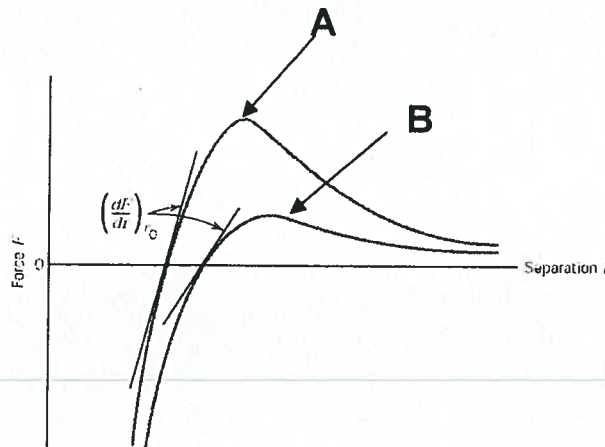


Problem 1. Fill in the blanks. Each correct answer is worth 1%.

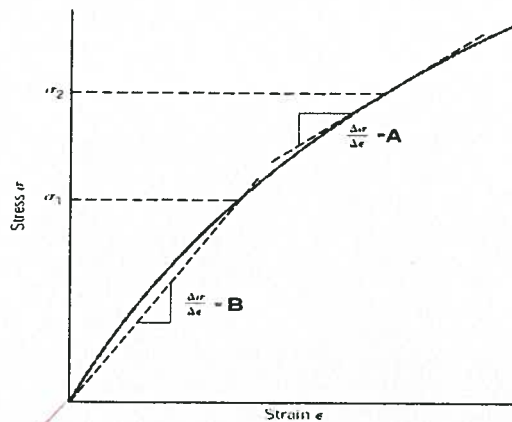
1. materials science investigates the relationships that exist between the structures and properties of materials.
2. materials engineering is the discipline, which on the basis of these structure–property correlations, designs or engineers the structure of a material to produce a predetermined set of properties.
3. Materials with little or no elongation or increase in length at fracture are called brittle.
4. crystalline are materials in which the atoms are in a repeated three-dimensional pattern.
5. Name four main groups that materials are classified into:
a) Metals, b) Ceramics, c) Composites, d) Polymers.
6. Name four types of properties of engineering materials:
a) mechanical, b) thermal, c) chemical, and d) physical.
7. Name four criteria that should be considered in the selection of materials for an application
a) in service conditions, b) deterioration, c) economics and d) environmental issues.
8. Small reversible deformations of materials due to external loading are called elastic deformations.
9. Poisson's ratio is the ratio of transverse strain : axial strain.
10. ductility is the measure of the degree of plastic deformation that a specimen undergoing a tensile strength tests has been sustained at fracture.
11. modulus of elasticity is a measure of a materials resistance to localized plastic deformation.

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12. The figure below shows a force versus interatomic separation for two materials. The atoms of material B are weakly bonded and the atoms of material A are strongly bonded.



13. In the figure below A is the secant modulus and B the tangent modulus.



14. polymorphism is the phenomenon of the existence of more than one crystal structure in the same element or compound. When found in elemental solids the condition is called allotropy.

15. coefficient of thermal expansion is a material property that is indicative of the extend to which a material expands upon heating.

16. The property that characterizes a material's ability to transfer heat is the thermal conductivity.

17. Cubic unit cells with atoms located at each of the corners and the centres of all its cube faces are called FCC.

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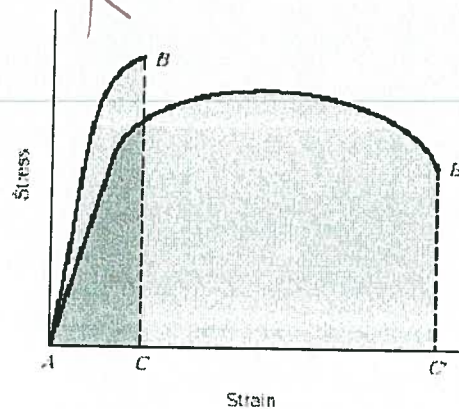
18. The atomic packing factor (APF) is the ratio of the volume unit cell atoms
 \div total unit cell volume.

