Prepared

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Industrial Engineering

"Materials Science and engineering"

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(Notes)
Chapter (1)

* Materials science is the study of the relationships between the processing, structure, properties and performance.

* Materials are classified into six majors depending on bonds:-

(1) Metals (Metallic) (2) ceramics (covalent/ionic) (3) polymers (covalent/Vander) (4) semiconductors (covalent)

(5) composites (6) Biomaterials (covalent/ionic/hydrogen)

Density	metals, ceramics, poly – composites, wood	Stiffness: metals, ceramics, composites (woods), Poly (Van der Walls)
Strength	Metals, ceramics, composits, poly	

* Structure exists at multiple levels: atomic, microscopic and macroscopic

* Materials selection depends on desired properties: (1) operating environment (2) cost (3) manufacturability

* What is the difference between materials science and material eng?

– Materials science focuses on understanding why materials behave the way they do.

– Materials engineering applies this knowledge to design and produce useful products.

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* The performance of a material in service is directly linked to it's properties which are determined by it's structure and processing.

* Materials science combining principles from physics chemistry and eng

* Understanding crystal structure and atomic bonding is foundational for predicting material behaviour.

* ductile means capable of large amounts of deformation without fracture

* Fe, Co, Ni ⇒ magnetic metals

* poly ⇒ soften

* Nanomaterial are no distinguished on their chemistry but their size (Sadly is not explored)

* bottom-up approach ⇒ making atoms arranged to provide mechanical, electrical, magnetic that are not otherwise possible

* hydrogen cell ⇒ non polluting for batteries

* Questions *

1) Classify each to Materials type!-

(brass, Al_2O_3, MgO, Plexiglass, Polychloroprene, boron carbide (B_4C), Cast iron)

brass ⇒ Ceramics
Al_2O_3 ⇒ Ceramics
MgO ⇒ ceramics
Plexiglass ⇒ Poly
Polychloroprene ⇒ Poly
boron carbide ⇒ metals
B_4C ⇒ metals
Cast iron ⇒ metals

2) What are the four components that defines materials science and eng?

Processing ⇒ structure ⇒ properties ⇒ performance

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* الفلزات ⇐ كهرباء + الوسط
* غير الفلزات ⇐ العزل

3) What does the term "structure" refer to in materials science?
atomic - micro - macro

4) Explain how processing affects the performance of a material?
Processing determine the internal structure (size, grain, phase) which affects properties like strength, ductile.

5) Why are composites used in eng? to achieve superior properties not possible with individual components

*6) Give an example of a trade-off in material properties that eng must know?
increasing strength may reduce ductility.

7) How does atomic bonding influence the mechanical prop of material?
Stronger atomic bonds like covalent often lead to higher stiffness and melting points, while weaker bonds like van der wals results in softer (poly)

8) Discuss how materials science integrates physics and chemistry?
uses physics to understand atomic interactions and Chemistry for reaction both to predict and control material behaviour.

9) Why is understanding crystal structure essential for predicting material behaviour? affects prop like density, conductivity and strength

10) How can the same material exhibit different prop depending on it's microstructure? Heat treatment or mech can change grain size or phase distribution, affecting hardness, toughness..

11) Compare electrical prop of metals, ceramics, poly and explain the reason?
metals conduct electricity due to free electrons, ceramics are insulators due to (covalent/ionic), poly are poor beacuse of their molecular structure

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Notes

Chapter (2)

* **Atomic structure:-**
  - protons (+) ⇒ Charge is 1.6×10^{-19} C , mass is 1.67×10^{-27} kg
  - Neutrons ⇒ mass is 1.67×10^{-27} kg
  - electrons (−) ⇒ Charge is 1.6×10^{-19} C , mass is 9.11×10^{-31} kg

* **Atomic number (Z)** = the atomic number also equals the number of electrons. (1 for hydrogen to 92 for uranium) — عدد البروتونات

* **Atomic mass (A)** = the sum of masses of protons and neutrons.

* **Isotopes** = atoms have the same neutrons. (have different atomic mass)

* **Atomic weight** = weighted-average of the atomic masses.

