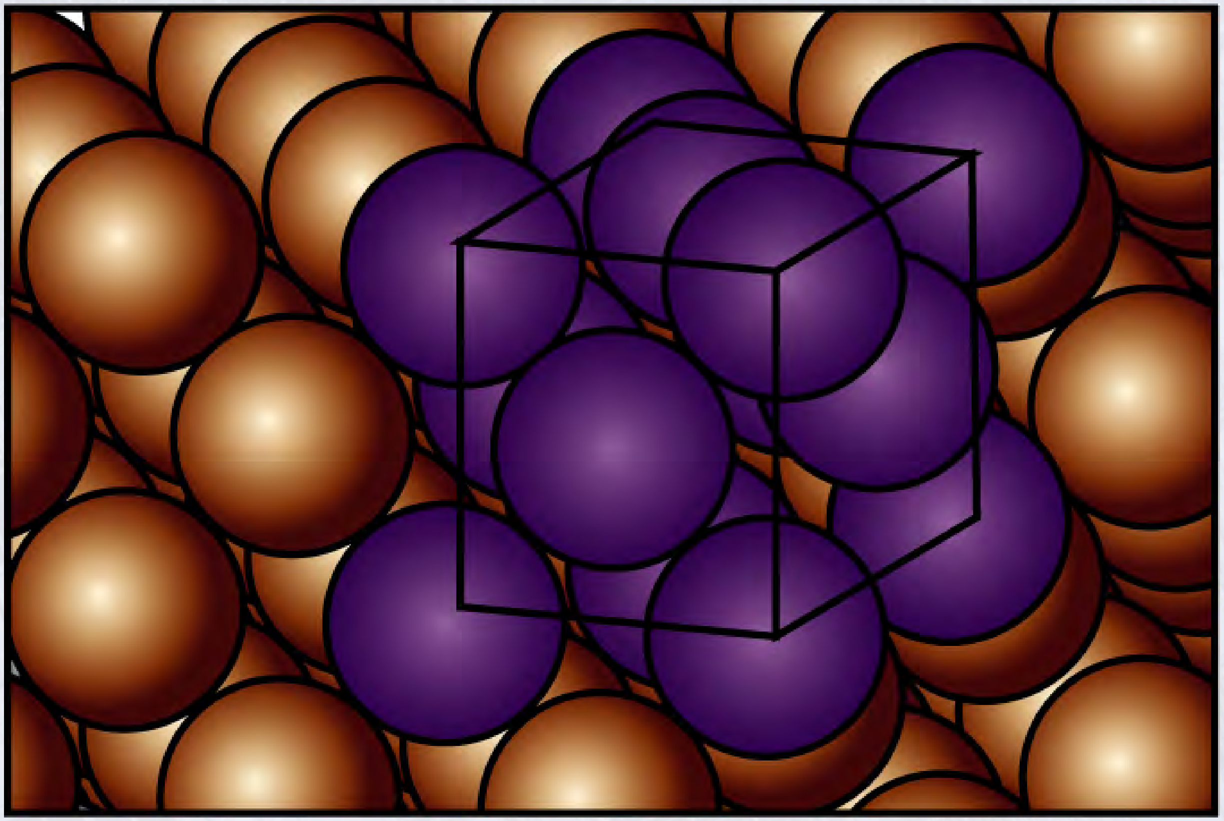
Chapter 1

The Structure of Metals



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Metal and Non-metal Use in Automobiles

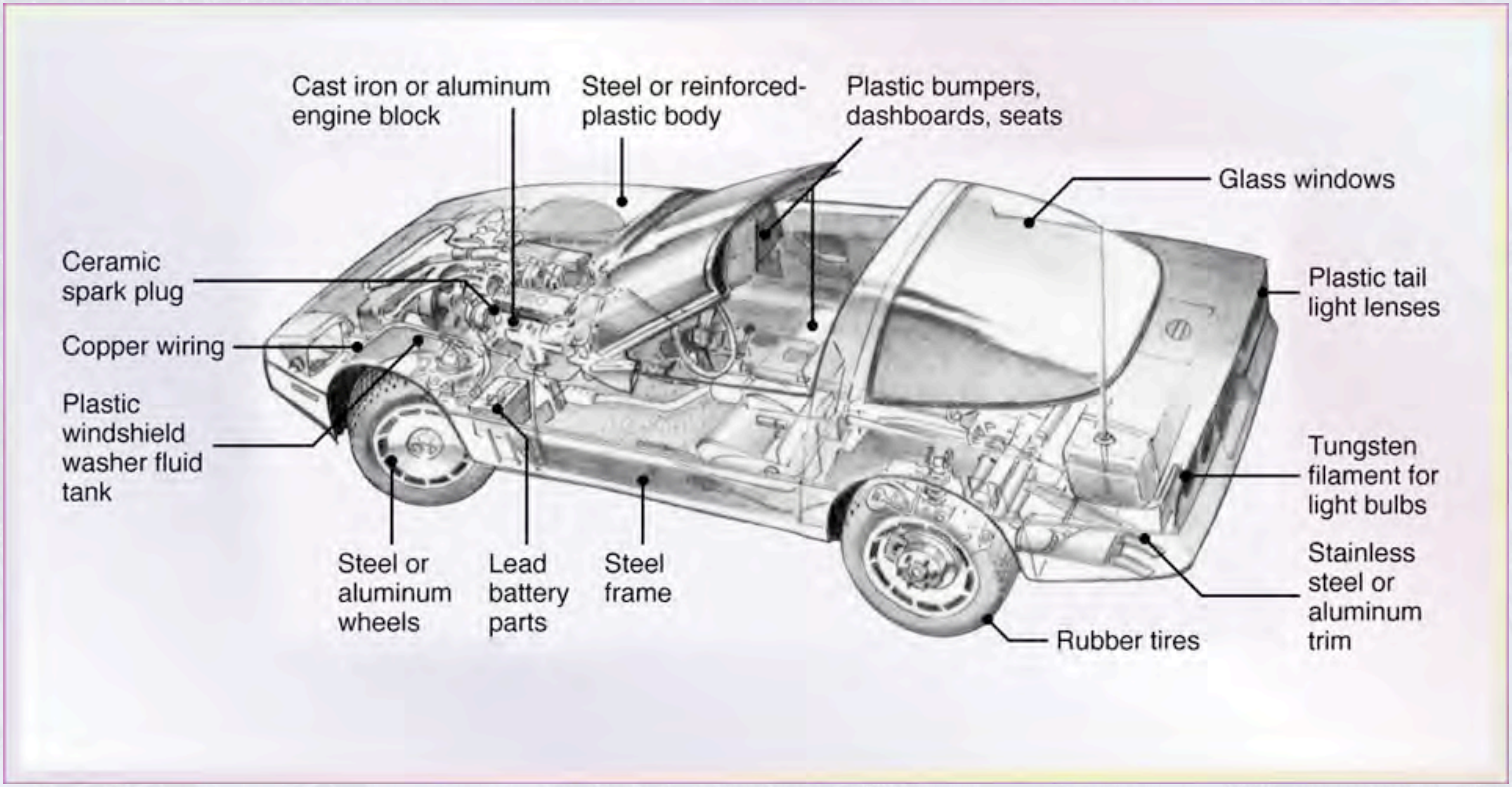

Figure I.1 Some of the metallic and nonmetallic materials used in a typical automobile

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Engineering Materials of Part I