19. Name two types of point defects in crystals and two types of line defects:

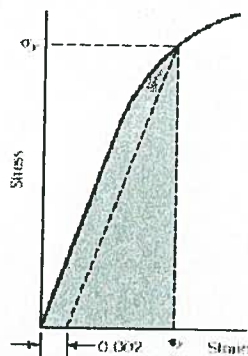
a. Point defects: a) Frenkel Defect, b) Schottky defect

b. Line defects: a) screw dislocation, b) edge dislocation

20. In the Figure below material with the curve A-B is a brittle material, while material with A-B' curve is a ductile material. The area under the curves represents the modulus of resilience.



21. The shaded area in the Figure below is the modulus of resilience.



Keywords: (Please note that there may be more keywords than used in question 1-21. Some keywords may be used twice and some may be redundant.)

Allotropy, amorphous materials, anisotropic, atomic packing factor (APF), BCC, brittle, ceramics, chemical, coefficient of thermal expansion, composites, coordination number, covalent, crystalline, ductile, ductility, edge dislocation, elastic, electrical, FCC, Frenkel defect, hardness, heat capacity, heterogeneous, interstitial, ionic, materials engineering, materials science, mechanical, metallic, metals, metastable state, modulus of resilience, phase, plastic, polymers, polymorphism, resilience, Schottky defect, screw dislocation, tangent modulus, secant modulus, stiffness, strength, tangent modulus, tensile strength, thermal, thermal conductivity, toughness, vacancy, yield strength, Young modulus.

Problem 2. (6%)

Calculate the APF of an FCC unit cell.

$$\begin{aligned} \text{APF} &= \frac{\text{volume of atoms in unit cell}}{\text{total volume of unit cell}} \\ &= \frac{N \left(\frac{4}{3} \pi R^3 \right)}{a^3} \end{aligned}$$