* **Atomic mass unit (amu)** ⇒ $1\text{ amu} = \frac{1}{12} C^{12}$

$$A = \underset{\text{Proton}}{Z} + \underset{\text{neutrons}}{N}$$

* **Avogadro's number (NA)** = 6.022×10^{23} atom/mol

* 1 amu/atom = 1 g/mol

* **Average atomic weight** = $\sum$ (fraction of isotope) x (mass of isotope)

لحساب متوسط الكتلة الذرية للعنصر الذي له أكثر من نظير

Ex: Cerium has isotops : 0.185% of ^{136}Ce with an atomic weight of 135.907 , 0.251% of ^{138}Ce with 137.906 amu , 88.450% of ^{140}Ce with 139.905 amu and 11.114% of ^{142}Ce with 141.909 amu . Calculate the average atomic weight.

$$\bar{A} = \frac{0.185}{100} * 135.907 + \frac{0.251}{100} * 137.906 + \frac{88.450}{100} * 139.905 + \frac{11.114}{100} * 141.909$$

$$= 140.115 \text{ amu}$$

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* Why are the atomic wights of the elements not integers?
Because they are the wighted avg of the masses of All isotops.

* Quantum mechanics: set of laws that govern atomic and subatomic

* Atomic models:-

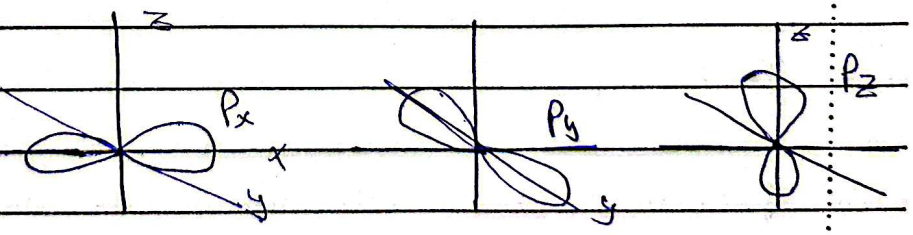
[1] Bohr atomic model ⇒ electrons revolve around the atomic nucleus in discrete orbitals and electrons have only specific values of energy.
- electrons may change energy by making a quantum jump (hydrogyn atom)
- Bohr model have some limitations because of inability to explain several phenomena involving electrons. solution

[2] Wave-mechanical model ⇒ electrons are considered to exhibit both wave like and particle like. Position is considered to be the prob of an electron's being at various locations around nucleus (electron cloud)

* Quantum Numbers: (size, shape, spatial orientation)
* Shell: (1, 2, 3) (n) principle quantum number (K, L, M, N, O) Size or avg dist
* Subsells: s, p, d, f

* Azimuthal (l) subshells within each shell (n-1) Shape for orbitals

0 → s
1 → p
2 → d
3 → f



* Magnetic quantum number (ML) (-L to L) number of electron orbitals for each subsell

* Spin moment (ms) (down $-\frac{1}{2}$ or up $\frac{1}{2}$)

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✱ Rules :-

- Aufbau principle : الإلكترونات تملأ المدارات الأقل طاقة
- Pauli exclusion principle : لا يمكن أن يكون لإلكترونين نفس الأربع أرقام
- Hund's Rule : الإلكترونات تملأ المدارات المتساوية

✱ Overlap in energy in one shell with states in an adjacent shell, is true of d and f. (3d and 4s) $3d^2\ 4s^1$ لأنه لو كانت $3d^1\ 4s^2$ ليست

✱ Electron states : Values of energy that are permitted for electrons.

✱ Ground state : the lowest energy in an atom.

✱ Electron configuration or structure

✱ Valence electrons (outermost shell) many physical and chemi prop depends on it

✱ Sp is found in C, Si and Ge

✱ Give electron configurations for Fe^{+3} and S^{-2} ions.

Fe^{+3} : $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^3$

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Si^{-2} : $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^4$

14

✱ The Periodic Tables (the elements are situated with increasing atomic)

= periods are horizontal

29 ← atomic number

Cu ← symbol

63.55 ← atomic weight

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= Groups IA and IIA are ground metals (Li, K, Na, Mg, Ca, Be ~)

= Groups IIIB to IIB are transition metals

= Groups IIIA, IVA and VA are between metals and nonmetals (B, Si, Ge, As)

* Electropositive: capable of giving valence
* electronegative: accept electrons

* Most of nonmetals are either gases or liquids, if it solid it's brittle

* Electronegativity ⇒ ↑ ⟶ تزيد

العناصر تكون أكثر قابلية لاكتساب الإلكترونات = عندما تكون طاقة الطاقة تحتها متساوية.

