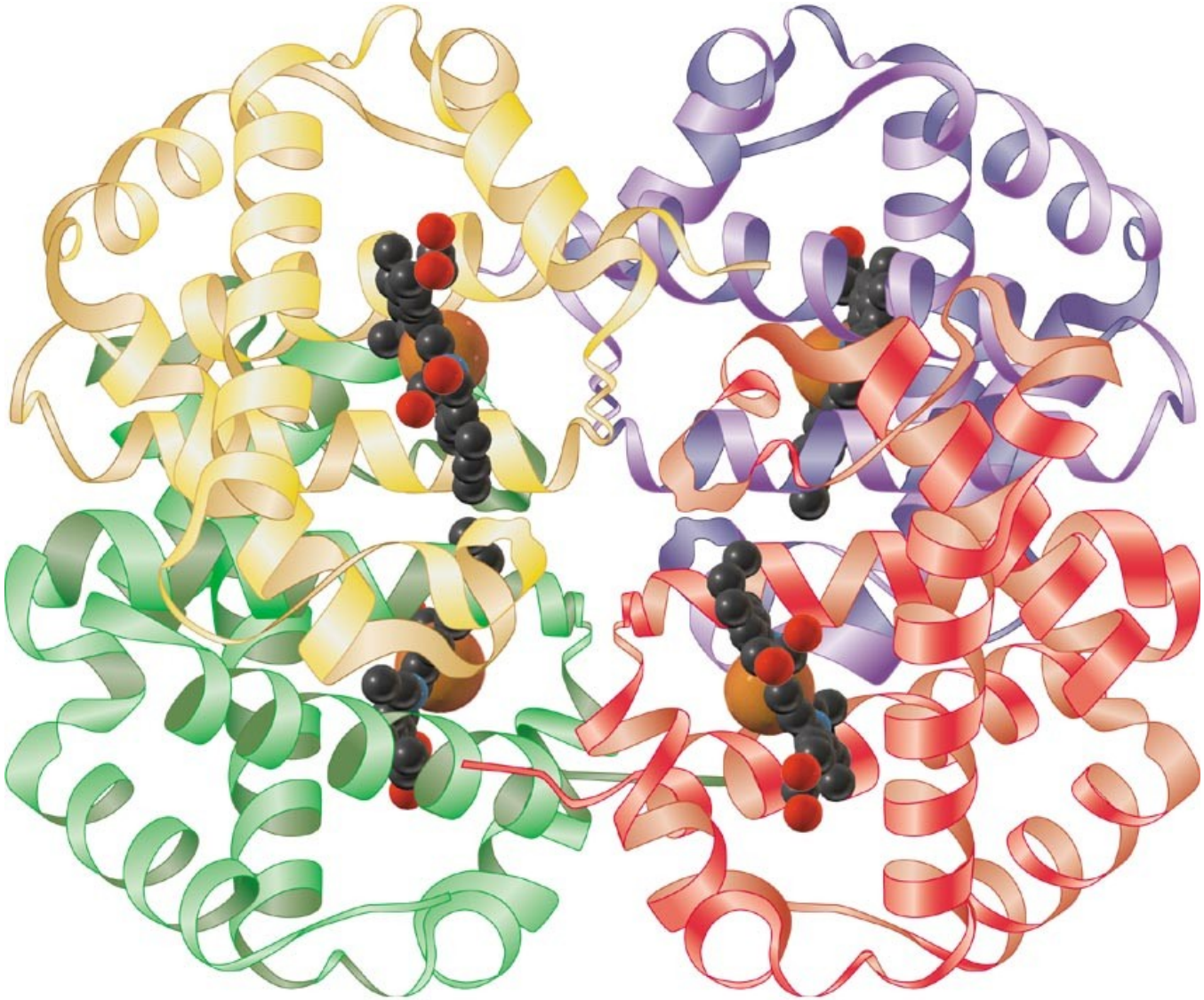
Glycine (R = H) + Glycine

First step toward poly(glycine)



Representation of the constitution of a protein

Three D representation of the structure of a protein



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DNA

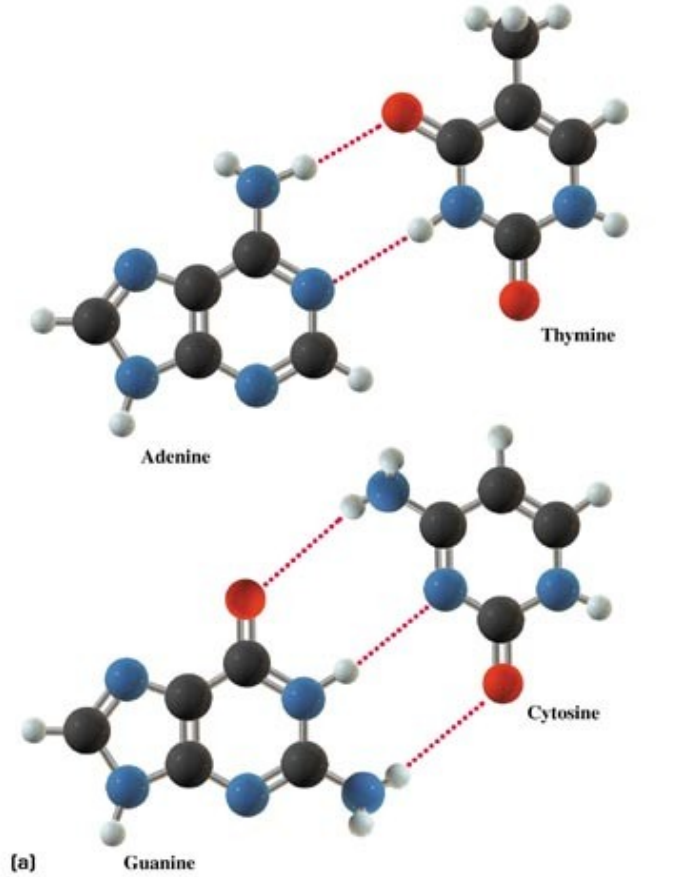
The monomers:

Adenine (A)

Guanine (G)

Thymine (T)

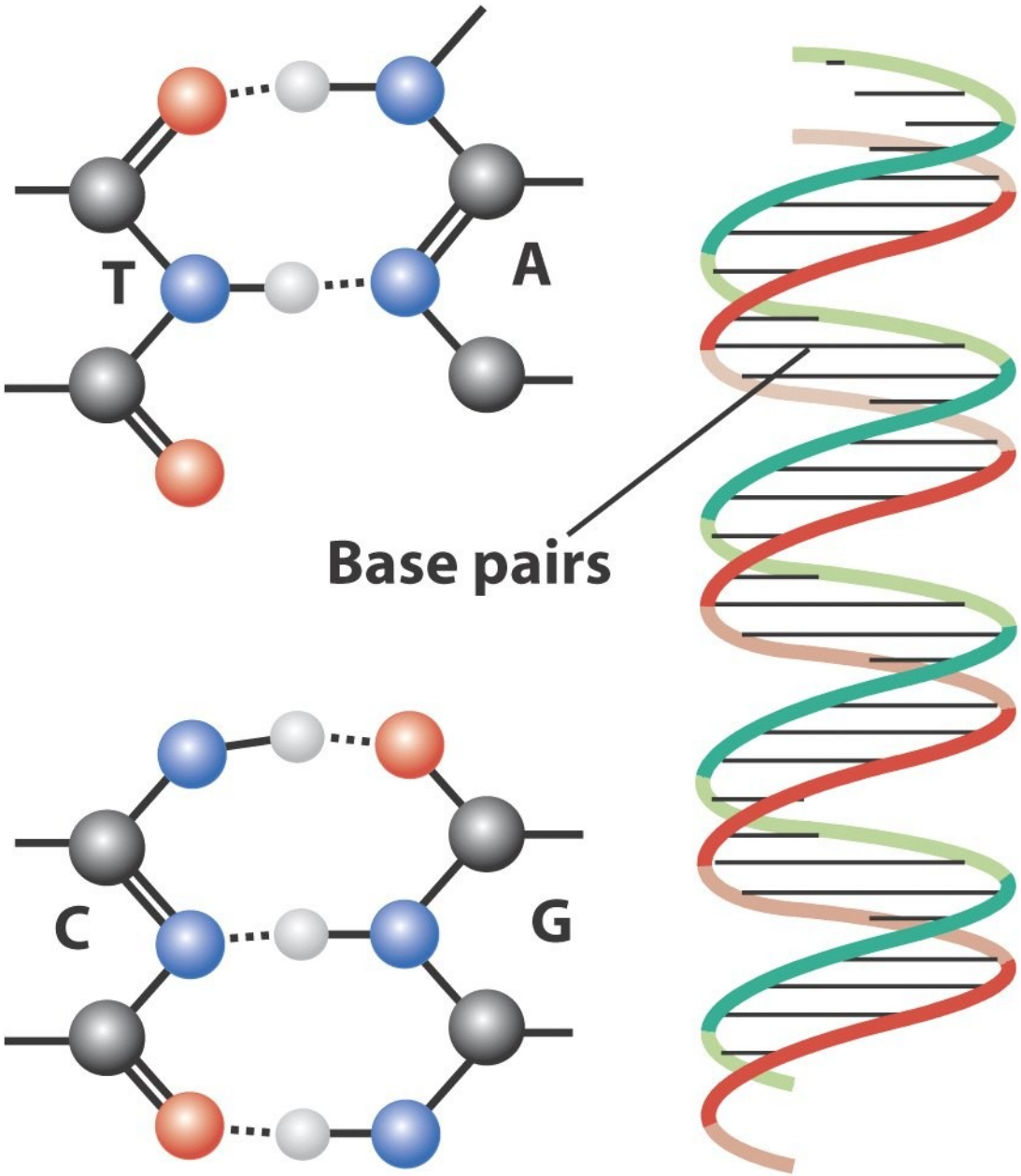
Cytosine (C)