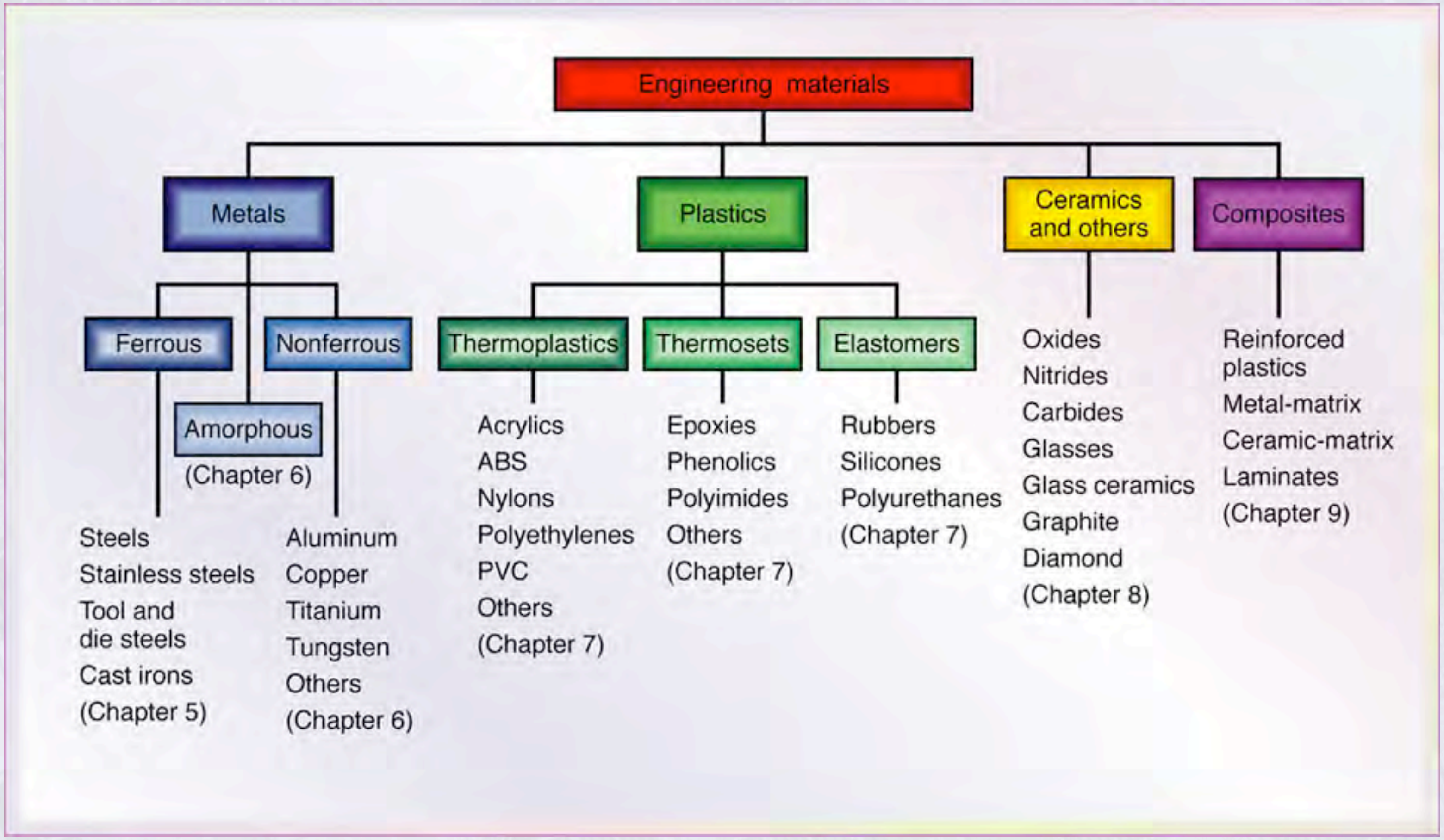

Figure I.2 An outline of the engineering materials described in Part I.

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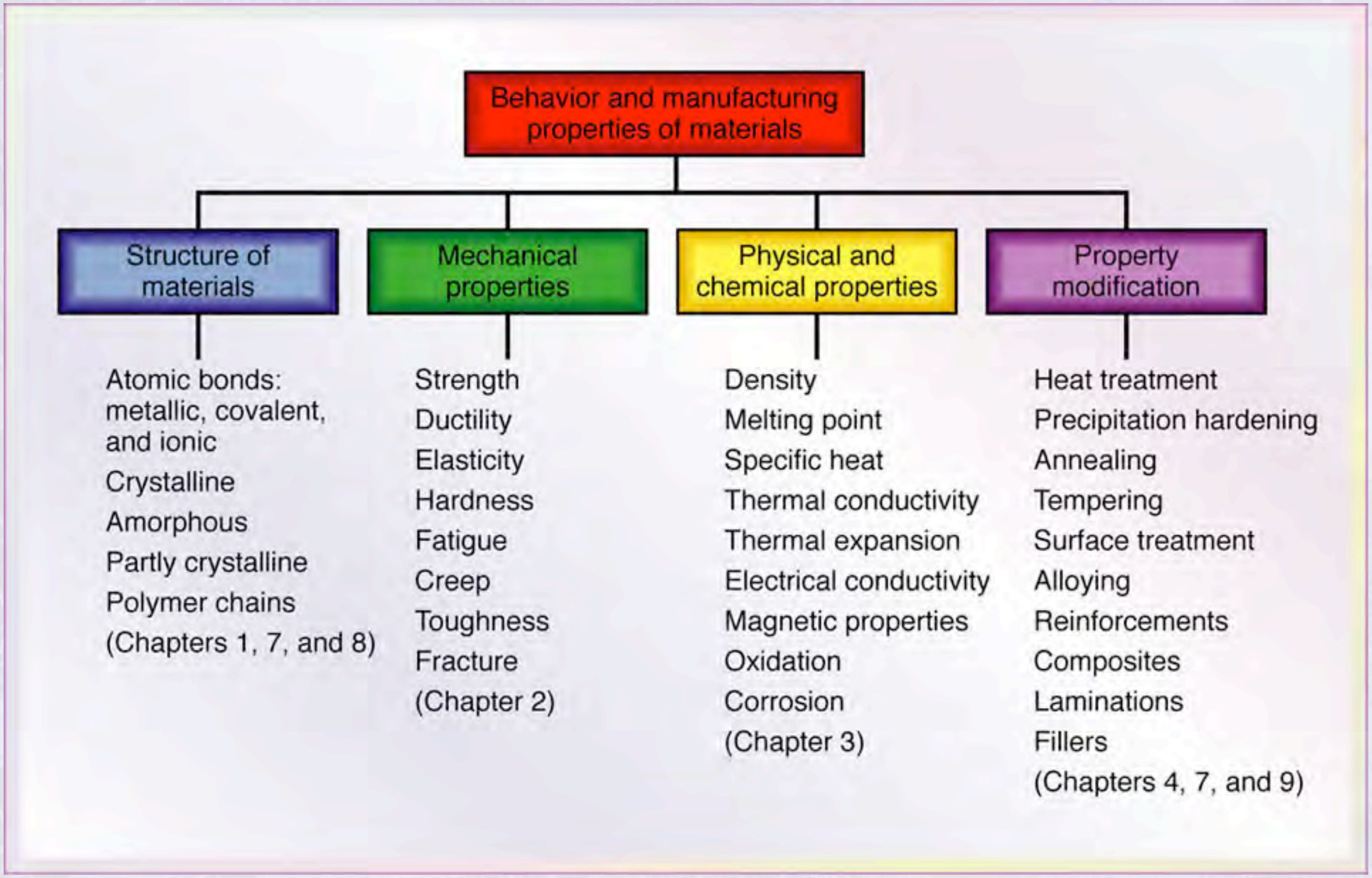
Behavior and Manufacturing Properties of Part I



Behavior and manufacturing properties of materials

- **Structure of materials**
  - Atomic bonds: metallic, covalent, and ionic
  - Crystalline
  - Amorphous
  - Partly crystalline
  - Polymer chains
  - (Chapters 1, 7, and 8)
- **Mechanical properties**
  - Strength
  - Ductility
  - Elasticity
  - Hardness
  - Fatigue
  - Creep
  - Toughness
  - Fracture
  - (Chapter 2)
- **Physical and chemical properties**
  - Density
  - Melting point
  - Specific heat
  - Thermal conductivity
  - Thermal expansion
  - Electrical conductivity
  - Magnetic properties
  - Oxidation
  - Corrosion
  - (Chapter 3)
- **Property modification**
  - Heat treatment
  - Precipitation hardening
  - Annealing
  - Tempering
  - Surface treatment
  - Alloying
  - Reinforcements
  - Composites
  - Laminations
  - Fillers
  - (Chapters 4, 7, and 9)

Figure I.3 An outline of the behavior and the manufacturing properties of materials described in Part I.