* Metals are prod at IIB to IIIB

* IVA (C, Si, Ge, Sn, Pb)

التوصيل الكهربائي يزداد بالنزول فيها

* (V, Nb, Ta)

درجة الانصهار تزداد بالنزول

* physical prop change in more or less manner

* Bonding forces and energies *

$F_N = F_{Attractive} + F_{Repulsion}$

$E = \int_{energy}^{r} F\,dr$ $\quad F = \frac{dE}{dr}$

$E_N = E_A + E_R$ bonding energy (the energy to seperate two atoms to an infinite).

Bond type depends on electronegativity and periodic position.

* number of properties depends on F, the curve shape and bonding type.
* Materials having large bonding energies have also high melting temp

* Mechanical stiffness (modulus of elasticity) depends on the shape of force

* The nature of the bond depends on electron structure

* The attractive bonding forces (Coulomic)

$$E_A = -\frac{A}{r^1} \quad \text{such that} \quad A = \frac{1}{4\pi\varepsilon_0}(Z_1 e)(Z_2 e)$$

electron charge

$\varepsilon_0 = 8.85\times10^{-12}$ F/m

* Repulsion energy

$$E_B = \frac{B}{r^n}$$

B and n are constants

K^+ , Br^-

$|+1| \cdot |-1| = e^2$

* Bonding energies range between 600 and 1500 kJ/mol

Ex The atomic radii of K^+ and Br^- are 0.138 and 0.196nm.

(a) Calculate the force of attraction and their equilibrium seperation.

Sol $F = \frac{dE_A}{dr} = \frac{d(-\frac{A}{r})}{dr} = \frac{A}{r^2} = \frac{1}{4\pi\varepsilon_0}\cdot\frac{(e)^2}{r^2}(Z_1 e)(Z_2 e) = 2.07\times10^{-8}$

$r_0 = r_{K^+} + r_{Br^-}$

$= 0.138 + 0.196 = 0.334\times10^{-9}$ m

Bonding Notes

- Secondary bonds are weak, but play a role in physical like, Surface tensions, Capillary action, Vapor pressure, Volatility and viscosity (تعتمد على قوة الترابط)
- Adhesives: Van der walls help surfaces stick together
- Surfactants: reduce surface tension (soaps).

- Emulsifiers : allow mixing liquids (milk and mayonnaise)
- Desiccants : absorb moisture (packaging)
- polymers : their mechanical prop depend on M

Mixed bonding (the degree of their bond type depend on difference in electronegativity) the close they are, the bigger bond

Percent of ionic energy in mixed

$$\%IC = \left(1 - e^{\frac{-(x_A - x_B)^2}{4}}\right) \times 100\%$$

x_A and x_B are electronegativity

M is found (B, Si, Ge, As, Sb, Te, At)

Ex: the %IC of a bond between A and B the electronegativity for C and are $X_C = 2.5$ and $X_H = 2.1$.

Sol

$$\%C = \left(1 - e^{\frac{-(2.5-2.1)^2}{4}}\right) \times 100 = 3.9\%$$

Thus that C–H covalent is 96.1%

Molecules

- a set of atoms like (F_2, O_2, H_2) have strong covalent bonds (H_2O, CO_2, CH_4)

these molecules have also van der Waals and hydrogen bonds.

- Molecules materials tend to have low melting and boiling points

لأن الجزيئات غير قطبية لذا تكون الروابط بينها ضعيفة والسبب يعود لأن covalent داخل كل جزيء ولكن الرابطة بين الجزيئات و melting يعتمد على الرابطة بين الجزيئات

Questions

1. What the difference between atomic mass and atomic weight:

atomic mass ⇒ mass of protons and neutrons

atomic weight ⇒ avg mass for all isotops

2. Silicon has three isotops 92.23% of ^{28}Si with 27.9769 amu, 4.68% of ^{29}Si with 28.9765 amu and 3.09% of ^{30}Si with 29.9738 amu. Find atomic weight.

$$\bar{A} = \frac{92.23}{100} * 27.9769 + \frac{4.68}{100} * 28.9765 + \frac{3.09}{100} * 29.9738$$

$$= 28.0853 \text{ amu}$$

3. Indium has two isotopes ^{113}In with 112.904 amu and ^{115}In with 114.904 amu If the avg atomic weight is 114.818 amu. Calculate the fraction of these isotopes.