Phosphate-
Sugar (backbone) of
DNA

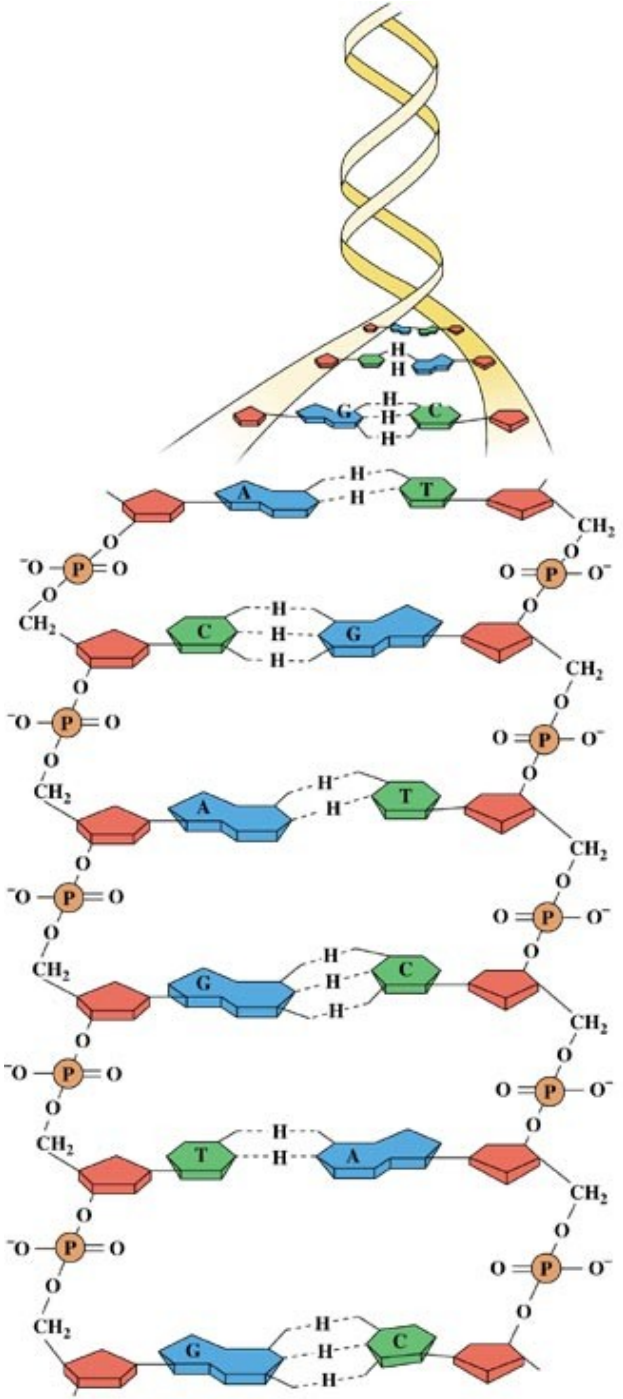


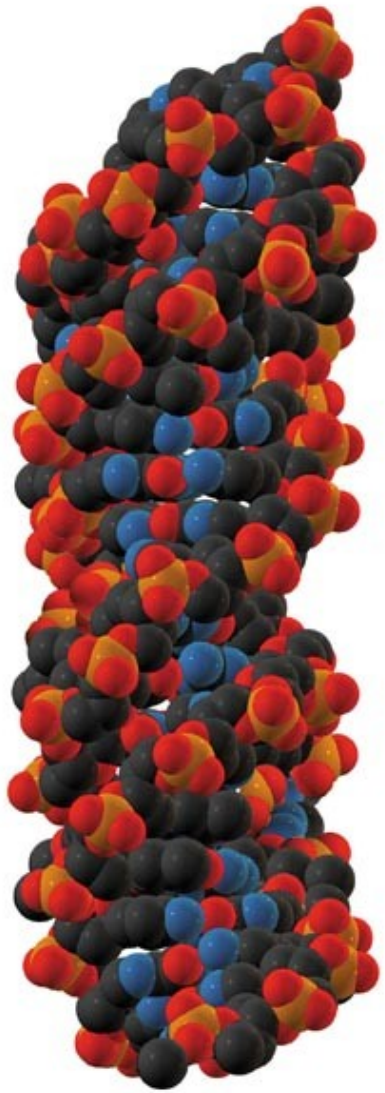
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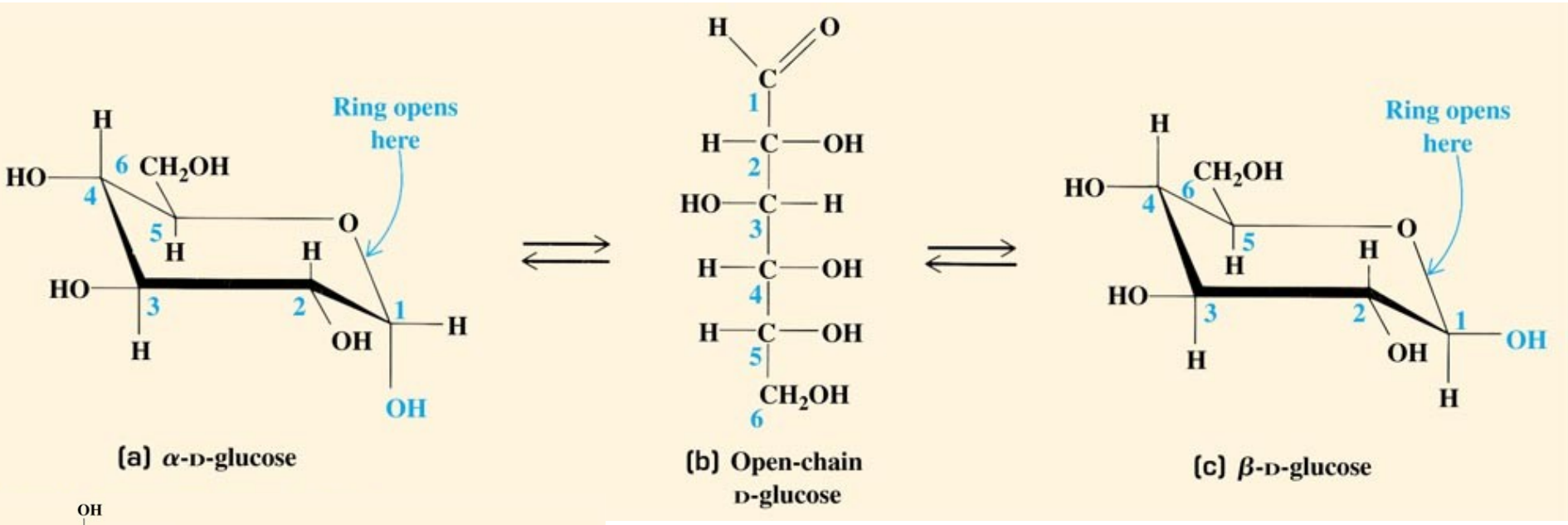
Phosphate-sugar backbone holds the DNA macromolecule together

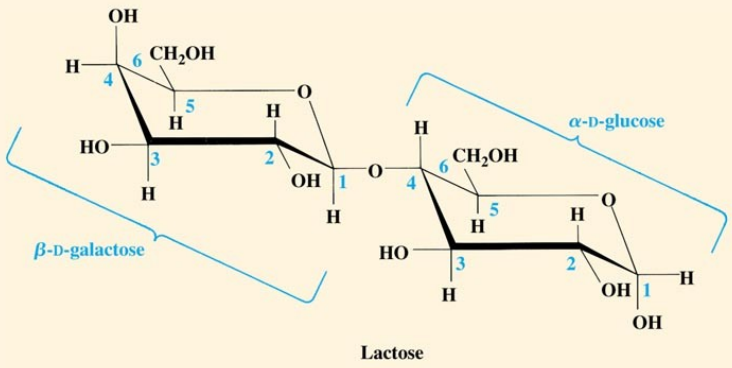
One strand unwinds to duplicate its complement via a polymerization of the monomers
C, G, A and T



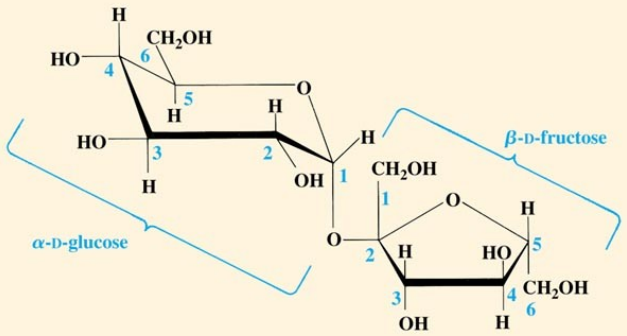


Carbohydrates



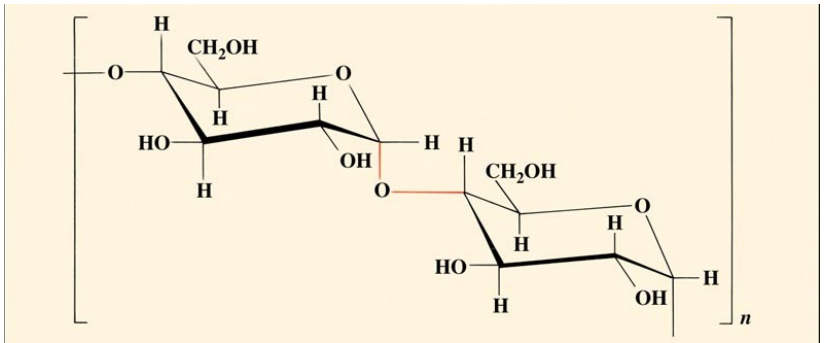


Lactose

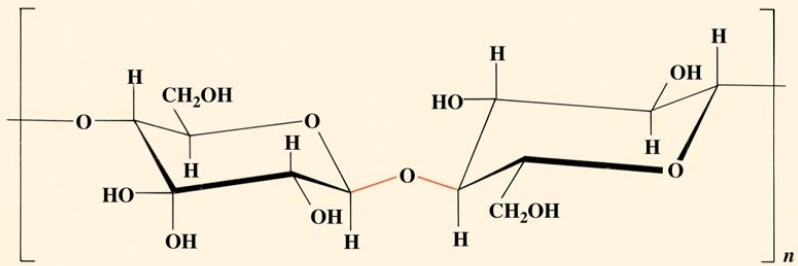


Sucrose

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(a) Starch



(b) Cellulose

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Addition Vs. Condensation Polymerization