where $N = 4$ and $a = 2\sqrt{2} R$

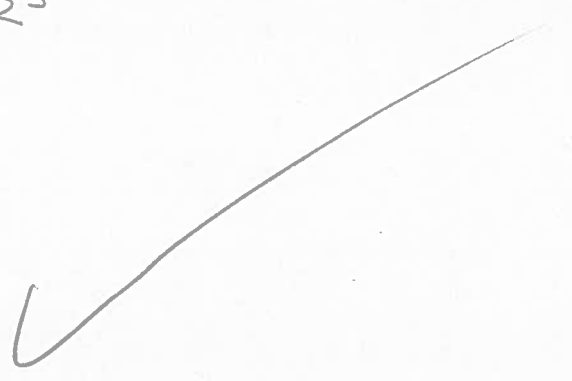
$$a^2 + a^2 = 4R^2$$

$$2a^2 = 16R^2$$

$$a^2 = 8R^2$$

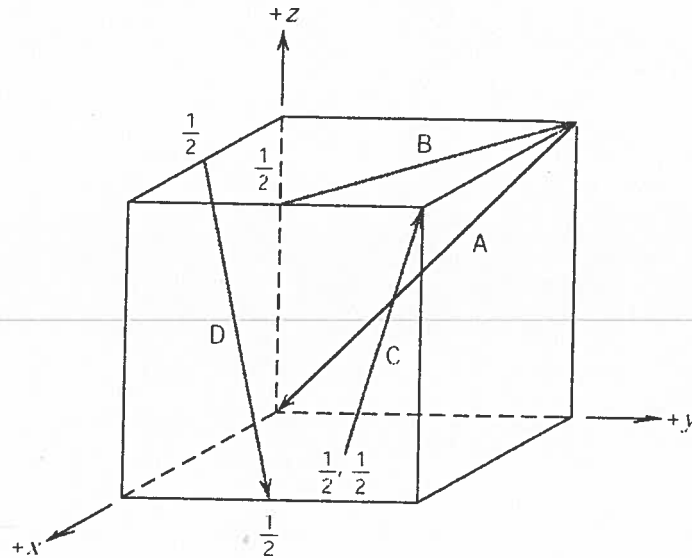
$$a = \sqrt{8} R$$

$$a = 2\sqrt{2} R$$

$$\begin{aligned} \text{APF} &= \frac{4 \left(\frac{4}{3} \pi R^3 \right)}{(2\sqrt{2} R)^3} \\ &= \frac{\frac{16\pi}{3} R^3}{(2\sqrt{2})^3 R^3} \\ &= \frac{\frac{16\pi}{3}}{16\sqrt{2}} \\ &= \frac{\pi}{3\sqrt{2}} \\ &= 0.74 \end{aligned}$$


Problem 3. (6%)

Determine the indices for **TWO** of the directions shown in the following cubic unit cell:



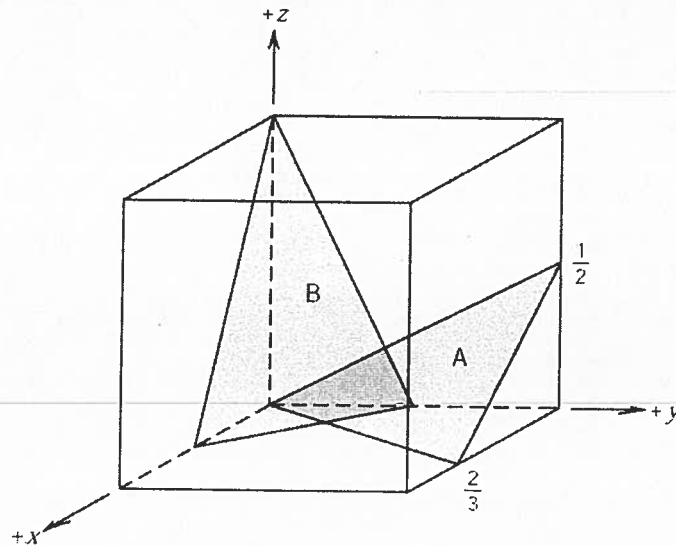
$$\begin{aligned} A &\Rightarrow (0, 0, 0) - (0, 1, 1) \\ &\Rightarrow (0, -1, -1) \\ &\Rightarrow [0 \bar{1} \bar{1}] \end{aligned}$$

$$\begin{aligned} C &\Rightarrow (1, 1, 1) - (\frac{1}{2}, \frac{1}{2}, 0) \\ &\Rightarrow (\frac{1}{2}, \frac{1}{2}, 1) \\ &\Rightarrow (1, 1, 2) \\ &\Rightarrow [1 \ 1 \ 2] \end{aligned}$$

6/6

Problem 4. (6%)

Determine the Miller Indices of the two planes shown in the following cubic unit cell.



$$\begin{aligned}
 B &\Rightarrow x = 1/2, \quad y = 1/2, \quad z = 1 \\
 &\Rightarrow \frac{1}{x} = 2, \quad \frac{1}{y} = 2, \quad \frac{1}{z} = 1 \\
 &\Rightarrow (2 \ 2 \ 1)
 \end{aligned}$$

$$\begin{aligned}
 A &\Rightarrow x = 2/3, \quad y = -1, \quad z = 1/2 \\
 &\Rightarrow \frac{1}{x} = 3/2, \quad \frac{1}{y} = -1, \quad \frac{1}{z} = 2 \\
 &\Rightarrow (3/2 \ \bar{1} \ 2) \\
 &\Rightarrow (3 \ \bar{2} \ 4)
 \end{aligned}$$

6/6

Problem 5 (14%)