$$x + y = 1 \Rightarrow x = 1 - y$$

$$114.818 = x(112.904) + y(114.904)$$

$$114.818 = 112.904 - 112.904y + 114.904y$$

$$1.914 = 2y \Rightarrow y = 0.957 = 95.7\%$$

$$x = 0.043 = 4.3\%$$

4. How many grams are there in one amu of a material?

$$1 \text{ amu} = 1.66 \times 10^{-24} \text{ grams}$$

5. How many atoms are there in pound-mole?

1 lbs = 453.592 g

$$453.592 * 6.022 \times 10^{23} = 2.73 \times 10^{26}$$

6. Cite two important quantum mechanical concepts with Bohr model?

Electrons have specific energy, they can't have random energy

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7) For K shell and L, M write the four quantum numbers for all:

	n	L	m_L	m_s		
K	1	0	0	$-\frac{1}{2}/\frac{1}{2}$	⇒ S	2 electrons
L	2	1	-1-1	$-\frac{1}{2}/\frac{1}{2}$	⇒ 2p / 2s	8 electrons
M	3	2	-2-2	$-\frac{1}{2}/\frac{1}{2}$	⇒ 3d / 3p / 3s	18 electrons

8) Give the electron configurations :-

P_{15}^{+5} : $1s^2\ 2s^2\ 2p^6$

P_{15}^{3-} : $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$

Sn_{50}^{4+} : $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^6\ 5s^2\ 4d^{10}$

I_{53}^{-} : $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^6\ 5s^2\ 4d^{10}\ 5p^6$

Ni_{28}^{+2} : $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^8$ (حذف إلكترونين)

He 2
Ne 10
Ar 18
Kr 36

9) To what group atomic number 112 belong?

$7s^2\ 5f^{14}\ 6d^{10}$ (آخر مدار)

10 + 2 = 12 المجموعة

10) Determine whether it is inert gas, helogen, alkali metal, earth metal or transition.

(a) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^5$ ⇒ 5+2=7 Helogen $(ns^2\ np^5)$

(b) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^7\ 4s^2$ ⇒ 2+7=9 transition d

(c) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}\ 4s^2\ 4p^6$ ⇒ 6+2=8 inert gas

(d) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^1$ ⇒ 1 Alkali metal (ns^1)

(e) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4d^{10}\ 4s^2\ 4p^6\ 4d^5\ 5s^2$ ⇒ 2+5=7 transition

(f) $1s^2\ 2p^6\ 3s^2$ ⇒ 2 earth metal (ns^2) ($2s^2$)

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11) What electron subshell is being filled for the rare earth series?
4f

12) " " " " " " for actinide series? 5f

13) Calculate the force of attraction between Ca^{+2} and O^{-2} whose centered seperated by 1.25nm.

$$F = k\frac{q_1 q_2}{r^2} = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q_1 q_2}{(1.25\times10^{-9})^2} = \frac{8.9\times10^{9}\times 4\times(1.6\times10^{-19})^2}{(1.25\times10^{-9})^2} = 5.91\times10^{-10}$$

$8.9\times10^{9} \leftarrow \frac{1}{4\pi\varepsilon_0}$, $(2e)(2e)$

14) The atomic radii of Mg^{+2} and F^{-} ions are 0.072 and 0.133nm.

(a) Calculate the force of attraction between these two ions at their equilibrium.

or use $F = \frac{A}{r^2}$.

$$F = k\frac{q_1 q_2}{r^2} \Rightarrow 8.9\times10^{9}\times\frac{(2e)(e)}{(0.072+0.133)^2} = 10.858\times10^{-9}\ N$$

(b) What is the force of repulsion at this same seperation distance?

$F = -10.858\times10^{-9}\ N$ على اعتبار ان
دائما بياورا السبز

15) The force of attraction between divalent cation and divalent anion is 1.67×10^{-8}. If the ionic radius of cation is 0.08nm, what is the anion radius?