- Polymerisation reactions can generally be written as

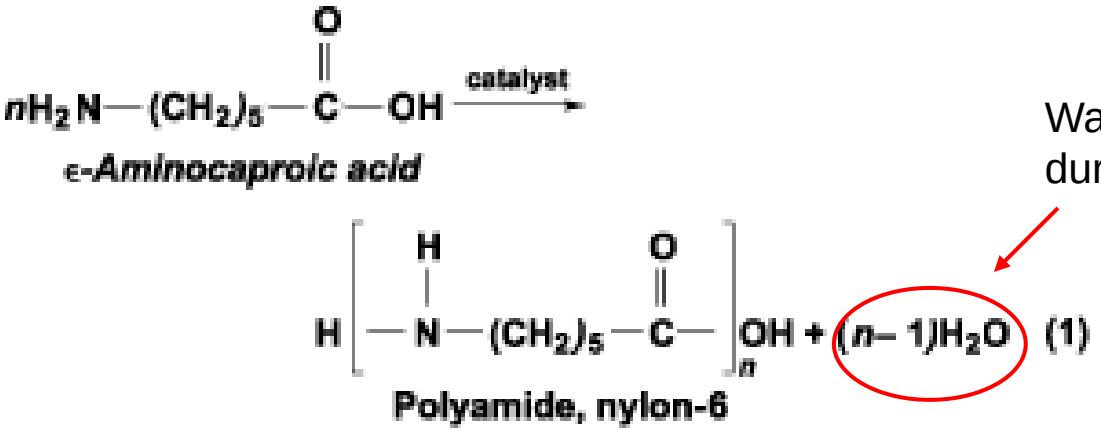
  x-mer + y-mer ⟶ (x + y)-mer

- In a reaction that leads to **condensation polymers**, x and y may assume any value
- i.e. chains of any size may react together as long as they are capped with the correct functional group

Addition Vs. Condensation Polymerization

- In **addition polymerization** although x may assume any value, y is confined to unity
- i.e. the growing chain can react only with a monomer molecule and continue its growth

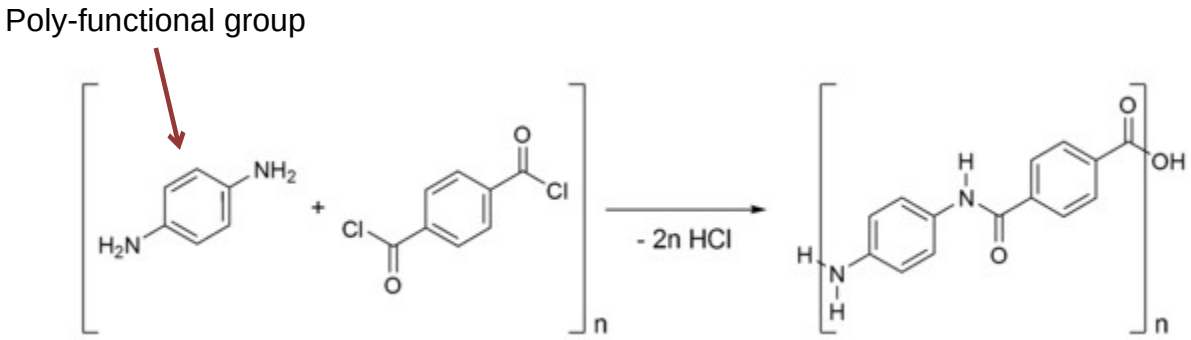
Condensation Polymerization



Water is “Condensed out” during polymerization of Nylon

- Some of the original monomer’s materials are shed (condensed out) during polymerization process – thus the name: Step Process
- Process is (typically) conducted in the presence of a catalyst to speed up the ‘stepping’
- Water or CO_2 are commonly condensed out but other compounds can be condensed out including HCN, HCl and other acids

Condensation Polymerization of “Kevlar”:



Kevlar is synthesised in solution from the monomers: 1,4-phenylene-diamine (*para*-phenylenediamine) and terephthaloyl chloride in a condensation reaction yielding hydrochloric acid as a byproduct.

Thermodynamics

- Thermodynamics of polymerization determines the position of the equilibrium between polymer and monomer(s).
- The well known thermodynamic expression:

$$\Delta G = \Delta H - T\Delta S$$

yields the basis for understanding polymerization/depolymerization behavior.

Thermodynamics

- For polymerization to occur (i.e., to be thermodynamically feasible), the Gibbs free energy of polymerization $\equiv$ $\mathbf{G_p < 0}$.

- If $\equiv$ $\mathbf{G_p > 0}$, then depolymerization will be favored.

Thermodynamics

- Standard enthalpy and entropy changes, $\Delta H^{o}p$ and $\Delta S^{o}p$ are reported for reactants and products in their appropriate standard states. Generally:
  - Temperature = 25°C = 298K
  - Monomer – pure, bulk monomer or 1 M solution
  - Polymer – solid amorphous or slightly crystalline

Thermodynamics

- Polymerization is an association reaction such that many monomers associate to form the polymer

- Thus: $\Delta S_p < 0$ for nearly all polymerization processes

Thermodynamics

- Since depolymerization is almost always <u>entropically</u> favored, the ΔH_p must then be sufficiently <u>negative</u> to compensate for the unfavorable entropic term.

- Only then will polymerization be thermodynamically favored by the resulting negative Δ Gp.

Thermodynamics

In practice:

- Polymerization is favored at low temperatures: $T\Delta S_p$ is small

- Depolymerization is favored at high temperatures: $T\Delta S_p$ is large

Thermodynamics

- Therefore, thermal instability of polymers results when $T\Delta S_p$ overrides ΔH_p and thus $\Delta G_p > 0$; this causes the system to spontaneously depolymerize (<u>if kinetic pathway exists</u>).

Types of Addition Polymerization

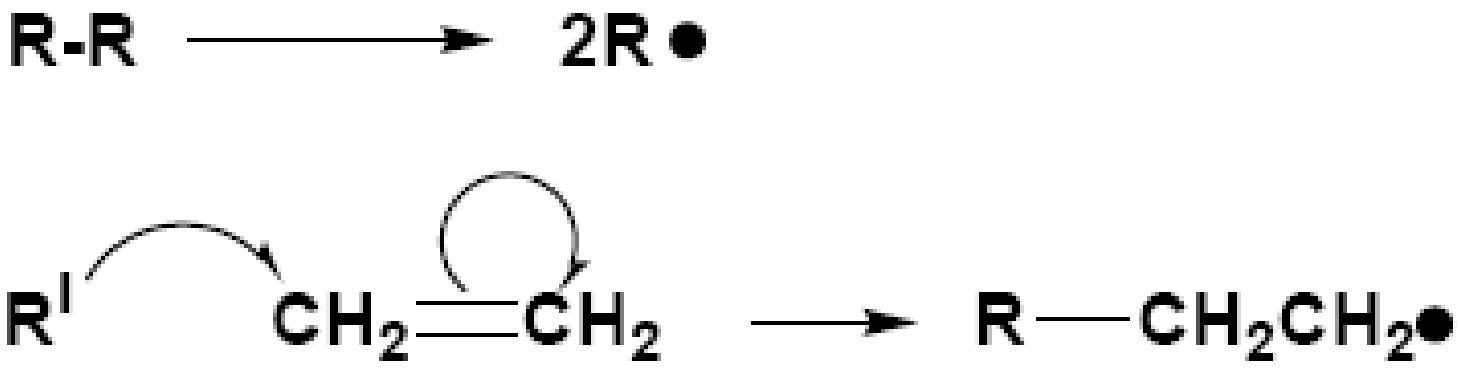
- Free Radical
- Cationic
- Anionic

Free Radical Polymerization

- Usually, many low molecular weight alkenes undergo rapid polymerization reactions when treated with small amounts of a radical initiator.
- For example, the polymerization of ethylene

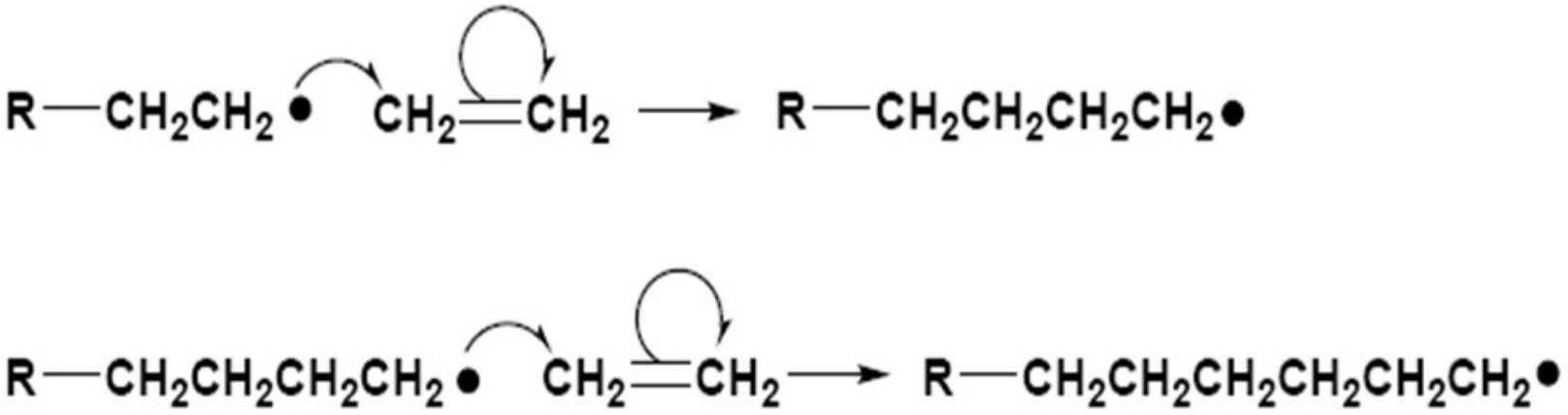
Free Radical Polymerization

step 1: Initiation



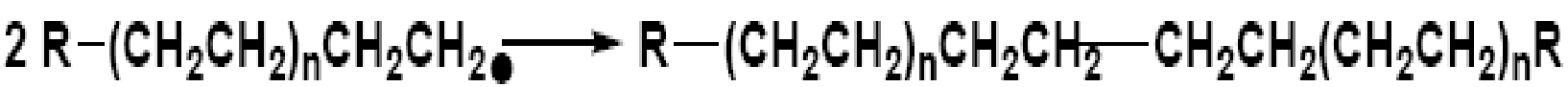
Free Radical Polymerization

step 2: Propagation



Free Radical Polymerization

step 3: Termination





Ionic Polymerization

- Ionic polymerization is more complex than free-radical polymerization

Ionic Polymerization

- Whereas free radical polymerization is non-specific, the type of ionic polymerization procedure and catalysts depend on the nature of the substituent (R) on the vinyl (ethenyl) monomer.