Chapter 1: The Structure of Metals

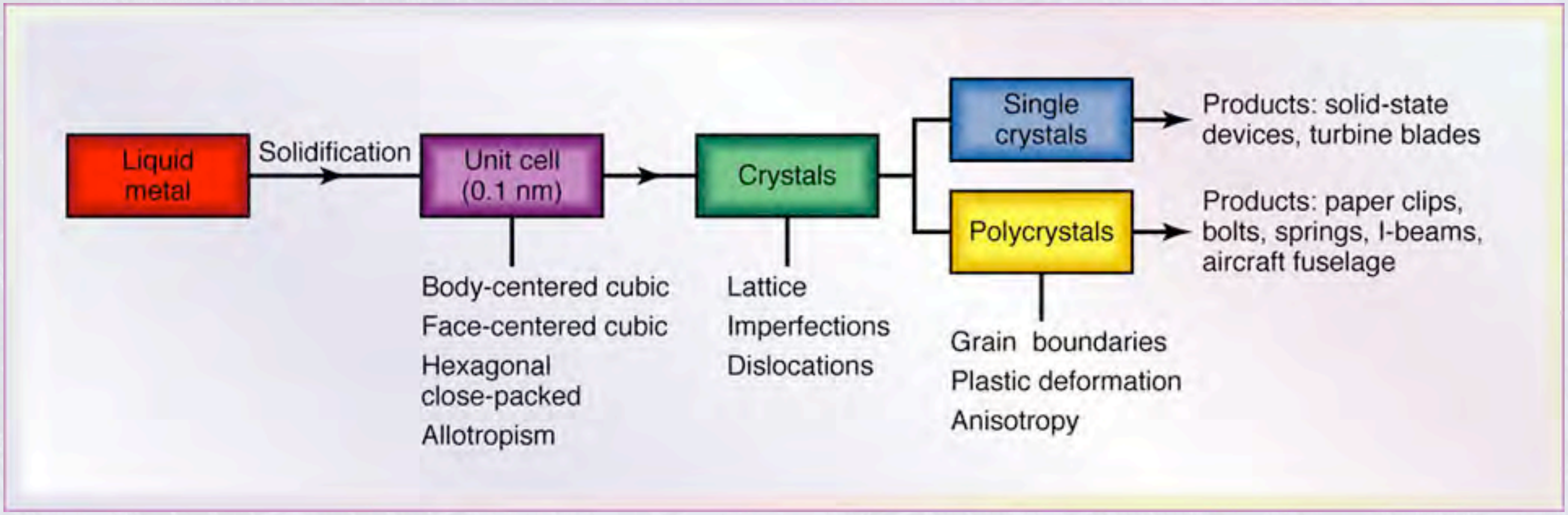


Figure 1.1 An outline of the topics described in Chapter 1.

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Crystal Structure of Metals

Common crystal structures for metals:

- Body-centered cubic (BCC) - alpha iron, chromium, molybdenum, tantalum, tungsten, and vanadium.
- Face-centered cubic (FCC) - gamma iron, aluminum, copper, nickel, lead, silver, gold and platinum.
- Hexagonal close-packed - beryllium, cadmium, cobalt, magnesium, alpha titanium, zinc and zirconium.

Body-centered Cubic Crystal Structure

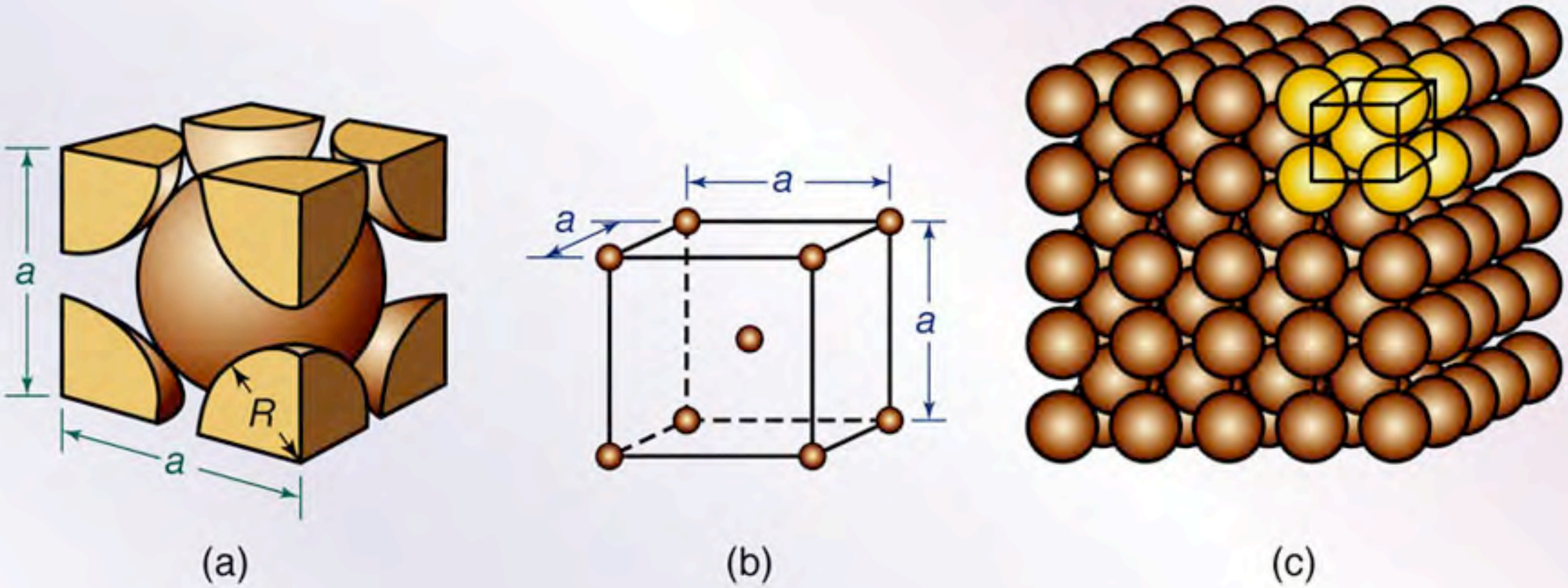

Figure 1.2 The body-centered cubic (bcc) crystal structure: (a) hard-ball model; (b) unit cell; and (c) single crystal with many unit cells

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Face-centered Cubic Crystal Structure

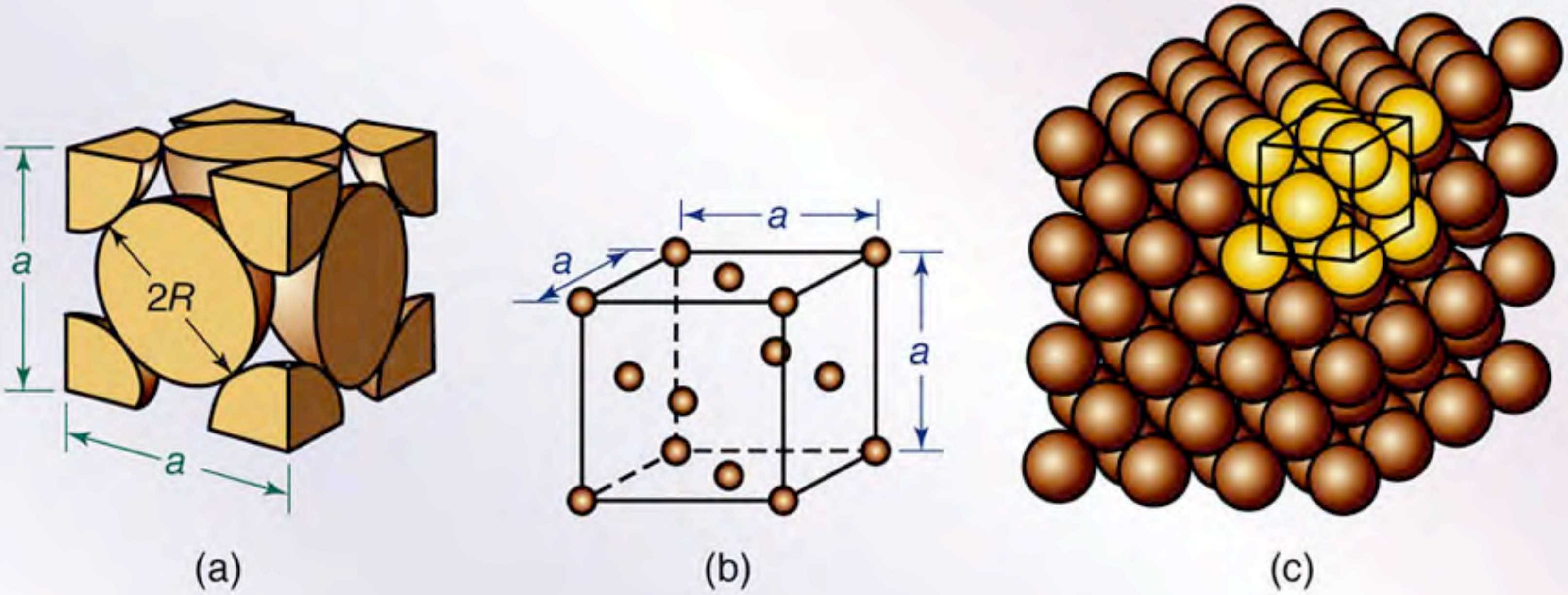

Figure 1.3 The face-centered cubic (fcc) crystal structure: (a) hard-ball model; (b) unit cell; and (c) single crystal with many unit cells

