Polymers are molecules that consist of a long, repeating chain of smaller units called *monomers*. They have the highest molecular weight among any molecules, and may consist of billions of atoms.

A polymer is a large molecule that is made up of repeating subunits connected to each other by chemical bonds.
### Types of Polymers in Everyday Use

**Natural (wool, hair, rubber, DNA) and Synthetic Polymers**

<table>
<thead>
<tr>
<th>Polymer</th>
<th>Structures</th>
<th>Common Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyethylene</td>
<td><img src="image" alt="Polyethylene Structure" /></td>
<td>Packaging, plastic bottles &amp; plastic bags</td>
</tr>
<tr>
<td>Poly(vinyl chloride)</td>
<td><img src="image" alt="Poly(vinyl chloride) Structure" /></td>
<td>Pipes, window &amp; door frame, waterproof fabric &amp; insulator for electronic wires</td>
</tr>
<tr>
<td>Polycarbonate</td>
<td><img src="image" alt="Polycarbonate Structure" /></td>
<td>Bullet-proof glass, headlamp lenses, sunglass &amp; eyeglass lenses, CD, DVD &amp; blu-ray disc</td>
</tr>
<tr>
<td>Polystyrene</td>
<td><img src="image" alt="Polystyrene Structure" /></td>
<td>License plate frames, CD cases, petri dishes, insulation, styrofoam packing peanuts &amp; cups</td>
</tr>
<tr>
<td>Polyacrylamide</td>
<td><img src="image" alt="Polyacrylamide Structure" /></td>
<td>Water purifier, paper coating, cosmetic additive, photographic emulsion, &amp; contact lenses</td>
</tr>
<tr>
<td>Polyurethane</td>
<td><img src="image" alt="Polyurethane Structure" /></td>
<td>Foam, paint, adhesive, spandex</td>
</tr>
</tbody>
</table>
Polymerization Reactions

Polymerization is the process of combining many small molecules known as monomers into a covalently bonded chain or network.

Synthetic methods are generally divided into two categories, step-growth polymerization and chain-growth polymerization.

**Step-growth polymerization** refers to a type of polymerization mechanism in which bi-functional or multifunctional monomers react to form first *dimers*, then *trimers*, longer *oligomers* and eventually long chain polymers.

**Chain-growth polymerization** or *chain polymerization* is a polymerization technique where unsaturated monomer molecules add onto the active site of a growing polymer chain one at a time. Growth of the polymer occurs only at one (or possibly more) ends.
Properties of Polymers

- **Crystallinity** (2 and 3D ordering) – x-ray crystallography
- **Morphology** – SEM and AFM
- **Chemical Structure** – FTIR, Raman spectroscopy, MS
- **Optical Properties** – UV/Vis and near-IR spectroscopy
- **Tensile Strength** (elongation stress) – mechanical testing
- **Glass Transition Temperature** (amorphous viscous liquid to an amorphous crystalline solid by lowering temperature) – thermal methods of analysis (TGA and DSC).
Electrons emitted from the sample and detected.

Electron beam = 10-50 µm from filament. Must control the beam diameter so a series of condensing lenses reduce the final diameter to about 5 nm.
How Much Energy Does an Accelerated Electron Beam Possess?

Let’s assume an electron emitted from a sharp tungsten filament is accelerated to a target using a voltage of 20 kV.

\[ E = eV \text{ where } e \text{ is the charge of the electron } (1.60 \times 10^{-19} \text{ C}) \text{ and } V \text{ is the accelerating voltage (V)}. \]

\[
E = (1.60 \times 10^{-19} \text{ C}) (20,000 \text{ V}) = 3.20 \times 10^{-15} \text{ J}
\]

Since 1 eV (electron volt) = 1.60 \times 10^{-19} \text{ J}, then the kinetic energy of an electron accelerated at 20,000 V is 20,000 eV.
Specimen Interactions with Electron Beam

When the incident electron beam interacts with the same, energy transfer occurs and several processes result to cause the release of lower energy electrons or x-rays that are used for imaging and analysis, respectively.
Specimen Interactions with Electron Beam

**Backscattered electrons** = electron beam passes close to the positively charged nucleus and is attracted. Beam is deflected without much energy loss. Kinetic energy is unchanged. Larger the Z number the greater the deflection. *Atomic number contrast.*

**Secondary electrons** = incident electrons knock loosely bound conduction electrons out of the sample. If these weak energy electrons (50 eV) are released near the surface (10 nm) they can be used to image topography.