Ionic Polymerization

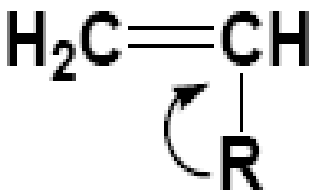
- Cationic initiation is therefore usually limited to the polymerization of monomers where the R group is electron-donating
- This helps stabilise the delocation of the positive charge through the p orbitals of the double bond

Ionic Polymerization

- Anionic initiation, requires the R group to be electron withdrawing in order to promote the formation of a stable carbanion (ie, -M and -I effects help stabilise the negative charge).

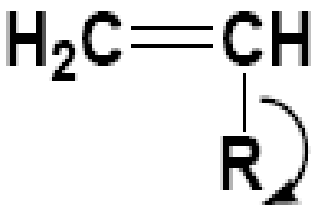
Ionic Polymerization

Cationic



R - Electron donating

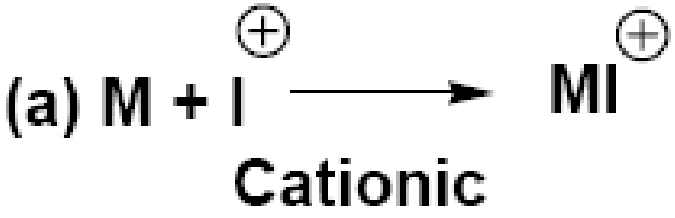
Anionic

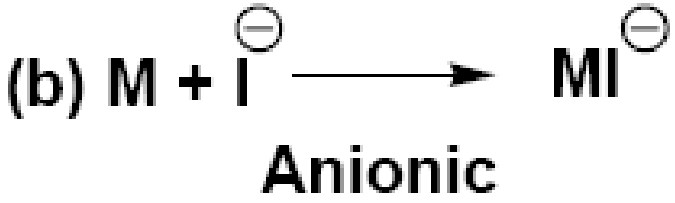


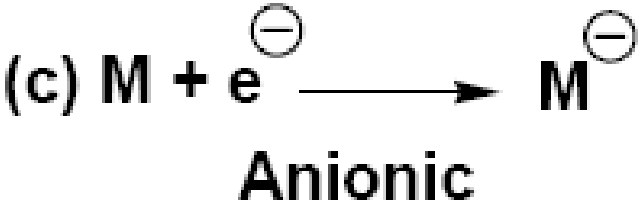
R - Electron withdrawing

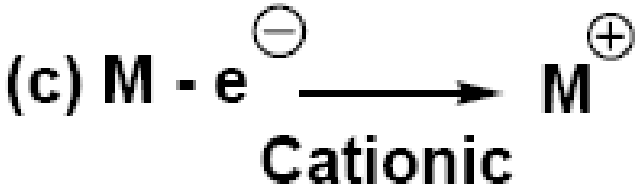
Ionic Polymerization

(i) Initiation can occur in one of the four following ways:

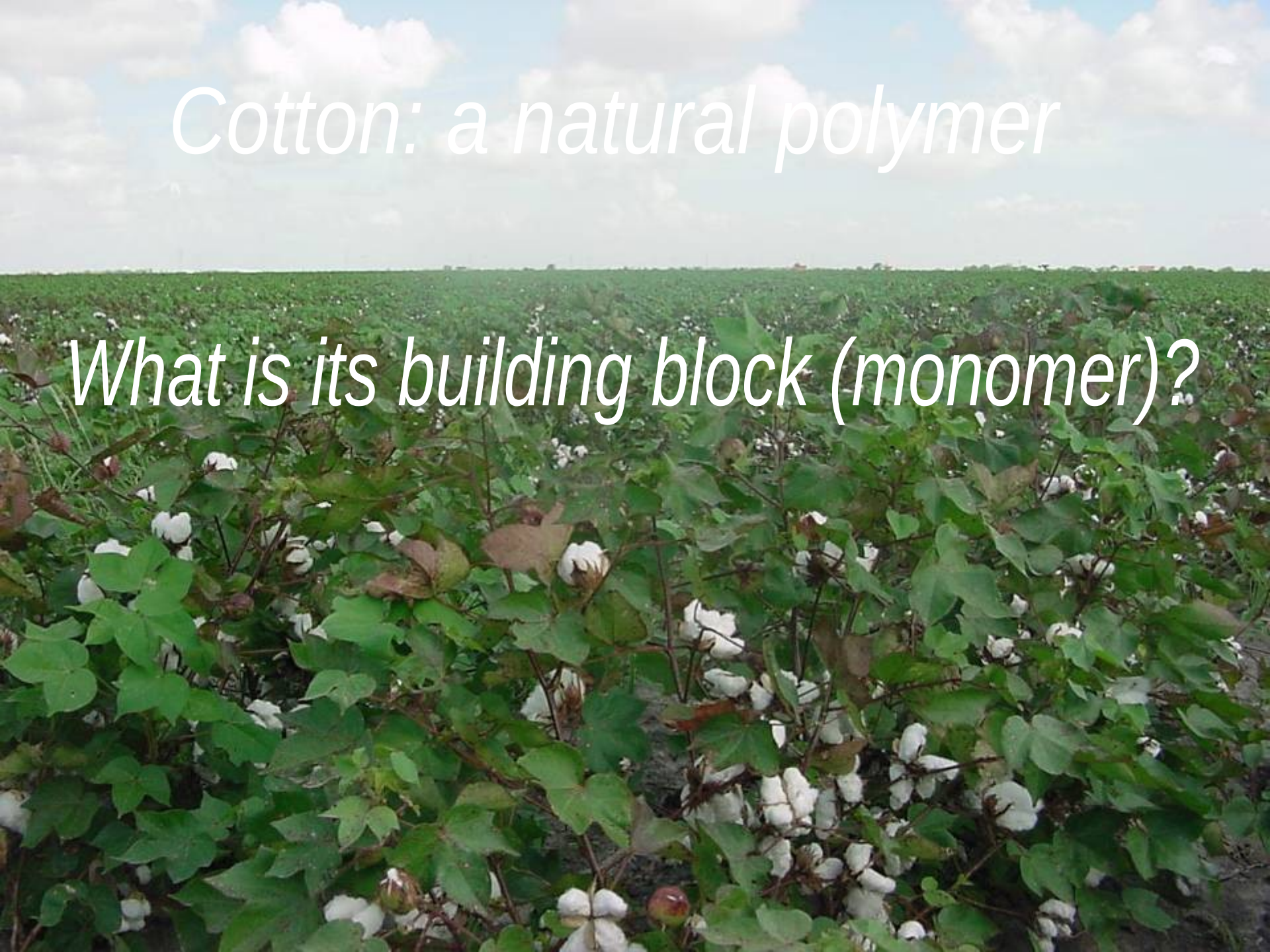






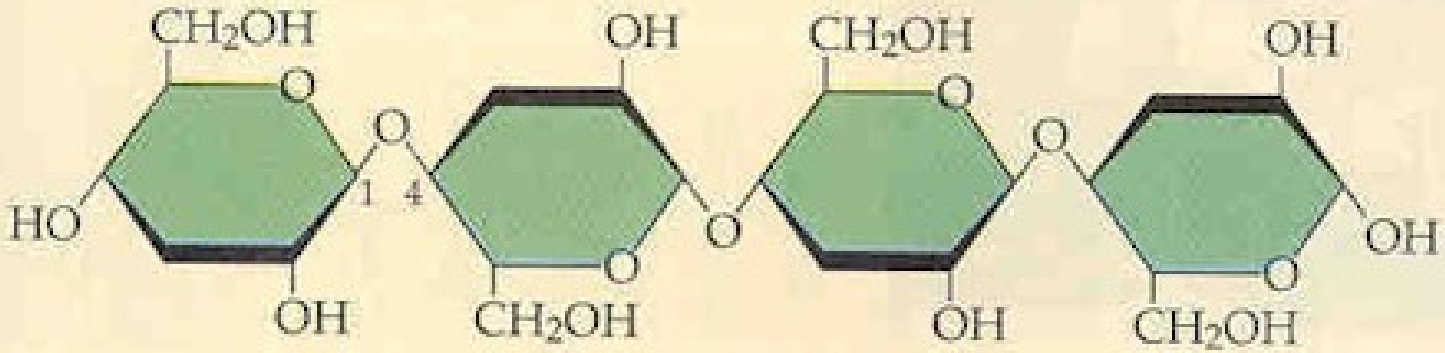


Cotton: a natural polymer



What is its building block (monomer)?

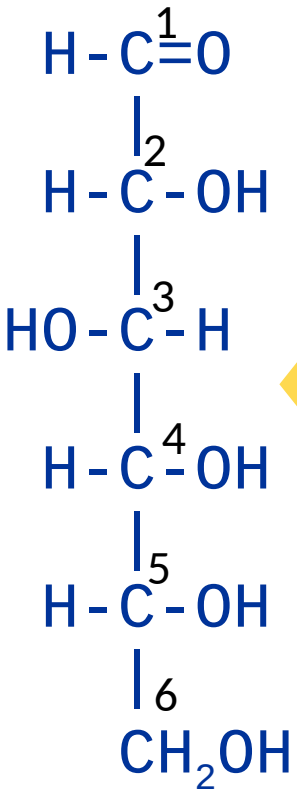
Cotton fiber is mostly cellulose, and cellulose is made of chains of the sugar, glucose linked together a certain way.