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Hexagonal Close-packed Crystal Structure

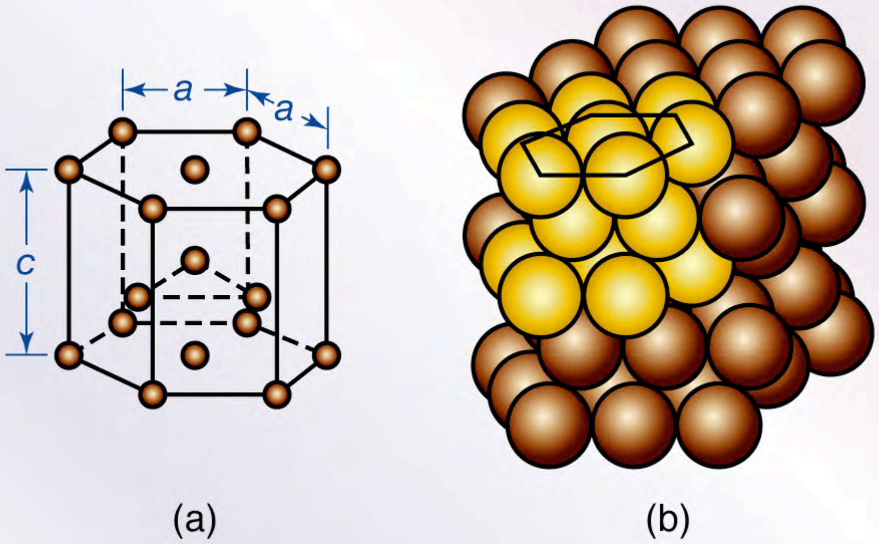

Figure 1.4 The hexagonal close-packed (hcp) crystal structure: (a) unit cell; and (b) single crystal with many unit cells.

Permanent Deformation

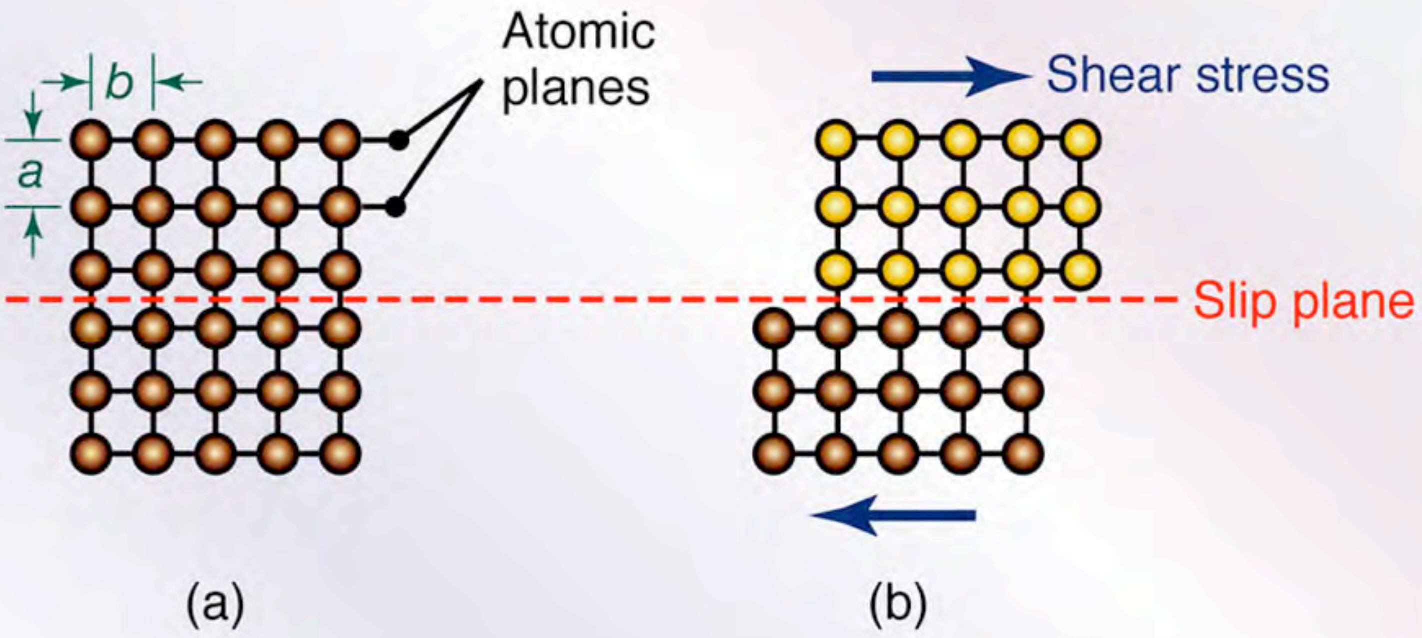

Figure 1.5 Permanent deformation (also called plastic deformation) of a single crystal subjected to a shear stress: (a) structure before deformation; and (b) permanent deformation by slip. The *b/a* ratio influences the magnitude of the shear stress required to cause slip.

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Permanent Deformation and Twinning in Crystal

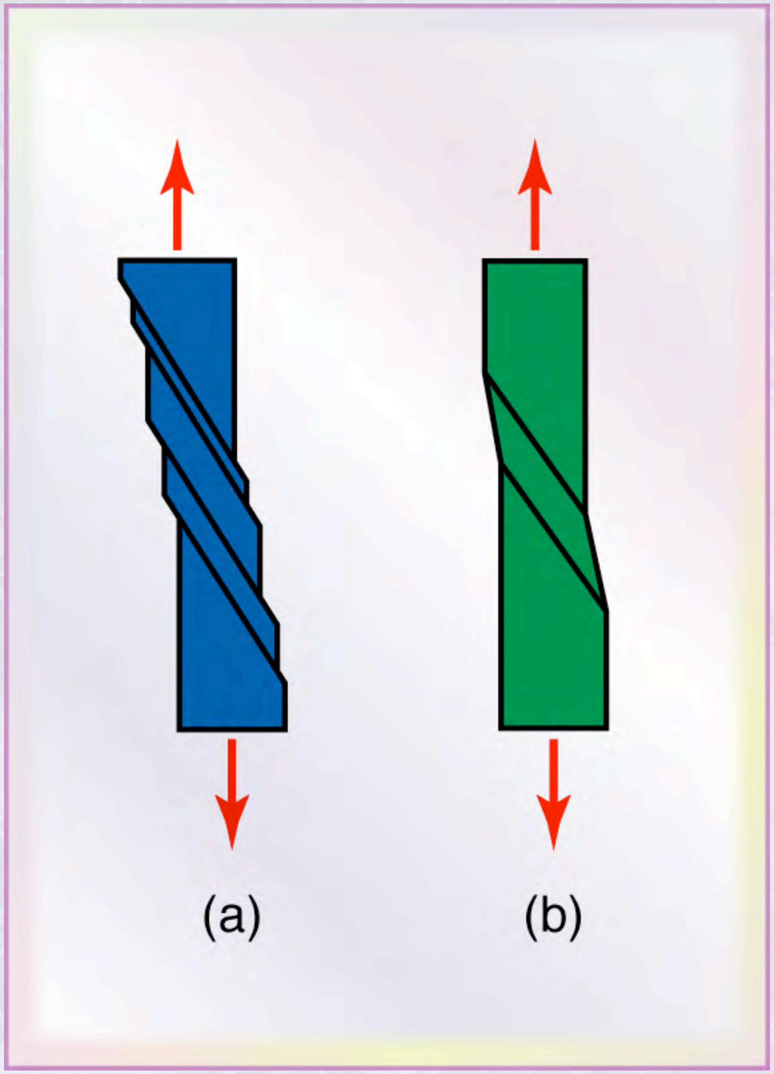

Figure 1.6 (a) Permanent deformation of a single crystal under a tensile load. Note that the slip planes tend to align themselves in the direction of the pulling force. This behavior can be simulated using a deck of cards with a rubber band around them. (b) Twinning in a single crystal in tension.

