Exercise walk-through

4.1
Structure and bonding

University Mechanical Engineering

Bonding sets the property family

metallic
steel, aluminium
ductile, tough, conducts heat and charge

covalent / ionic
alumina, silicon carbide
stiff, hard, brittle, insulating, heat-resistant

polymer chains
nylon, epoxy
light, compliant, viscoelastic, creeps

> Polymer chains give light, viscoelastic solids

Selection in action: one method, two answers

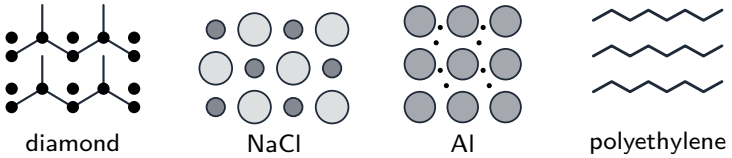
1. **Rank** $\sqrt{E}/\rho$: CFRP 7.37 wins stiffness-per-mass at 2.4× aluminium.
2. **Eliminate** Plain nylon fails the T_g constraint; ceramics fail the survival probability at these loads.
3. **Split** The mount ships quenched-and-tempered steel (620 MPa, 16%); the carry-handle ships CFRP.

The project sheet, reproducible

1. **Structure** BCC 0.6802, FCC 0.7405; Hall-Petch 183.6 $\rightarrow$ 262.3 MPa for 50 $\rightarrow$ 10 µm.
2. **Certificate** Rod 191.0 MPa: 0.477 vs 1.364 mm; true ln 1.2 $=$ 0.1823; **toughness** 92.8 MJ/m^3.
3. **Choice** Routes 280/24, 260/26, 620/16, 950/8; Chvorinov 22.2 vs 50.0 s; Basquin 303.1 at 10^5, 250 at 10^6; Goodman 175.0; index 7.37 / 3.10 / 1.80 / 1.23 - steel mount, CFRP handle.

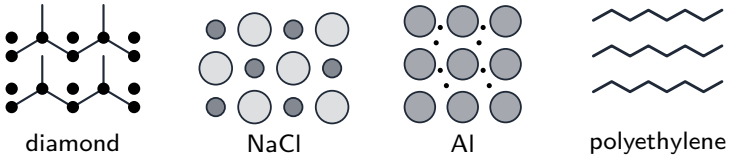
Exercise 2.1

2.1 The figure shows the structures of diamond, sodium chloride, aluminium and polyethylene. Name the main bonding in each, and put them in order of melting point. Explain why polyethylene melts lowest even though its chains are held by strong covalent bonds. [3]



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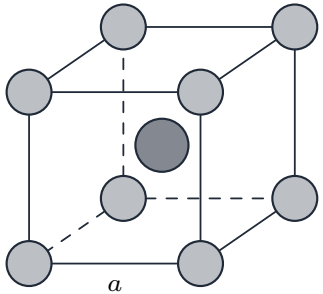


2.1

covalent, ionic, metallic, covalent chains with van der Waals between them; order: diamond > NaCl > Al > polyethylene; melting only has to separate the chains, which are held by weak van der Waals forces

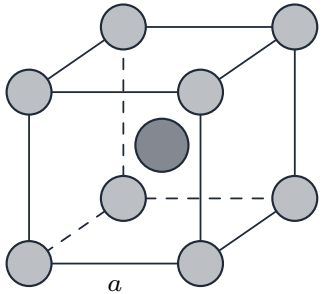
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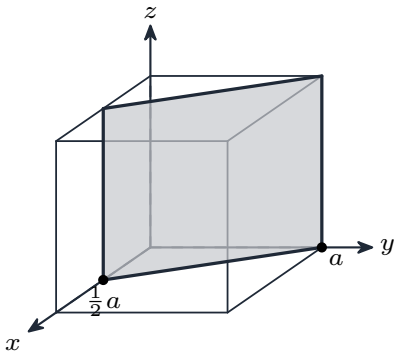


2.2

$$a = \frac{4r}{\sqrt{3}} = \mathbf{0.286\ nm};\ \rho = \frac{2 \times 55.85}{(2.864 \times 10^{-8})^3 \times 6.022 \times 10^{23}} = \mathbf{7.90\ g/cm^3}$$

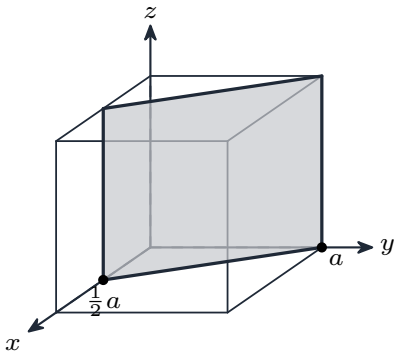
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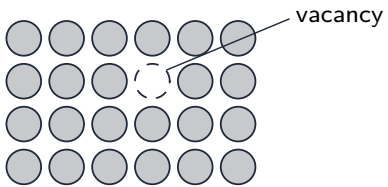


2.3

intercepts $\frac{1}{2},\ 1,\ \infty$; reciprocals $2,\ 1,\ 0$; (**210**)

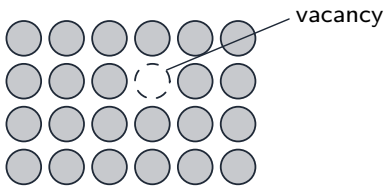
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2.4 Copper has 8.47×10^{28} atoms per m^3, and the energy to form a vacancy is $Q_v = 0.90$ eV. Find the fraction of empty sites and the number of vacancies per m^3 at 1000°C. Say why this matters for diffusion. [3]