(c) Cellulose: 1–4 linkage of β glucose

Glucose

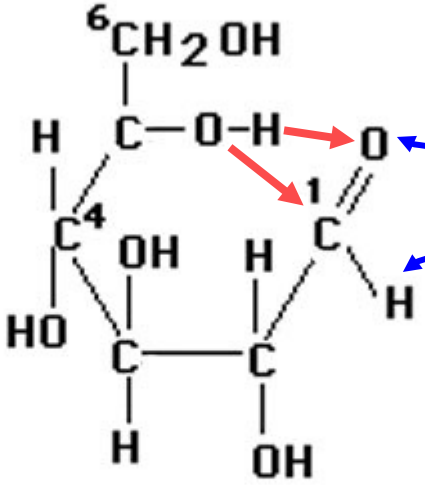
Structural formula.
Straight chain glucose



bends

Glucose

glucose bending

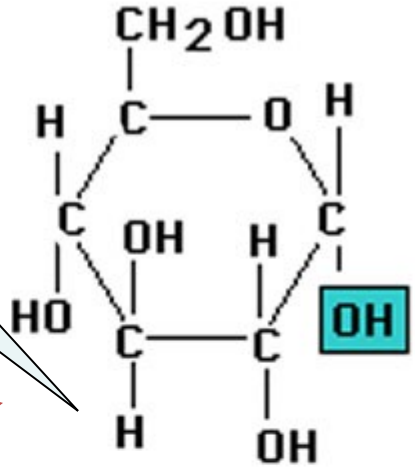


flips either way

Glucose

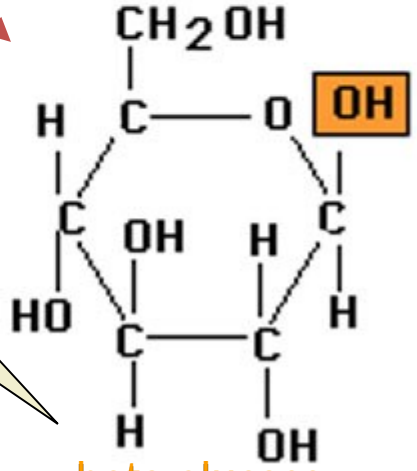
Two ring-shape versions

Used in making starch



alpha-glucose

Used in making cellulose

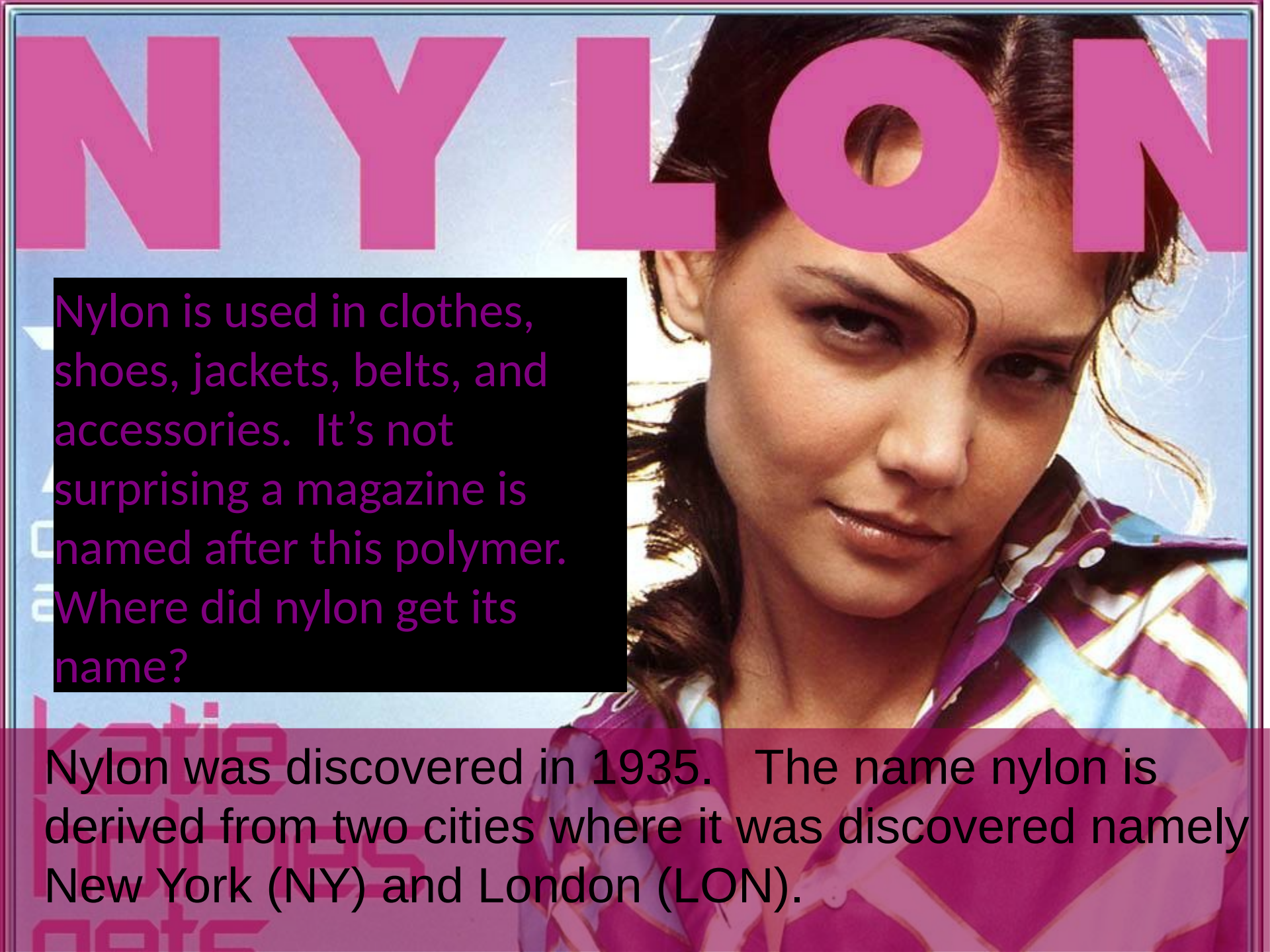


beta-glucose

Glucose bends itself into 4 different shapes **millions** of times a second

NYLON





Nylon is used in clothes, shoes, jackets, belts, and accessories. It's not surprising a magazine is named after this polymer. Where did nylon get its name?

Nylon was discovered in 1935. The name nylon is derived from two cities where it was discovered namely New York (NY) and London (LON).

Two ingredients are mixed and a solid begins to form at the junction between the two layers of liquid.

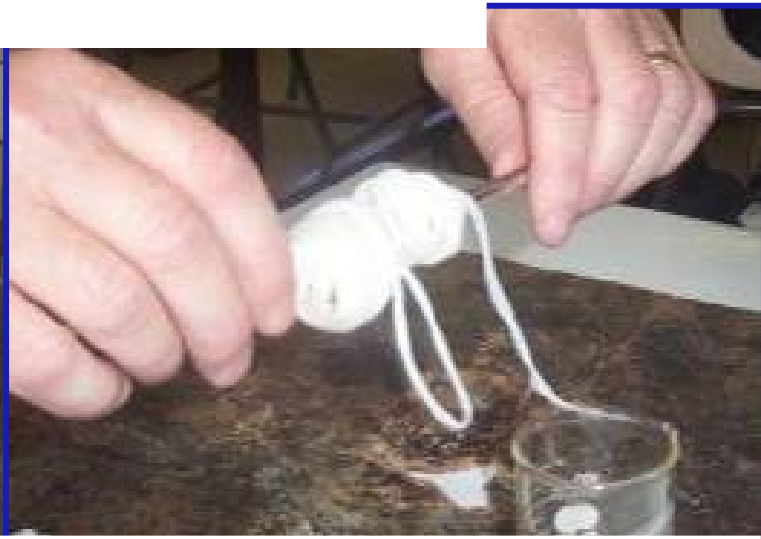




Hot nylon spaghetti can be extracted.







We say certain polymers are man-made, but the truth is they make themselves. Humans only have to get the ingredients near each other. The chemicals will assemble themselves.

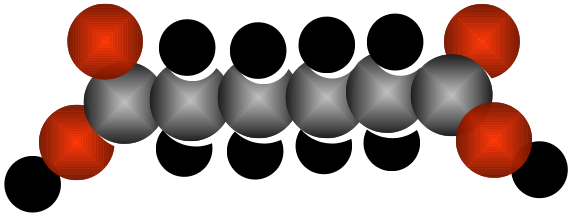




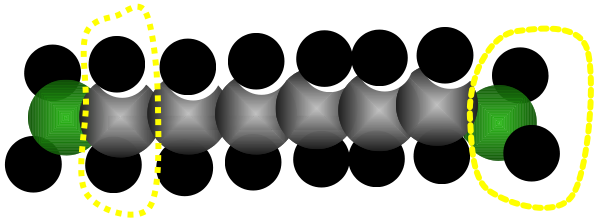


The students are handling the nylon string that was produced. Notice there's some kind of odor that is being noticed.

Tetramethylene dicarboxylic acid (adipic acid)



Hexamethylene diamine



methylene x 6 (hexa)

amine x 2 (di)

Nylon is actually a “copolymer” because is it made from two monomers. When these two monomers are in the same beaker, they combine and give off a molecule of water. This is called a “dehydration” reaction because we are taking away (*de*) water (*hydra*). (regarding odor: amines smell like fish or worse. Adipic acid is odorless)

Polyester is a another copolymer. It is made from equal amounts of two different monomers. Polyester is used to make bottles and fabrics.