$2e \rightarrow 4e^2$

$$F = \frac{kq_1q_2}{r^2} \Rightarrow 1.67\times10^{-8} = \frac{8.9\times10^{9}\times 4\times(1.6\times10^{-19})^2}{(0.08\times10^{-9}+X)^2}$$

$$(0.08\times10^{-9}+x) = \sqrt{\frac{9.1136\times10^{-28}}{1.67\times10^{-8}}}$$

$$(0.08\times10^{-9}+x) = 2.336\times10^{-10}$$

$$X = 1.53\times10^{-10}\ m$$

$$= 0.153\ nm$$

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قانون جديد :-

$$r_o = \left(\frac{A}{nB}\right)^{1/(1-n)}$$

حيث $n = 8$ حسب السؤال

16] For an $Na^+ - Cl^-$ $E_A = \frac{-1.436}{r}$ and $E_B = \frac{7.32 \times 10^{-6}}{r^8}$ Find r_o and E_o.

Sol

$$r_o = \left(\frac{-1.436}{8 \times 7.32 \times 10^{-6}}\right)^{1/7} = 0.279\,nm$$

$$E_o = \frac{-1.436}{0.279 \times 10^{-9}} + \frac{7.32 \times 10^{-6}}{(0.279 \times 10^{-9})^8} = -4.57\,eV$$

17] $E_o = \frac{C}{r_o}\left(\frac{P}{r_o} - 1\right)$ bonding energy

18] Explain why hydrogyn Fluoride (HF) has a higher boiling temperature than (HCl) (19.4 C° vs 85°C) even though HF has a lower molecular weight.

HF contains F which is highly electronegativity so stronger hydrogyn bond. (hydrogyn, Vanderwaals)

19] Compute %IC for each MgO, GaP, CsF and FeO.

$$\%IC = \left(1 - e^{\frac{-(X_A - X_B)^2}{4}}\right) * 100\%$$

$MgO \Rightarrow \left(1 - e^{\frac{-(3.44-1.31)^2}{4}}\right) * 100\% = 68\%$

$GaP \Rightarrow 5\%$

$CsF \Rightarrow 92\%$

$FeO \Rightarrow 58\%$

[20] Calculated the %C for Al6Mn. then decide what is the bond?

%C = 0.25%

Covalent أو ionic

Metallic بالتالي الرابطة

[21] What type of bonding would you expect for CaF_2, bronze, CdTe and Tungesten?

CaF_2 ⇒ ionic

bronze ⇒ Metallic

CdTe ⇒ ionic with covalent

Tungesten ⇒ Metallic

Rubber ⇒ Covalent + Van der waals

[22] What type of bonding would be expected for (copper-zinc alloy)?

CuZn both are metals then it is metallic

Note: ~~المجموعة الأولى والثانية والعناصر الانتقالية~~ metals هي

nonmetals O, N, C, S, Cl هي الباقي

[23] The chemical composition of nylon 6.6 is given by $C_{12}H_{22}N_2O_2$. Atomic weight for each one is $A_C = 12$, $A_H = 1$, $A_N = 14$ and $A_O = 16$. Find the percentage by weight of Carbon.

$12 \times 12 + 22 + 14 \times 2 + 2 \times 16 = 226$

$$\%C = \frac{144}{226} \times 100\% = 63.7\%$$

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Chapter (3)

- properties of crystalline solids depend on the crystal structure.
- Solid sphere hewings well defined diameters.
- lattice means three dimensional arrays of point coinciding with atom position.
- Unit cell chosen to represent symmetry of crystal structure.
- Parallelpiped corners coincide with centers of the hard sphere atom.
- each sphere represents an ion core.
- How to know number of atoms in cubic (FCC, BCC, SC)

$$N = N_{i_{center}} + \frac{N_{face}}{2} + \frac{N_{corner}}{8}$$

ex FCC $N = 0 + \frac{6}{2} + \frac{8}{8} = 4$ atoms

- $APF = \frac{V_s}{V_c}$ = Volume of atoms in unit cell (sphere) $\frac{4}{3}\pi r^3$ / total unit cell volume
- Because CN for BCC is less than FCC, APF is also lower
- atoms situated only at corners of a cube is called simple cubic (S.C.)
- How to know number of atoms in hexagonal :-

$$N = N_i + \frac{N_f}{2} + \frac{N_c}{6}$$

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FCC ⇒ {111}

BCC ⇒ {110}

HCP ⇒ {0001}

Ex Calculate the volume of FCC in terms of R.

$$V_c = a^3 = (2R\sqrt{2})^3 = 16R^3\sqrt{2}$$

Ex Show that APF for FCC is 0.74.