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Slip Lines and Slip Bands in Crystal

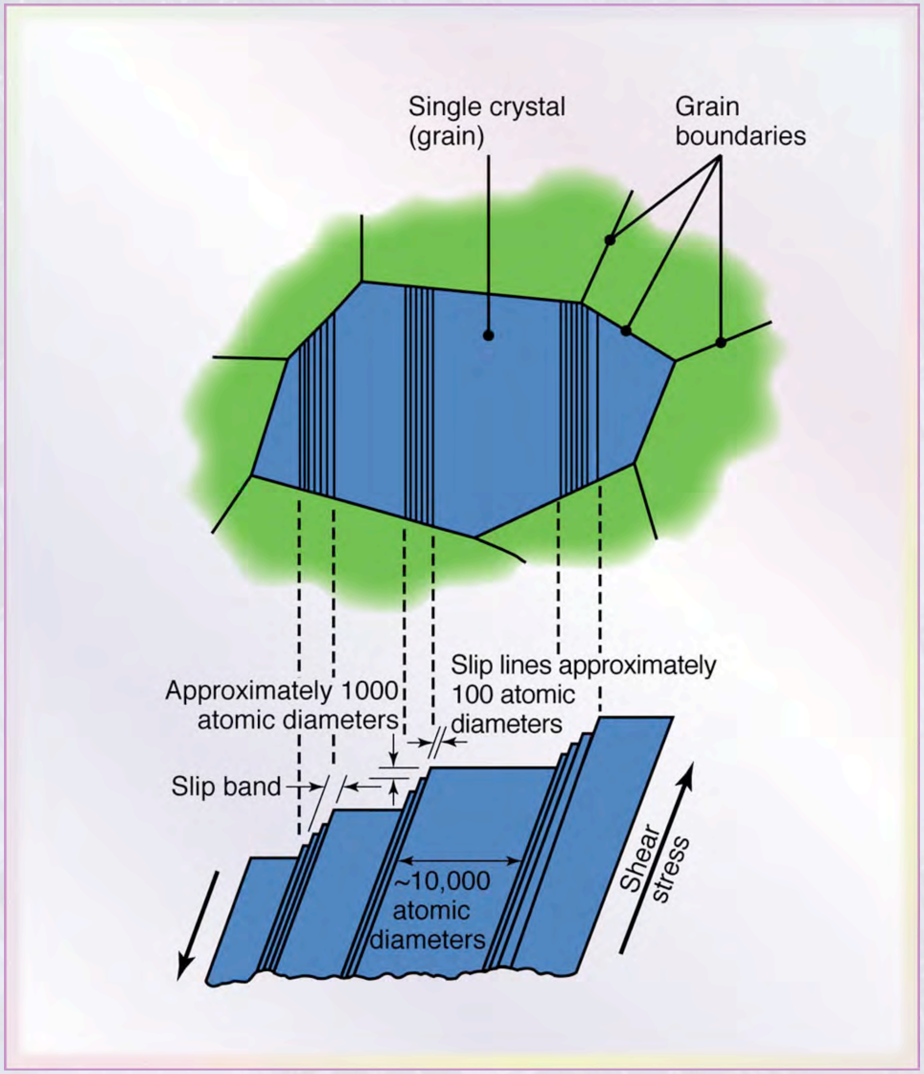

Figure 1.7 Schematic illustration of slip lines and slip bands in a single crystal (grain) subjected to a shear stress. A slip band consists of a number of slip planes. The crystal at the center of the upper illustration is an individual grain surrounded by several other grains

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Defects in a Single-Crystal Lattice

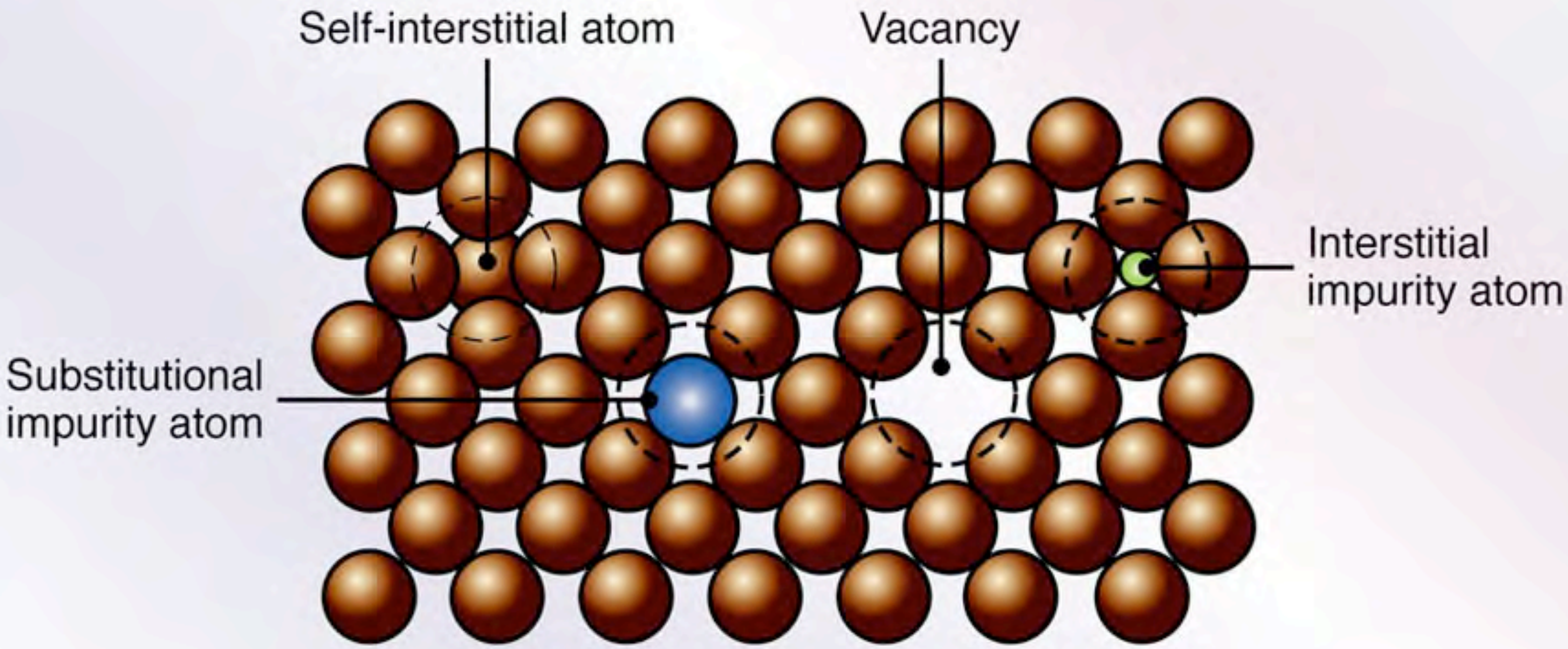

Figure 1.8 Schematic illustration of types of defects in a single-crystal lattice: self-interstitial, vacancy, interstitial, and substitutional