The surface of a 0.1 % C steel gear is to be hardened by carburizing. The gear is placed in a gas atmosphere that provides 1.2% C at the surface of the steel. Calculate the time required to achieve a C concentration of 0.45% at a depth of 2 mm below the surface. The heat treatment temperature is 1000 °C

and the diffusion coefficient for diffusion of C in FCC iron is given by $D = D_0 \exp\left(\frac{-Q}{RT}\right)$, where

$D_0 = 0.23 \text{ (cm}^2/\text{s)}$, the activation energy Q is 60,000 cal/mol and the gas constant $R = 1.987 \text{ cal/(K-mol)}$.

$$D = D_0 \exp\left(\frac{-Q}{RT}\right)$$

$$\left(\frac{-Q}{RT}\right) = \frac{-60,000 \frac{\text{cal}}{\text{mol}}}{1.987 \frac{\text{cal}}{\text{K mol}} \cdot 1273 \text{ K}}$$

$$= -23.7215$$

$$D = (0.23 \text{ cm}^2/\text{s})^{-23.7215}$$

$$= 1.38 \times 10^{15} \text{ cm}^2/\text{s}$$

$x = 0.2 \text{ cm}$

$$\frac{C_x - C_0}{C_s - C_0} = 1 - \text{erf}\left(\frac{x}{2\sqrt{Dt}}\right)$$

$$\frac{0.45 - 0.1}{1.2 - 0.1} = 1 - \text{erf}\left(\frac{0.2 \text{ cm}}{2\sqrt{(1.38 \times 10^{15} \text{ cm}^2/\text{s}) t}}\right)$$

$$0.6818 = \text{erf}\left(\frac{3.0 \times 10^{-9}}{\sqrt{t}}\right)$$

z	erf	
0.7	0.6778	$\frac{0.75 - 0.7}{0.7112 - 0.6778} = \frac{0.75 - z}{0.7112 - 0.6818}$
z	0.6818	
0.75	0.7112	
		$z = 0.705988024$

$$0.705988024 = \frac{3.0 \times 10^{-9}}{\sqrt{t}}$$

$$\sqrt{t} = 4.0 \times 10^{-9} \text{ s}$$

$$t = 1.8 \times 10^{-17} \text{ s}$$

$\frac{10}{14}$

Problem 6 (14%)

- a) Determine the number of vacancies (vacancies/cm³) needed for BCC iron crystal to have a density of 7.87 g/cm³. The lattice parameter of the iron is 2.866 x 10⁻⁸ cm. The atomic mass of iron is 55.847 g/mol.
- b) At what temperature do we have to heat treat iron to produce the vacancies found in (a) if 15,000 cal are required to produce a mole of vacancies in iron?

$$\rho = \frac{NA}{V_c N_a}$$

$$7.87 \frac{\text{g}}{\text{cm}^3} = \frac{(2) (55.847 \frac{\text{g}}{\text{mol}})}{V_c (6.023 \times 10^{23} \frac{\text{atoms}}{\text{mol}})}$$

$$V_c (6.023 \times 10^{23} \frac{\text{atoms}}{\text{mol}}) (7.87 \frac{\text{g}}{\text{cm}^3}) = 111.694 \frac{\text{g}}{\text{mol}} + 2$$

$$V_c 4.740101 \times 10^{24} \frac{\text{atoms g}}{\text{mol cm}^3} = 111.694 \frac{\text{g}}{\text{mol}}$$

$$V_c = (2.36 \times 10^{-23} \frac{\text{cm}^3}{\text{atoms}})$$

$$N_v = 4.24 \times 10^{22} \frac{\text{atoms}}{\text{cm}^3}$$

$$N_v = N (-Q/RT)$$

$$\left(\frac{-Q}{RT} \right) = \frac{-15000 \text{ cal}}{1.987 \text{ cal} \frac{\text{mol K}}{\text{T}}}$$

$$= \frac{-7549.07}{\text{T}} \text{ mol K}$$

$$4.24 \times 10^{22} = 2 \left(\frac{-7549.07}{\text{T}} \right)$$

$$\ln 4.24 \times 10^{22} = \ln 2 \left(\frac{-7549.07}{\text{T}} \right)$$

$$52.10 = \left(\frac{-7549.07}{\text{T}} \right) \ln 2$$

$$52.10 = \frac{-5232.62}{\text{T}}$$

$$\text{T} = -100.43 \text{ K}$$

9
T4

+7

Problem 7 (16%)

16

The following data were collected from a 12-mm-diameter test specimen of magnesium having an initial length l_0 of 30-mm.