$$V_s = (4)\frac{4}{3}\pi R^3 = \frac{16}{3}\pi R^3$$

$$V_c = 16R^3\sqrt{2}$$

$$APF = 0.74 \#$$

Ex What is the coordination number for SC and APF for SC?

$$N = N_i + \frac{N_f}{2} + \frac{N_c}{8} = 0 + 0 + \frac{8}{8} = 1 \text{ atom}$$

$$APF = \frac{\frac{4}{3}\pi R^3}{16R^3\sqrt{2}} = 0.185$$

Ex Copper has an atomic radius of 0.128nm, an FCC structure and an atomic weight 63.5 g/mol. Compute density.

$$\rho = \frac{nA}{N_A V_c} = \frac{4 * 63.5}{6.022\times10^{23} \times 16\sqrt{2}(0.128)^3} = 8.89 \text{ g/cm}^3$$

* Metals as well as nonmetals may have more than one structure.

* Crystal structure depends on temperature and external pressure.

* The unit cell has six parameters < three lengths a, b and c / three angles α, β and γ and they called the lattice parameter.

* There are seven different combinations of them each called (Crystal system) → cubic, tetragonal ($a=b\neq c$ $\alpha=90°$), hexagonal, triclinic

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✱ Cubic system has the greatest degree of symmetry.

$a = b = c$, $\alpha = \beta = \gamma = 90°$

the least one is triclinic.

✱ What is the difference between crystal system and crystal structure?

Crystal system describes the geometry of the unit cell, crystal structure includes both geometry and the atomic arrangement.

✱ Crystal structure are most often described in terms of unit cell, which are normally more complex than those for FCC, BCC and HCP

✱ Cubic $a = b = c$ $\alpha = \beta = \gamma = 90°$

hexagonal $a = b \neq c$ $\alpha = \beta = \gamma = 120°$

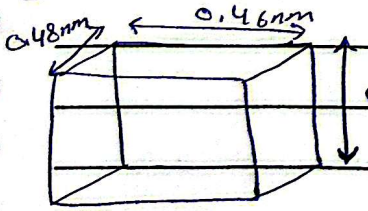
✱ Point Coordinates :-

q.a ⇒ to the x axis

r.b ⇒ to the y axis

s.c ⇒ to the z axis.

Ex For the unit cell shown, locate the point having coordinates $\left(\frac{1}{4}\ 1\ \frac{1}{2}\right)$.



(q) a ⇒ $\frac{1}{4} \times 0.48nm = 0.12nm$

(r) b ⇒ $1 \times 0.46\ nm = 0.46nm$

(s) c ⇒ $\frac{1}{2} \times 0.4\ nm = 0.2nm$

Cubic

✱ Crystallographic direction is defined as a line directed two points.

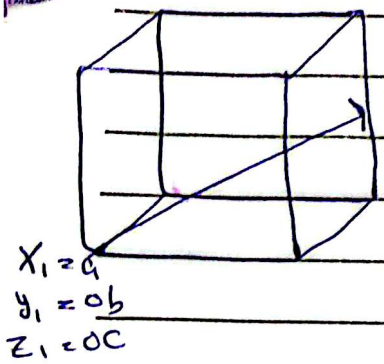
↳ If you have two points, then you can find [u v w] direction.

$u = n\left(\frac{x_2 - x_1}{a}\right)$, $v = n\left(\frac{y_2 - y_1}{b}\right)$, $w = n\left(\frac{z_2 - z_1}{c}\right)$

lab. ↙

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Ex Determine the indices for the direction shown.



Sol $u = 2\left(\frac{-a}{a}\right) = -2$

$V = 2\left(\frac{b}{b}\right) = 2$

$w = 2\left(\frac{c/2}{c}\right) = 1$

$[\bar{2}\ 2\ 1]$

* Family of direction $\langle\ \rangle$

There is a special case $\langle 100 \rangle$ is a special case

تضم جميع الاتجاهات التي يتشابه ذرتها كما المثال الآخر

* Directions in Hexagonal :- HCP

① $u = \frac{1}{3}(2u - v)$

$V = \frac{1}{3}(2v - u)$

$t = -(u+v)$

$w = w$

يستخدم للتحويل من $[uvw]$ إلى $[uvtw]$

② $u = 3n\left(\frac{a_1' - a_1''}{a}\right)$ ← axis

$V = 3n\left(\frac{a_2' - a_2''}{a}\right)$

$t = 3n\left(\frac{a_3' - a_3''}{a}\right)$

$w = 3n\left(\frac{z' - z''}{c}\right)$

head − tail

يستخدم لمعرفة $[uvtw]$

a_1' عندما يعطي المحاور

a_2'

a_3'

z

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fcc

Ex Convert [111] into four index.