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Dislocations in Crystals

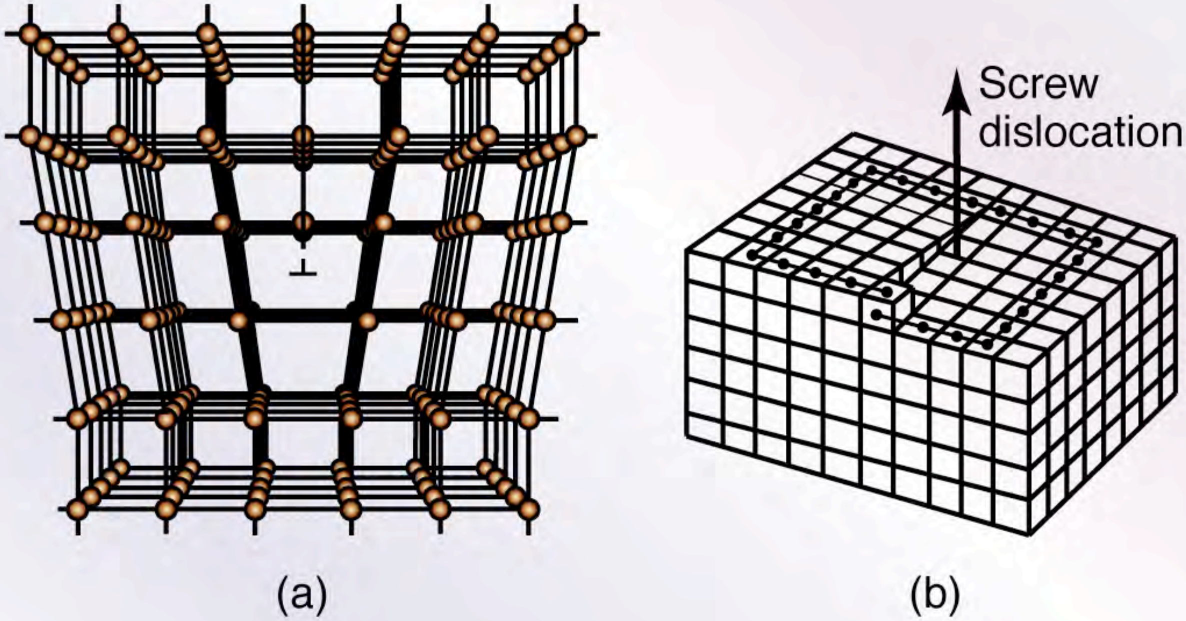

Figure 1.9 Types of dislocations in a single crystal:
(a) edge dislocation; and (b) screw dislocation

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Edge Dislocation Movement

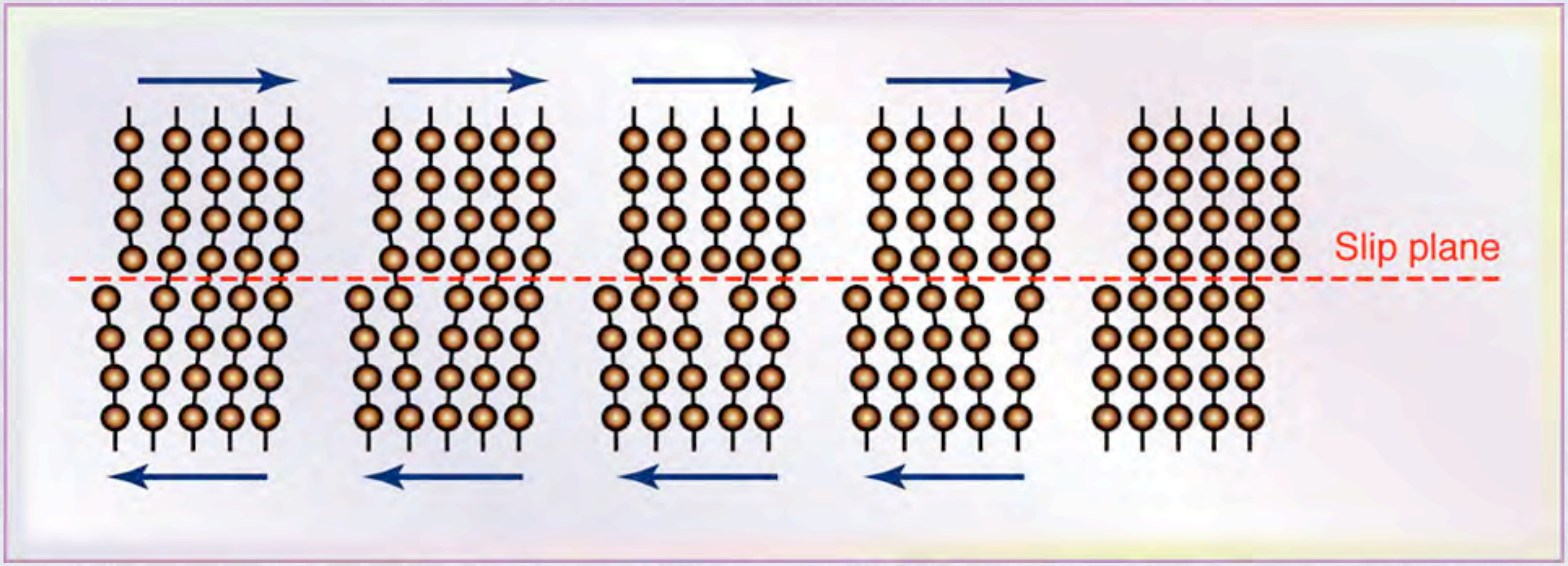

Figure 1.10 Movement of an edge dislocation across the crystal lattice under a shear stress. Dislocations help explain why the actual strength of metals is much lower than that predicted by theory.

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Solidification of Molten Metal

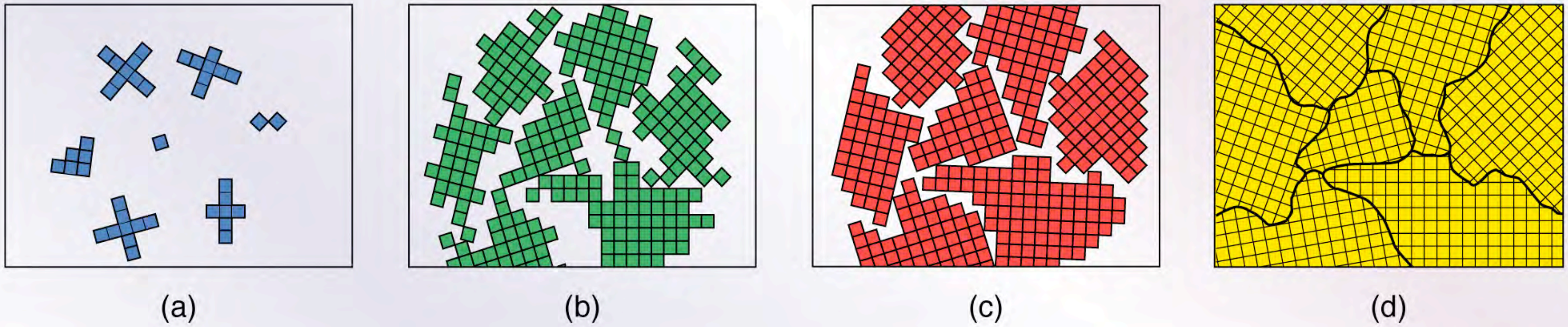

Figure 1.11 Schematic illustration of the stages during solidification of molten metal; each small square represents a unit cell. (a) Nucleation of crystals at random sites in the molten metal; note that the crystallographic orientation of each site is different. (b) and (c) Growth of crystals as solidification continues. (d) Solidified metal, showing individual grains and grain boundaries; note the different angles at which neighboring grains meet each other.