σ		44.2	88.4	132.6	176.8	221.0	229.9	238.7	234.3	221.0
Load (N)	0	5,000	10,000	15,000	20,000	25,000	26,000	27,000	26,500	25,000
Δl (mm)	0.0000	0.0296	0.0592	0.0888	0.15	0.51	0.90	1.50	2.10	2.79
ϵ	0	0.001	0.002	0.003	0.005	0.017	0.03	0.05	0.07	0.093

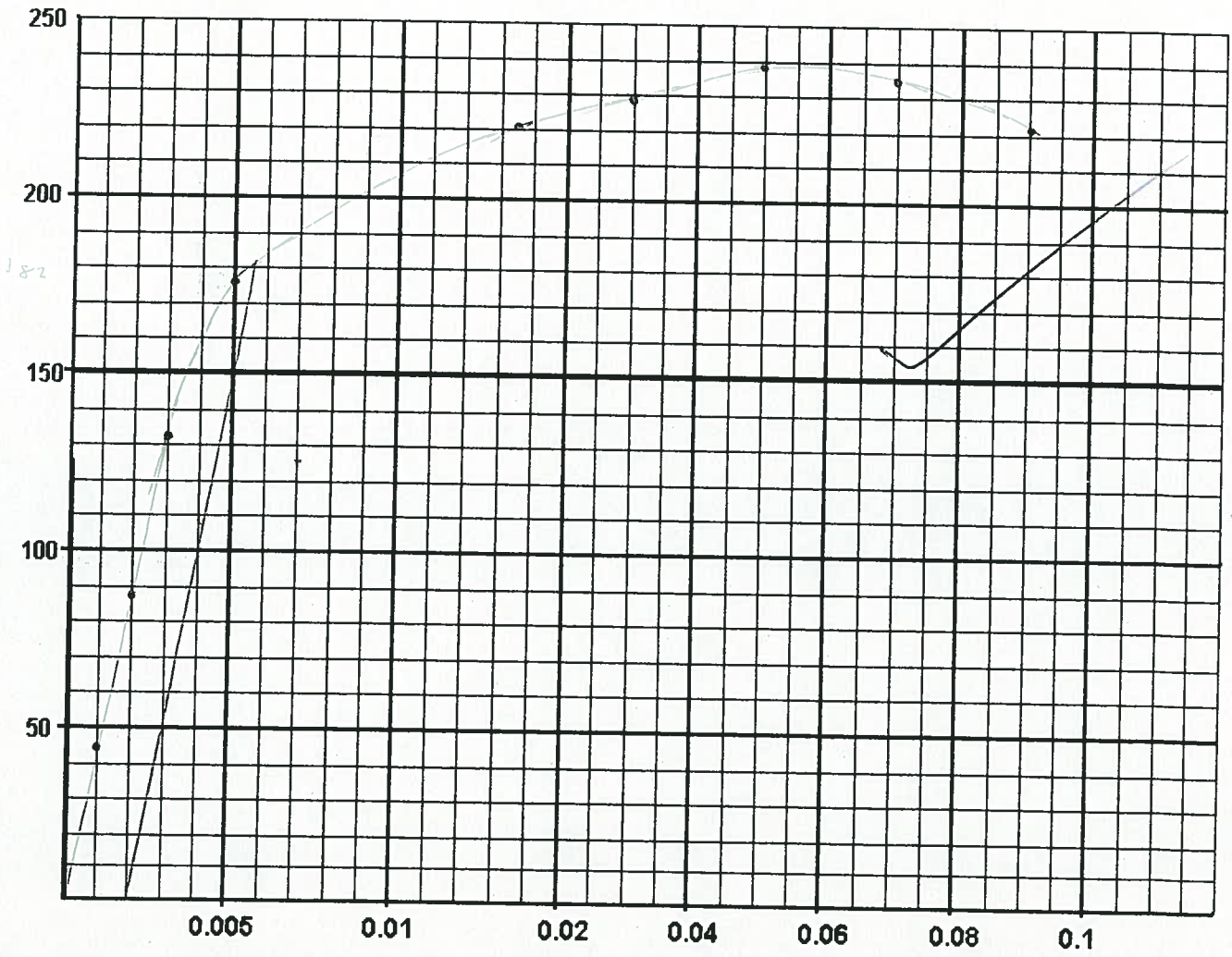
After the fracture the total length was 32.61 mm and the diameter was 11.74 mm. Plot the stress-strain data and calculate:

- the 0.2% offset yield strength
- the proportionality limit
- the tensile strength
- the modulus of elasticity
- the % elongation
- the % reduction in area
- the modulus of resilience.

$$\sigma = \frac{N}{A} \quad \epsilon = \frac{\Delta L}{L}$$

$$A = \frac{\pi}{4} (12 \text{ mm})^2$$

$$= 113.1 \text{ mm}^2$$



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a) yield strength at 0.2% offset

$$\Rightarrow \sigma_y = 182$$

b) proportionality limit

$$\Rightarrow \sigma = 132.6$$

c) tensile strength

$$\Rightarrow \sigma_u = 238.7$$

$$\begin{aligned} \text{d) } E &= \frac{132.6 - 44.2}{0.003 - 0.001} \\ &= 44200 \end{aligned}$$

$$\begin{aligned} \text{e) } \% \text{ elongation} &= \frac{32.61 - 30}{30} (100) \\ &= 8.7\% \end{aligned}$$

$$\begin{aligned} \text{f) } \% \text{ reduction in area} &= \frac{\frac{\pi}{4} (12)^2 - \frac{\pi}{4} (11.74)^2}{\frac{\pi}{4} (12)^2} (100) \\ &= 4.3\% \end{aligned}$$

$$\begin{aligned} \text{g) modulus of resilience} &= \frac{\sigma_y^2}{2E} \\ &= \frac{(182)^2}{2(44200)} \\ &= 0.37 \end{aligned}$$

Equations and other data

$$\rho = \frac{nA}{V_c N_A}$$

where :

n = number of atoms per cell

A = Atomic mass

V_c = volume of unit cell

N_A = Avogadro's number, $(6.023 \times 10^{23} \text{ atoms/mol})$

$$\frac{4}{3} \pi R^3$$

$$N_v = N \exp\left(-\frac{Q_v}{RT}\right) \quad (2)$$

where :

N_v = number of vacancies

N = number of atomic sites

Q_v = energy required for the formation of a mole of vacancies

R = gas constant, 1.987 (cal/mol-K)

T = absolute temperature, K

$$\frac{C_x - C_0}{C_s - C_0} = 1 - \operatorname{erf}\left(\frac{x}{2\sqrt{Dt}}\right) \quad (3)$$

z	$\operatorname{erf}(z)$	z	$\operatorname{erf}(z)$	z	$\operatorname{erf}(z)$
0	0	0.25	0.2763	0.55	0.5633
0.025	0.0282	0.30	0.3286	0.60	0.6039
0.05	0.0564	0.35	0.3794	0.65	0.6420
0.10	0.1125	0.40	0.4284	0.70	0.6778
0.15	0.1680	0.45	0.4755	0.75	0.7112
0.20	0.2227	0.50	0.5205	0.80	0.7421