$u = \frac{1}{3}(2u - v) = \frac{1}{3}$

$v = \frac{1}{3}(2v - u) = \frac{1}{3}$

$t = -(u+v) = -\frac{2}{3}$

$w = 1$

Ex Determine four index system that is shown. p.102 of text

$u = n\left(\frac{a_1 - a'_1}{a}\right) = 2\left(\frac{0a - 0a}{a}\right) = 0$

$v = 2\left(\frac{-a - 0a}{a}\right) = -2$

$w = 2\left(\frac{c/2 - 0}{c}\right) = 1$

To find [uvtw]

$u = \frac{1}{3}(2u - v) = \frac{2}{3}$

$v = -\frac{u}{3}$

$t = \frac{2}{3}$

$w = 1$

* Crystallographic planes (hkl) Miller indices

$h = \frac{na}{A}$, $k = \frac{nb}{B}$, $l = \frac{nc}{C}$

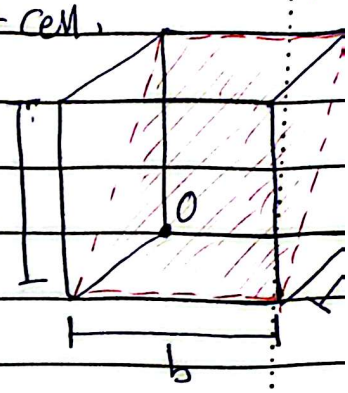
Ex p.105

Q/ Construct a (101) plane within the following unit cell.

$h = 1 \Rightarrow A = \frac{na}{h} = a$

$k = 0 \Rightarrow B = \infty b$

$L = 1 \Rightarrow C = c$



* Atomic arrangements depends on crystal structure.

* We have (hkil) and $(i = -(h+k))$ If M is hexagonal
→ ex p. 108

* Linear and planer densities are important to the process of slip.

* most denesly packed have greatest atomic packing.

* planes having a maximum atom or sphere packing density

مهم * عدد الذرات (LD)

FCC [110] ⇒ 1 ✓
FCC [100] ⇒ 1 ✓
FCC [111] ⇒ 1 ✓

BCC [110] ⇒ 1 ✓
BCC [100] ⇒ 1
BCC [111] ⇒ 1 ✓

لإيجاد a بدلالة R

FCC ⇒ $a = 2\sqrt{2}R$ or $a \Rightarrow a^2$ [100]

$2R\sqrt{2}$

BCC ⇒ $a_1 = \frac{\sqrt{3}}{4R\sqrt{2}}$

$a_1 = \frac{1}{2R}$

مهم * كثافة الذرات (PD)

FCC (100) ⇒ 2 ✓
FCC (110) ⇒ 2
FCC (111) ⇒ 2 ✓

مساحة السطح ⇒ a^2

$8R^2\sqrt{2} \Rightarrow \sqrt{2}a^2$

$\frac{\sqrt{3}}{2}a^2 = \frac{1}{2R^2\sqrt{3}}$

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المستوى FCC في (111) هو الأكثر كثافة ذرية

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BCC (100) ⇒ 1 ✓ $\frac{1}{a^2}$

BCC (110) ⇒ 2 ✓ $a^2\sqrt{2}$

BCC (111) ⇒ 3 ✓ $\frac{\sqrt{3}}{2}a^2$

$a = \frac{4R}{\sqrt{3}}$

HCP

(0001)

3 atoms

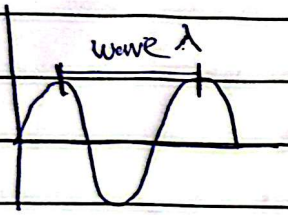
$6R^2\sqrt{3}$

FCC ⇒ 111 > 110 > 100

BCC ⇒ 110 > 100 > 111

X-Ray used to develop new materials.