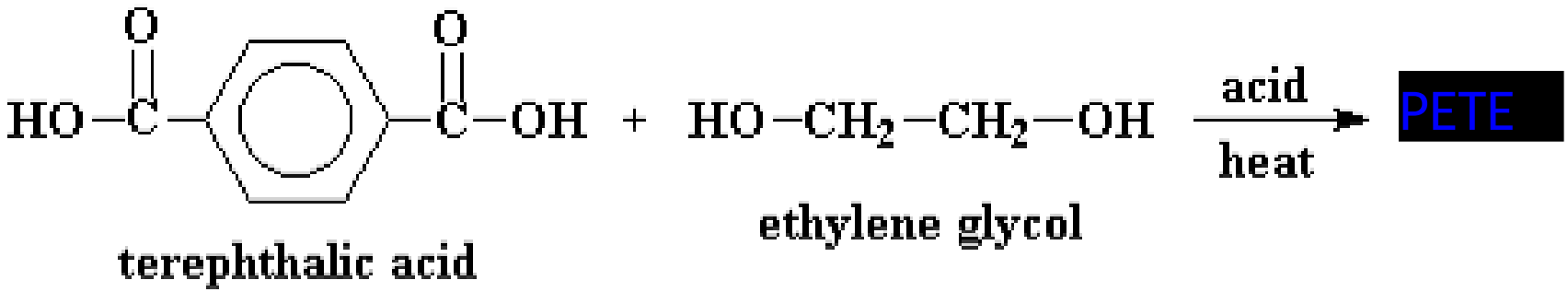


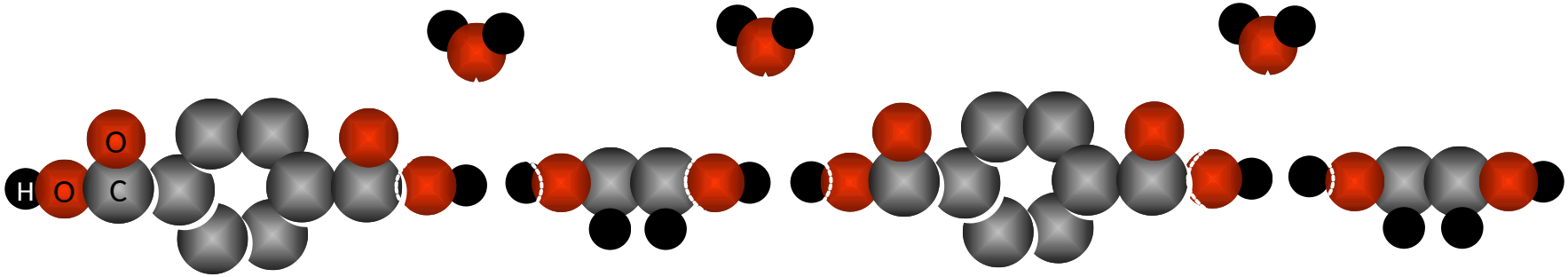
terephthalic acid

ethylene glycol

PETE P e T e

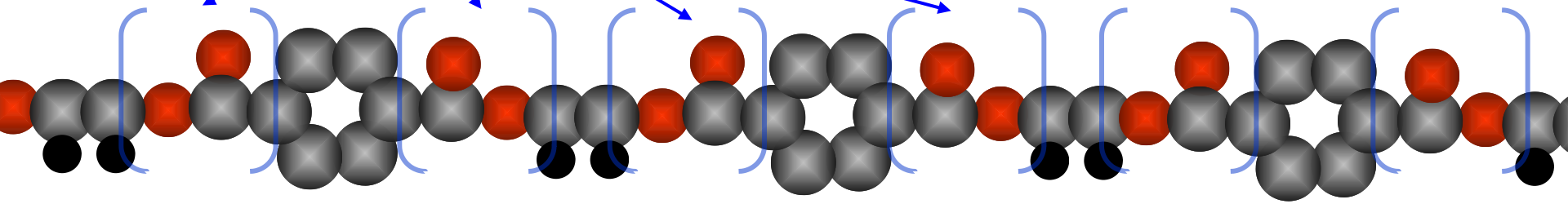
dehydration water



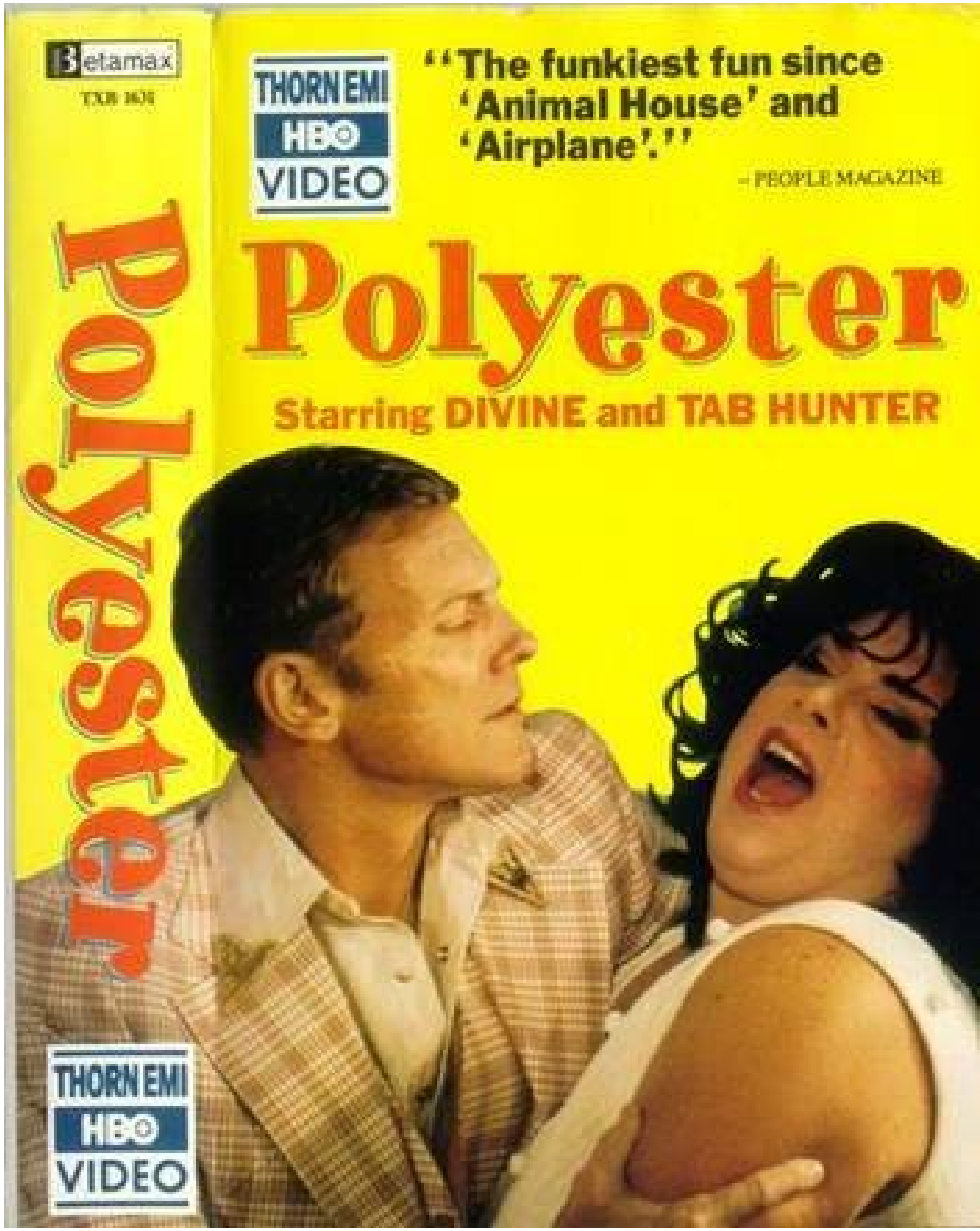


ESTER groups formed

ESTER



There was even a movie called "Polyester" which showcased a carefree lifestyle. Polyester fabrics were "drip-dry" also called “wash and wear”, meaning they were quick to wash, quick to dry, and no ironing needed. This freed you to have fun rather than doing household chores.