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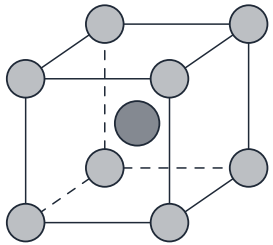
2.4

$\frac{N_v}{N} = \exp\left(-\frac{0.90}{8.617 \times 10^{-5} \times 1273}\right) = \mathbf{2.7 \times 10^{-4}}$; $N_v = \mathbf{2.3 \times 10^{25}}\ \mathbf{m^{-3}}$; atoms diffuse by jumping into vacancies, so diffusion speeds up quickly with temperature

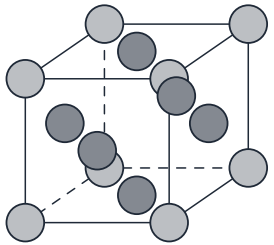
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3.1 Pure iron changes from BCC to FCC when heated through 912°C. At 912°C, $a_{BCC} = 0.2906$ nm and $a_{FCC} = 0.3647$ nm.

Find the volume per atom in each structure and the percentage volume change on heating. Explain why this change matters when steel parts are quenched. [4]



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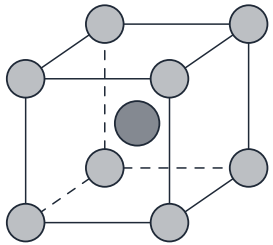


FCC, $a = 0.3647$ nm

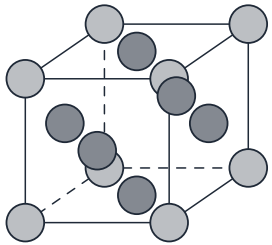
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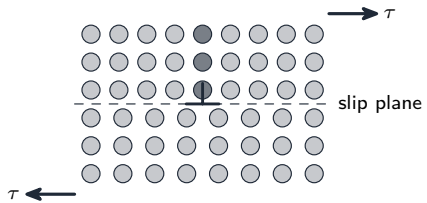
BCC: $\dfrac{a^3}{2} = 0.01227$ nm^3; FCC: $\dfrac{a^3}{4} = 0.01213$ nm^3

change $= -\mathbf{1.2}\%$: iron **shrinks** when it becomes FCC; on cooling it grows again, and uneven change through a thick part causes distortion or cracks

Exercise 3.2

3.2 The figure shows an edge dislocation : an extra half-plane of atoms. FCC metals such as copper stay ductile at $-200°C$, but BCC steel can break in a brittle way in cold weather.

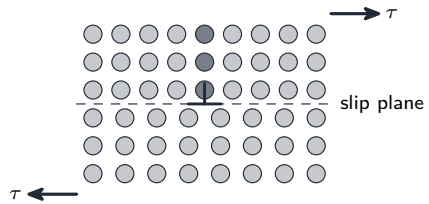
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3.2

a dislocation moves one row of bonds at a time, so slip needs far less stress than shearing a whole plane

FCC has 12 slip systems on close-packed planes, where dislocations move easily; in BCC the stress to move a dislocation rises sharply as temperature falls, so it can fracture before it slips

Exercise 3.3 (a)

3.3 An X-ray diffraction scan ($\lambda = 0.1542$ nm) of a steel weld shows a large peak at $2\theta = 44.7°$ and a small extra peak at $2\theta = 43.3°$.

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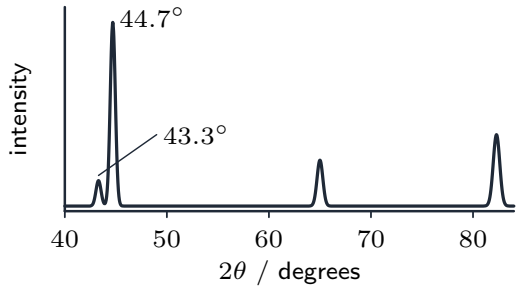
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(a) $d = \dfrac{\lambda}{2\sin\theta} = \dfrac{0.1542}{2\sin 22.35°} = \mathbf{0.2028\ nm}$

Exercise 3.3 (b)

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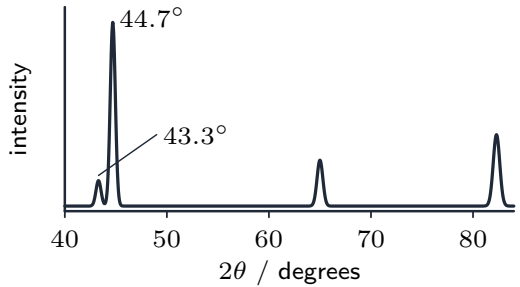
(b) Take the large peak as BCC (110). Find a and the density, and say whether it is ferrite (BCC iron, 7.87 g/cm^3). [3]



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(b) $a = d\sqrt{2} = \mathbf{0.287\ nm}$; $\rho = \dfrac{2 \times 55.85}{a^3 N_A} = \mathbf{7.87\ g/cm^3}$; this matches **ferrite**

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(c) $d = 0.2090$ nm, $a = d\sqrt{3} =$ **0.362 nm**: FCC iron, **retained austenite** ; it can change to martensite later and alter the size or crack the weld, so temper it (or treat it below zero) before service