**X-ray production** = incident electrons excite core electrons. Outer shell or valence electron drop down to fill the vacancy. Excess energy is released as an x-ray characteristic of the Z number of the atom from which it was produced.

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**Elastic (without energy loss) and inelastic (with energy loss) interactions with the electron beam. The latter is transfer of energy to the solid creating an excited solid.**
Cross-Section of the Electron Gun

Filament heated to >2500 K. This causes electron emission from the tip (thermionic emission). If the tip is biased negatively, then the released electrons are repelled from the tip and given an energy proportional to the accelerating voltage = 2-25 kV.
Image is Created by Rastering the Electron Beam Across the Sample

Electron beam is scanned across the sample. Emitted electrons detected and the image formed.
Important Specimen/Electron Interactions --- Escape Depth

Greater the energy of the electron beam, the greater the penetration depth. Also depends on atomic density and number of the sample.

Better contrast using secondary electrons is possible at lower beam energies.

Best for the sample to be a conductor so as to avoid charging and beam damage. Insulating samples can be coated with a thin layer of metal (Au) to improve image contrast.

**FIGURE 21-21** The interaction volume and the volumes from which each type of SEM signal arises.
Detection of Backscattered Electrons

High energy electron beam (elastically scattered) and wide compared to the incident beam diameter.

- Insensitive to lower energy secondary electrons.
- Small and robust so they can be located close to the sample.

Bandgap exists in the semiconductor. Inelastic scattering occurs creating an electron-hole pair. These charges can be swept away if a small potential is applied across the semiconductor. This produces a photocurrent that is proportional to the bse intensity.

Fig. 1.4a. Solid state electron detector
Production of a Photoelectron (Excitation) and Relaxation Via Emission of X-ray Photon

Fig. 3.2b. Magnesium atom in exited state

Fig. 3.2c. Magnesium atom in relaxation state
SEM Images of Polymer Materials

Electrospun polymer for water filtration

Superabsorbent polyacrylate

Glass reinforced polypropylene

Hollow fiber porous membrane

Public domain images taken from internet
Nanotechnology is science, engineering, and technology conducted at the nanoscale, which is about 1 to 100 nanometers. (Nanoscience and nanotechnology involve the ability to see and to control individual atoms and molecules. Synthesis of materials on the nanometer scale.

One nanometer is a billionth of a meter, or $10^{-9}$ of a meter. Here are a few illustrative examples:

- There are 25,400,000 nanometers in an inch.
- A sheet of newspaper is about 100,000 nanometers thick.
- On a comparative scale, if a marble were a nanometer, then one meter would be the size of the Earth.
Applications of Nanotechnology in Life

Health care products

Targeted drug delivery and imaging

Advanced electronics

Advanced packaging

Public domain images taken from internet
Nanotechnology Research

Environmental and Health Risk Assessment

http://www.nano.gov
Relaxation Events Producing an X-ray or Auger Electron

K shell vacancies are higher energy than L shell vacancies.

L shell vacancies are higher energy than M shell vacancies.

$$\lambda_{\text{x-ray}} = \frac{hc}{\Delta E}$$

$$\Delta E = E_{\text{inner shell}} - E_{\text{outer shell}}$$
Typical X-ray Emission Spectrum

Tables of x-ray energies or wavelengths can be used to identify characteristic peaks – qualitative analysis. Done automatically with computers.

Only the area of the sample being scanned by the electron beam will be analyzed.

Fig. 3.6a. Typical X-ray spectrum (EDX)
X-ray count is not a direct indication of concentration. More information is needed about the spectrometer’s geometry and about the behavior of the specimen.

X-rays from the near-surface region are emitted without energy loss, whereas those produced deeper in the sample are likely to be absorbed before escaping. Therefore, take-off angle must be known.

Fig. 3.6e. *Effect of take-off angle on absorption path length*
Concentrations usually given as atomic percent or weight percent.

Atomic % = \[ \frac{\text{# atoms of element}}{\text{Total # atoms in substance}} \times 100 \]

Weight % = \[ \frac{\text{Mass of element}}{\text{Total mass of substance}} \times 100 \]

1 ppm = 1 part in $10^6 = \text{mg/kg} = 1 \times 10^{-4}\%$

1 ppb = 1 part in $10^9 = \mu\text{g/kg} = 1 \times 10^{-7}\%$