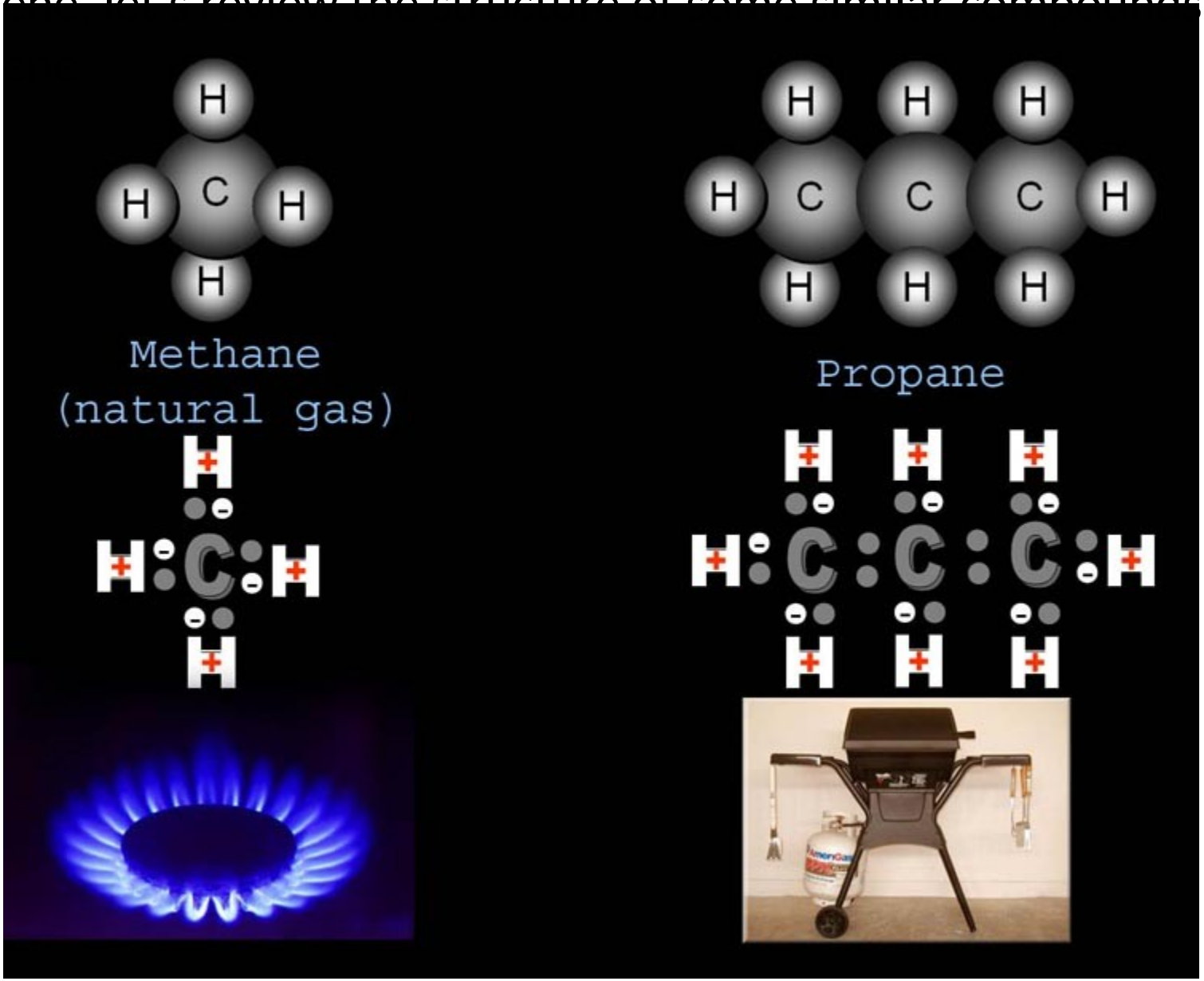


A polymer made form just one monomer is polyethylene. It is the most common plastic you see.

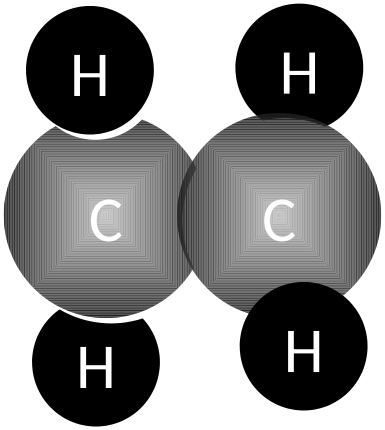
It is used for bottles, buckets, jugs, containers, toys, even synthetic lumber, and many other things.

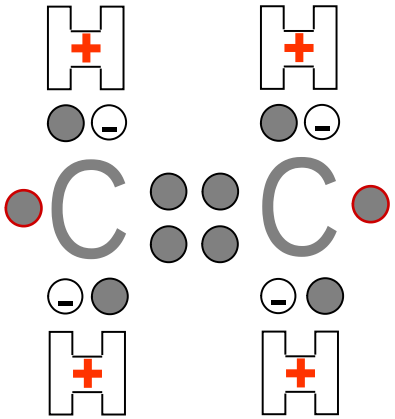


Before we show how polyethylene is made from its monomer, ethylene, let's review the structure of some similar compounds to ethyl



Ethylene has two carbons; plus, instead of the two carbons sharing just one electron each, they share two electrons each. High temperature or UV light can cause two of these shared (paired) electrons to become unshared (unpaired).





These unpaired electrons are eager to pair up with another electron. If this ethylene molecule bumps another ethylene molecule, the unpaired electrons will cause the one it bumped into to lend one of its inner electrons.

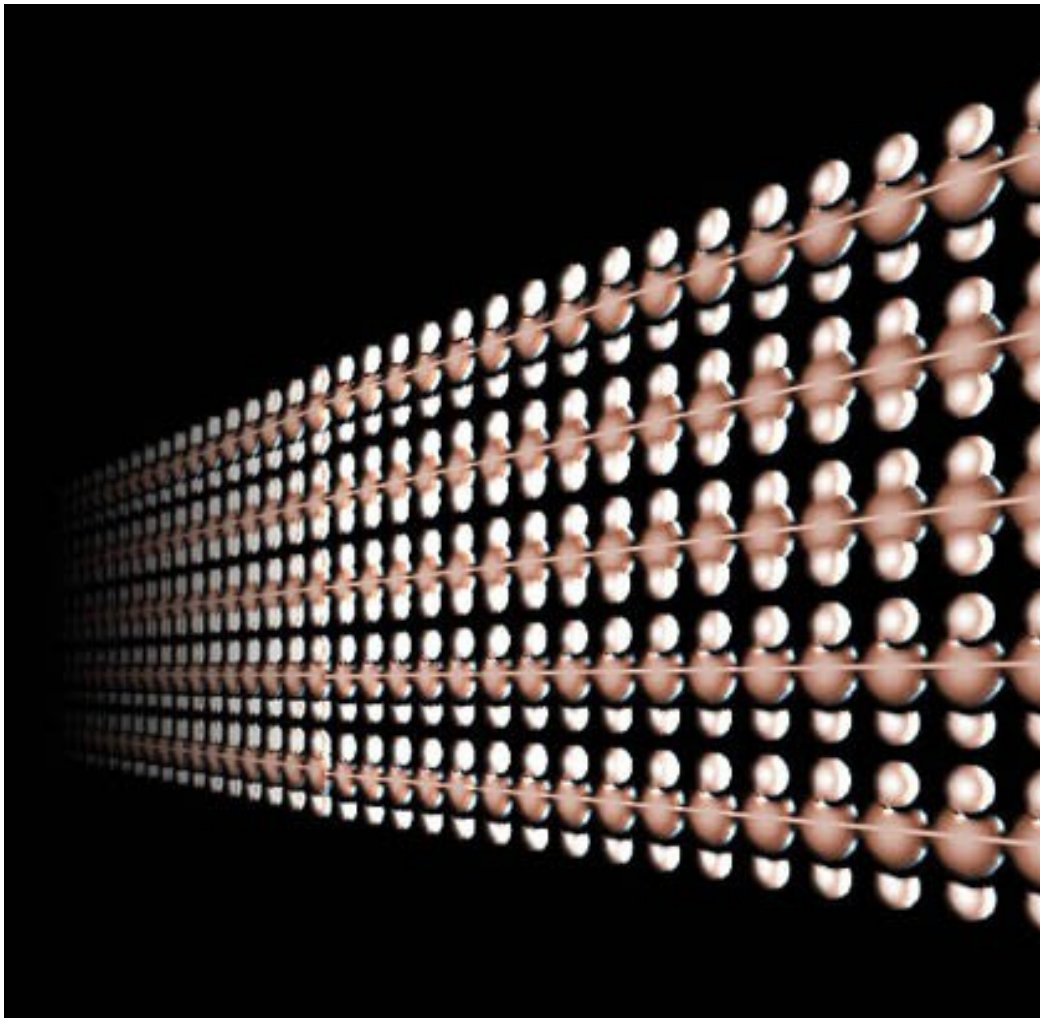


Here's another way to see the chain reaction. These are the carbon atoms with their double-bond (2 shared electrons each). The hydrogen atoms are not shown. A collision breaks the first bond.



Once the first double bond is broken, a chain reaction will occur. In about a second an entire chamber of compressed ethylene gas turns into the polymer, polyethylene.

There are two types of polyethylene polymers (plastics). One is when the polyethylene exists as long straight chains. The picture here shows the chains of one carbon with two hydrogen atoms repeating. The chain can be as long as 20,000 carbons to 35,000 carbons. This is called high density polyethylene (HDPE).



When the chains get up to 500,000 carbons long, they are tough enough for synthetic ice, replacement joints, and bullet-proof vests.

Think about it. You start with ethylene gas molecules that can't stop a feather from passing through them. But after the double-bond of one ethylene molecule breaks, it causes a chain reaction that connects thousands to it. In less than a second, these long straight chains of carbon and hydrogen are strong enough to stop a bullet or play ice hockey on. Isn't chemistry wonderful.



We've mentioned high density polyethylene (HDPE); you probably were thinking, there must be low density polyethylene (LDPE). You are correct. It is made by causing the long chains of ethylene to branch. That way they cannot lie next each other, which reduces the density and strength of the polyethylene. This makes the plastic lighter and more flexible.



Commodity Polyolefins

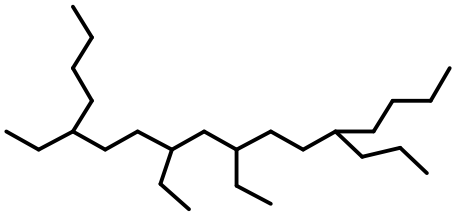
Polyethylene



High Density (1954)

HDPE

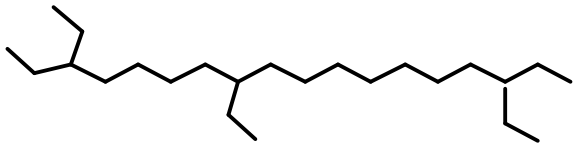
Bottles, drums, pipe, conduit, sheet, film



Low Density (1939-1945)

LDPE

Packaging Film, wire and cable coating, toys, flexible bottles, house wares, coatings

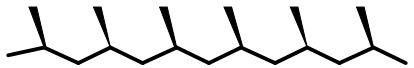


Linear Low Density (1975)

Shirt bags, high strength films LLDE

Commodity Polyolefins

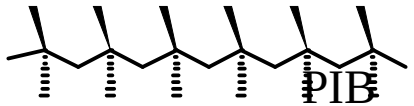
Polypropylene (1954) _



PP

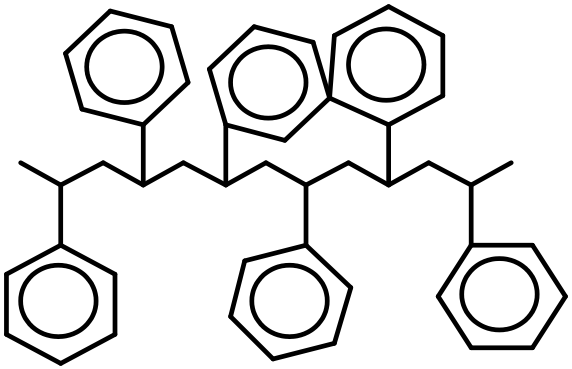
dishwasher safe plastic ware, carpet yarn, fibers and ropes, webbing, auto parts