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Grain Sizes

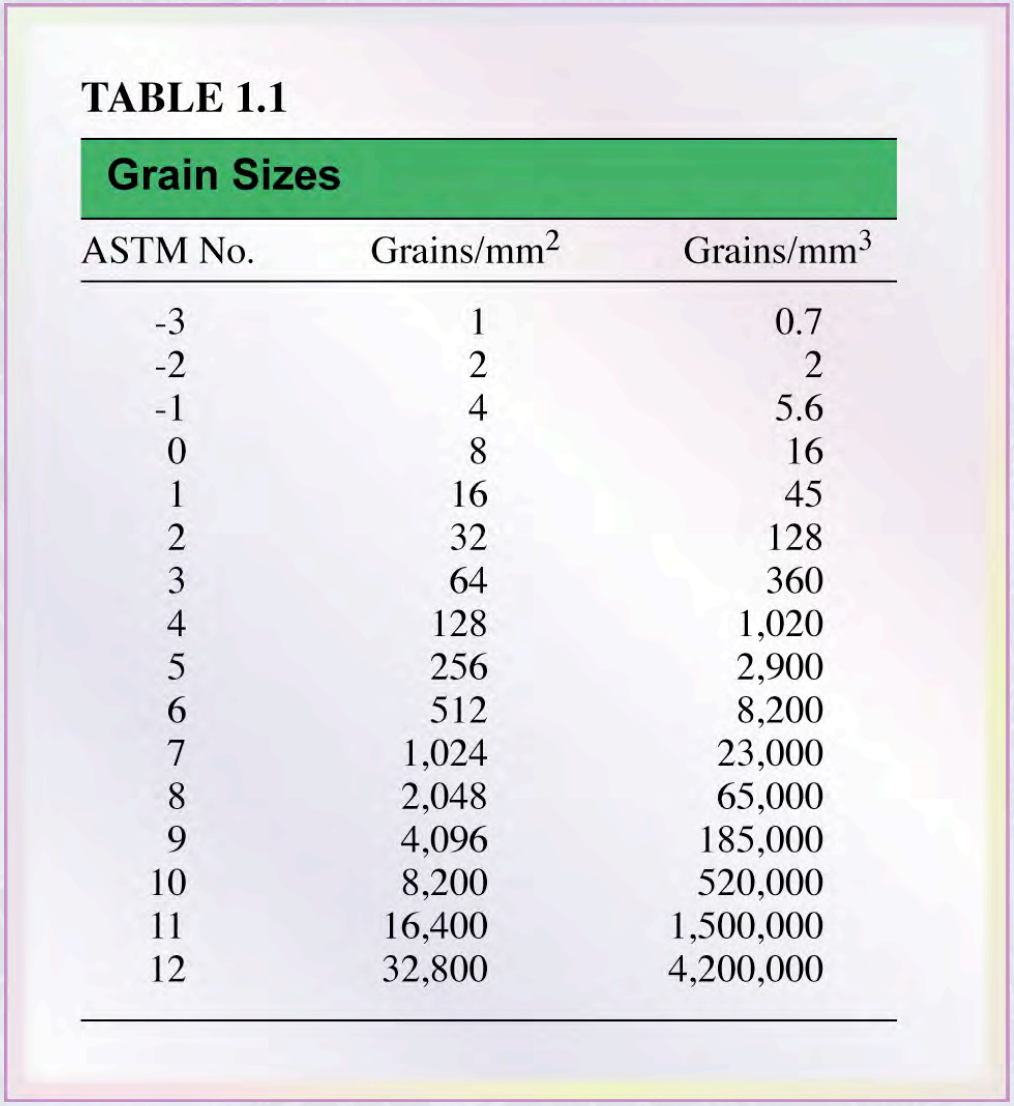

TABLE 1.1

Grain Sizes

ASTM No.	Grains/mm^2	Grains/mm^3
-3	1	0.7
-2	2	2
-1	4	5.6
0	8	16
1	16	45
2	32	128
3	64	360
4	128	1,020
5	256	2,900
6	512	8,200
7	1,024	23,000
8	2,048	65,000
9	4,096	185,000
10	8,200	520,000
11	16,400	1,500,000
12	32,800	4,200,000

ASTM Grain Size:

$$N = 2^{n-1}$$

where

N = Grains per square inch at 100x magnification

n = ASTM grain size number

Plastic Deformation of Idealized Grains

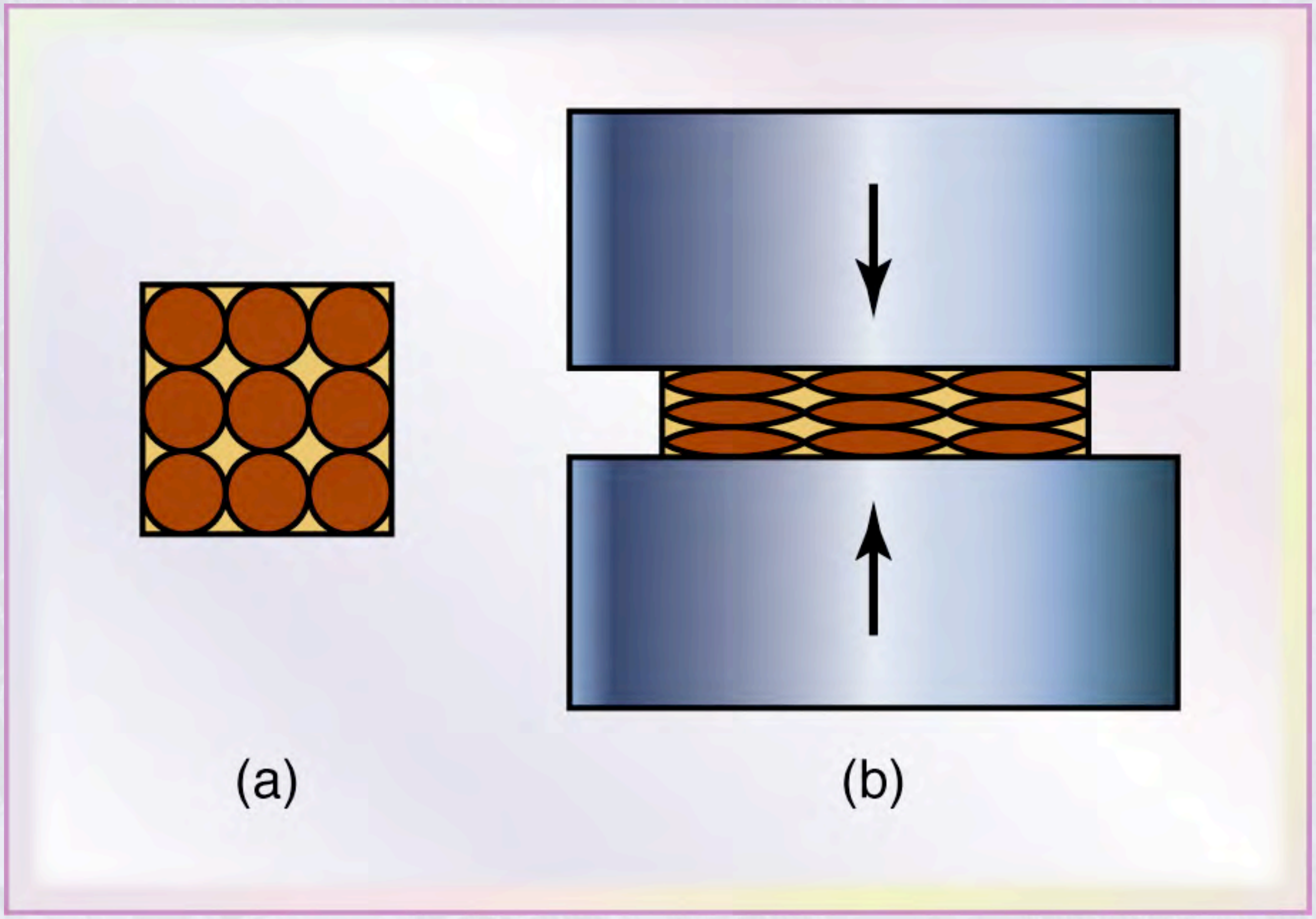

Figure 1.12 Plastic deformation of idealized (equiaxed) grains in a specimen subjected to compression (such as occurs in the forging or rolling of metals): (a) before deformation; and (b) after deformation. Note the alignment of grain boundaries along a horizontal direction; this effect is known as preferred orientation.