Polyisobutylene (1940)



inner tubes, flexible adhesives, raincoats

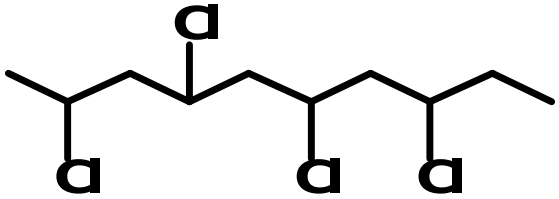
Commodity Vinyl Polymers



Polystyrene (1920)

PS

Styrofoam, clear plastic cups
envelop windows, toys

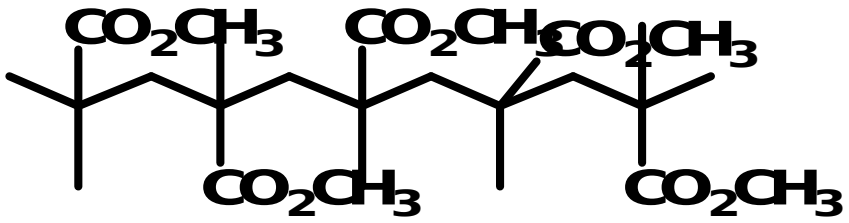


Poly(vinyl chloride) (1927)

PVC

garden hose, pipe, car trim, seat covers, records, floor tiles

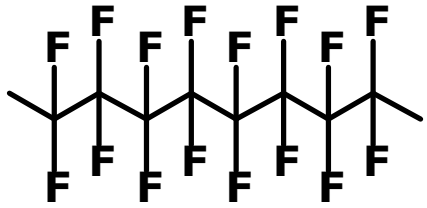
Semi-Commodity Polymers



Poly(methyl methacrylate) (1931)

PMMA

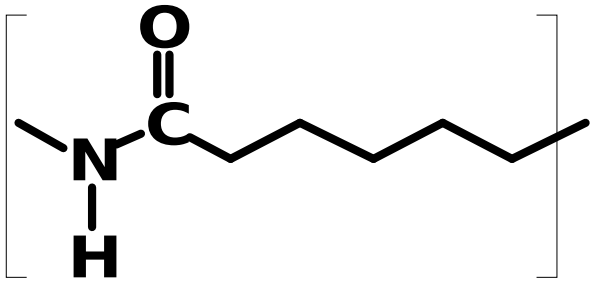
plexiglas, embedding resin, resist for X-ray applications

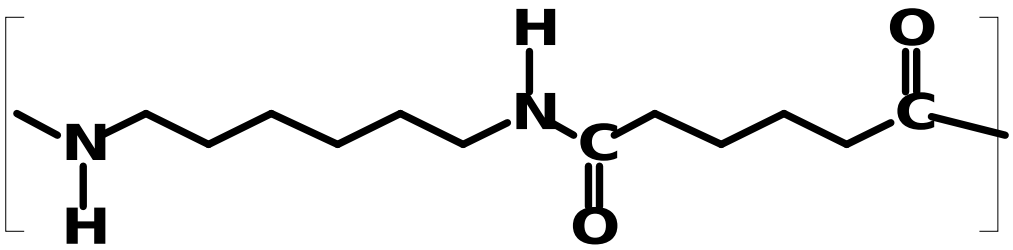


Polytetrafluoroethylene. (1943)

teflon, non stick cookware, no grease bearings,
pipe-seal tape

Commodity Condensation Polymers

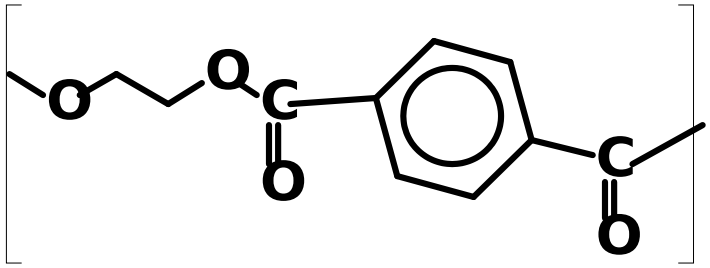




Nylon 6 /
bearings, molded parts
carpet yarn
marine rope
cooking/boiling bags

Nylon 66 (1939)
Fibers, tire cord, fishing line

Commodity Condensation Polymers

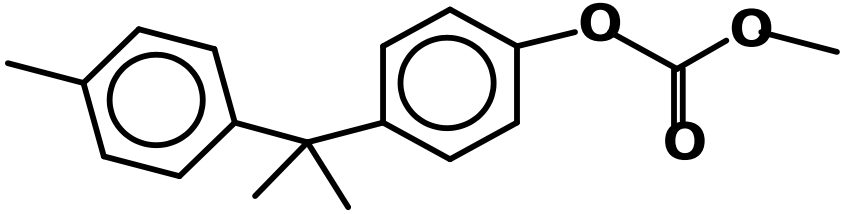


Polyester (1941)

PET, dacron, mylar, kodel

fibers, film-backing, magnetic tapes, soft drink bottles, tire cord, moldings

Polycarbonate (1957)



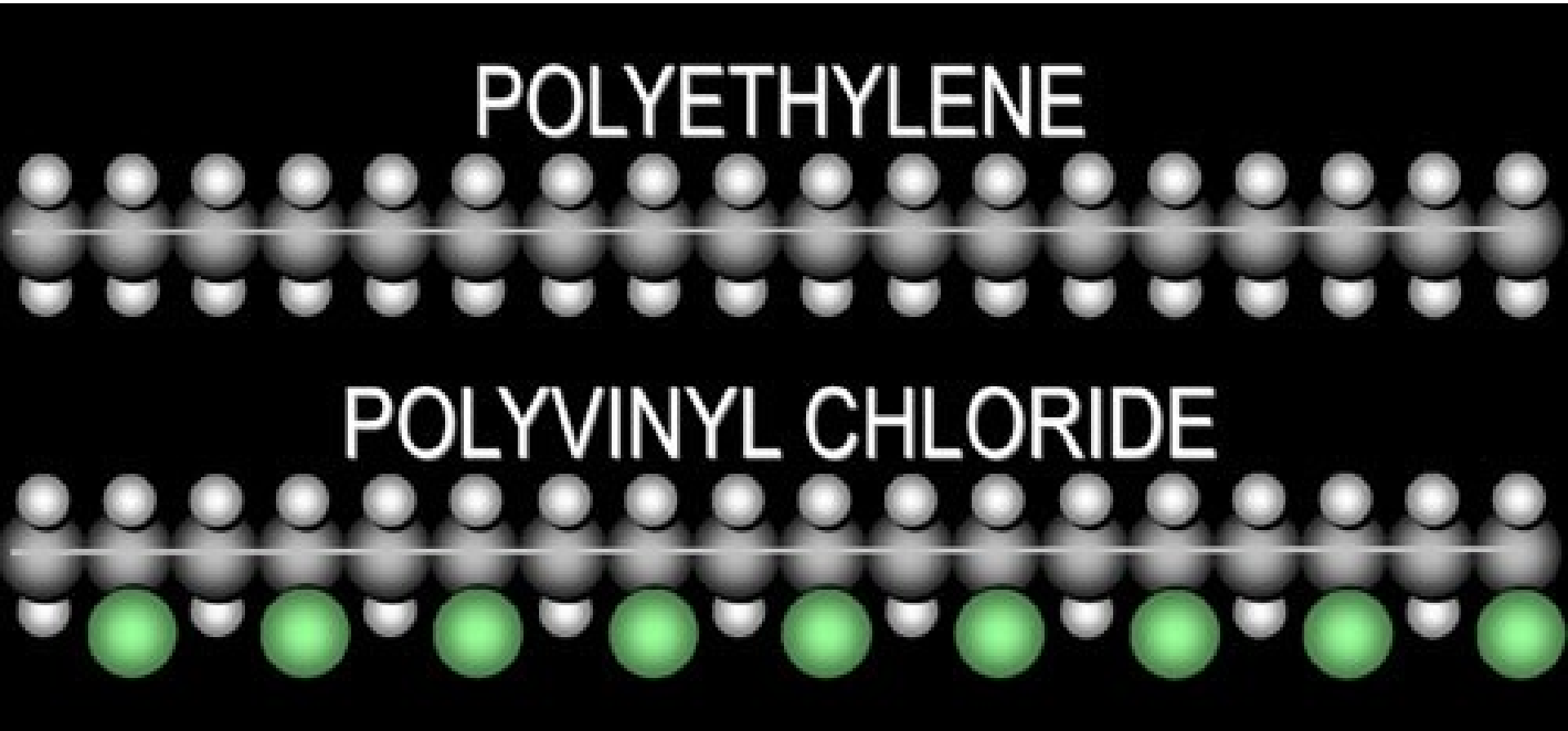
PC, Lexan

shatter proof glass, cd-disks, car doors and roofs, appliance housings

Low density polyethylene is used to make plastic bags, plastic wrap, and squeeze bottles, plus many other things.



Another polymer, which is almost the same as polyethylene, is **P**oly**V**inyl **C**hloride or PVC. The difference is that every other hydrogen is replaced with a chlorine atom (green sphere).



$(CH_2CHCl)_n + O_2 \rightarrow CO_2 + CO + HCl + H_2O$

PVC pipes are used in our homes and they are even handy for making a table or chair. PVC is also used as insulation around electric wires in the home and the automobile. PVC is quite safe until it burns. The chlorines in the PVC combine with the hydrogen atoms in the PVC to form hydrogen chloride gas (HCl). When this contacts water in lungs or mouth, it turns to hydrochloric acid ($HCl_{(aq)}$).




HEWLETT
PACKARD
MediaStream Server

The favorite properties of plastics are that they are inert and won't react with what is stored in them. They also are durable and won't easily decay, dissolve, or break apart. These are great qualities for things you keep, but when you throw them away, they won't decompose.



Since they don’t decompose, the answer is to recycle the plastics so they can be remade into something else. Here we see a bunch of CDs getting recycled.



The decks, fence, stepping stones, house shingles, and the sweat shirt, were all made from recycled plastic.