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Cracks in Sheet Metal

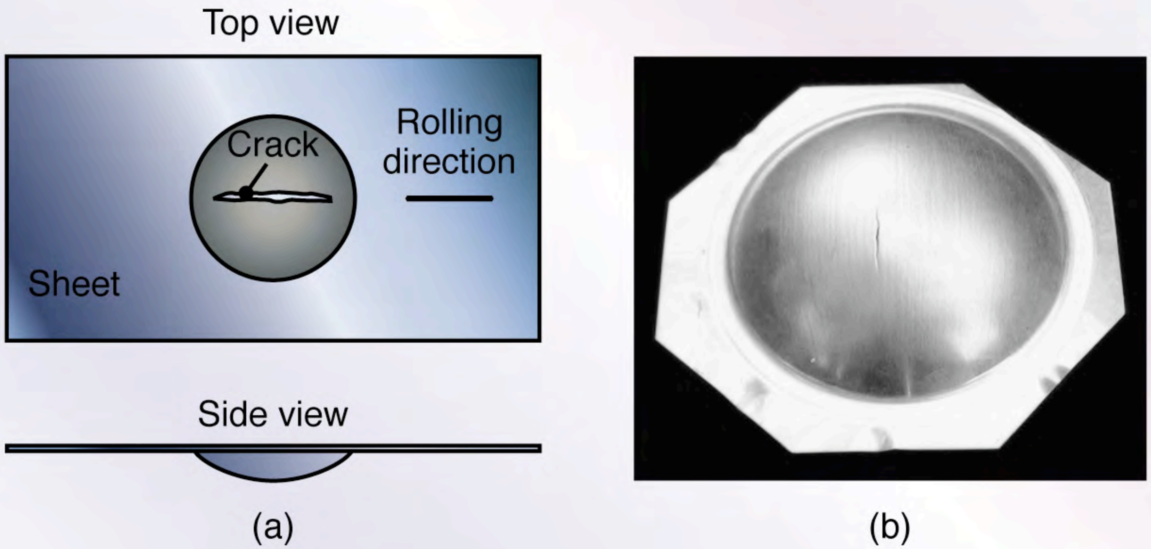

Figure 1.13 (a) Schematic illustration of a crack in sheet metal that has been subjected to bulging (caused by, for example, pushing a steel ball against the sheet). Note the orientation of the crack with respect to the rolling direction of the sheet; this sheet is anisotropic. (b) Aluminum sheet with a crack (vertical dark line at the center) developed in a bulge test; the rolling direction of the sheet was vertical. *Source*: Courtesy of J.S. Kallend, Illinois Institute of Technology

Recovery, Recrystallization, and Grain Growth Effects

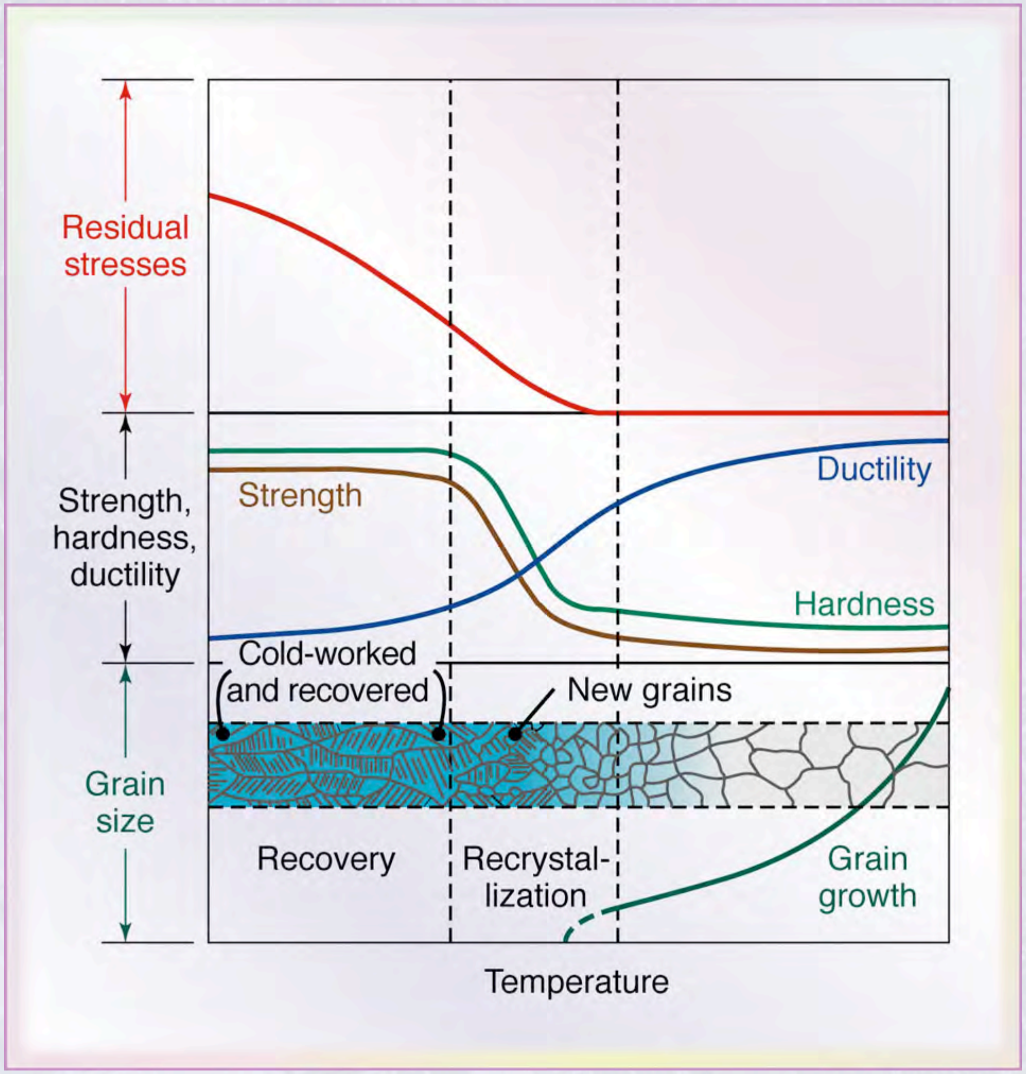

Figure 1.14 Schematic illustration of the effects of recovery, recrystallization, and grain growth on mechanical properties and on the shape and size of grains. Note the formation of small new grains during recrystallization.

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Temperature Ranges for Cold, Warm and Hot Working

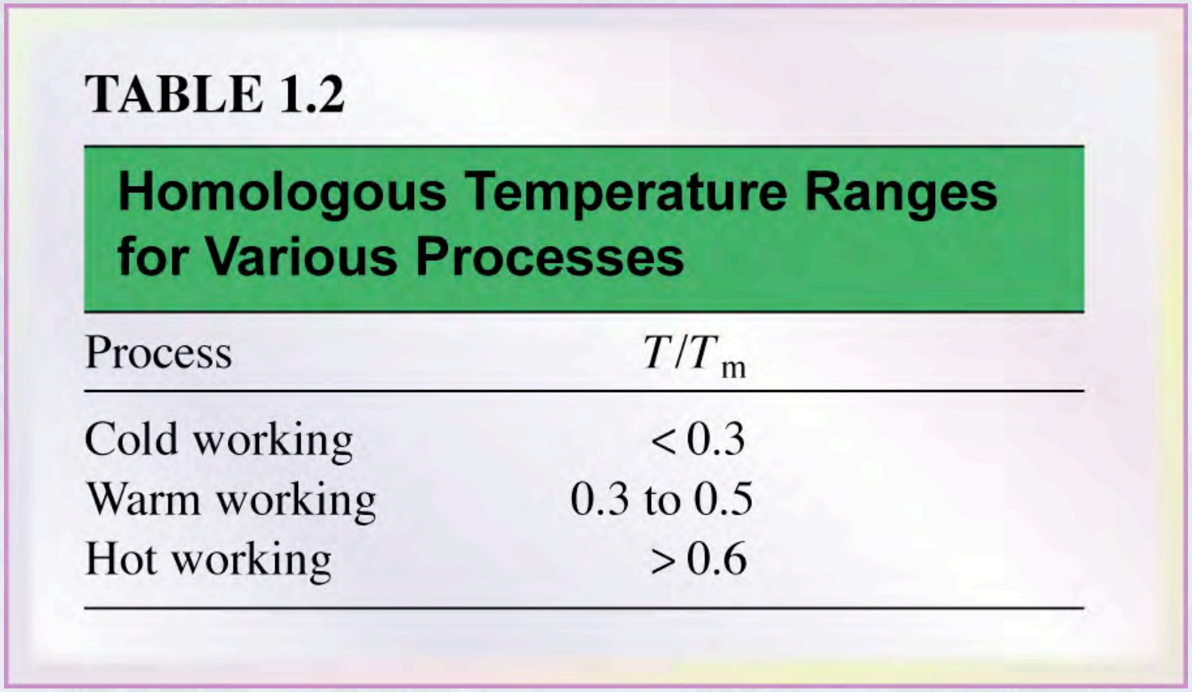

TABLE 1.2

Homologous Temperature Ranges for Various Processes

Process	T/T_m
Cold working	< 0.3
Warm working	0.3 to 0.5
Hot working	> 0.6