Diffraction occurs when (1) wave encounters a series that are capable of scattering the wave (2) have spacings that are comparable in magnitude.



diffraction means when amplitudes are added the wave shown.

Other phase relationship are possible between scattered waves that will not lead to this mutual reinforcement.

For cubic crystals, as values of planer indices h, k and l increase does the distance between adjacent and parallel planes increase?

$d = \frac{a}{\sqrt{h^2+k^2+l^2}}$ ↑ decrease

What is the experiment?

— Main Components —

- X-ray source toward the sample
- Crystaline sample (polycrystaline)
- Detector (counter) Measures X-ray reflected
- angle θ between incident beam and reflected beam

— What do we Gain??

- analyzing diffraction we identify crystal structure, Calculate dimensions and unit cell dimensions.

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Questions

1] What is the difference between atomic structure and crystal structure?

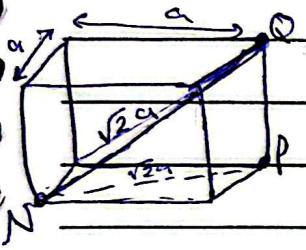
Atomic is about what's inside an atom (electron, proton, neutron)

Crystal structure is about geometry and atoms arrangments

2] If the atomic radius of lead is 0.175nm, Calculate the volume of it's unit cell in cubic meters.

Sol Lead ⇒ FCC $V_c = a^3 = 16\sqrt{2}R^3 = 16\sqrt{2}(0.175 \times 10^{-9})^3$

3] Show for the body-centered cubic crystal structure that the unit cell edge Length a, and the atomic radius R are related through $a = 4R/\sqrt{3}$.



$(NQ)^2 = a^2 + 2a^2 = 3a^2$

$(4R)^2 = 3a^2$

$a = \frac{4R}{\sqrt{3}}$

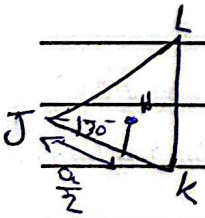
4] For HCP show that c/a is 1.633.



$JM = JK = 2R = a$

$(JM)^2 = (JH)^2 + (MH)^2$

$a^2 = (JH)^2 + (\frac{c}{2})^2$



$\cos 30 = \frac{a/2}{JH} = \frac{\sqrt{3}}{2}$

$JH = \frac{a}{\sqrt{3}}$

$a^2 = \frac{a^2}{3} + \frac{c^2}{4}$

$\frac{c}{a} = \sqrt{\frac{8}{3}} = 1.633$

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Lab

5 Show that the atomic packing factor for BCC is 0.68.

$$APF = \frac{V_s}{V_c} = \frac{\frac{4}{3}\pi r^3 (2)}{a^3} = \frac{\frac{8}{3}\pi r^3}{(4R/\sqrt{3})^3} = \frac{\frac{8}{3}\pi}{64/3\sqrt{3}} = 0.68$$

6 MO has a BCC, an atomic radius of 0.1363 nm and an atomic weight of 95.94 g/mol. Compute and compare its density with the experimental value found inside the front cover of the book.

$$\rho = \frac{nA}{N_A \times V_c} = \frac{2 \times 95.94}{6.022\times10^{23} \times (4(0.1363)/\sqrt{3})^3} = 1.02\times10^{-20} = 10.2\ g/cm^3$$

7 Sr has FCC, an atomic radius of 0.215 nm, and an atomic weight of 87.62 g/mol. Calculate the density.

$$\rho = \frac{4 \times 87.62}{6.022\times10^{23} \times (2\sqrt{2}(0.215\times10^{-9})^3}$$

$$m = \frac{4 \times 87.62}{6.022\times10^{23}} = 5.81\times10^{-22}$$

$$V = a^3 = (2\sqrt{2}(0.215\times10^{-9}))^3 = 2.24\times10^{-22}$$

$$\rho = \frac{m}{V} = \frac{5.81\times10^{-22}}{2.24\times10^{-22}} = 2.58\ g/cm^3$$

8 Calculate the radius of Pd atom given that Pd has an FCC structure, a density 12 g/cm^3, and an atomic weight of 106.4 g/mol.

$$12 = \frac{4 \times 106.4}{6.022\times10^{23}(2\sqrt{2}R)^3} \Rightarrow 1.69\times10^{22} = \frac{1}{16\sqrt{2}R^3}$$

$$3.84\times10^{23} = \frac{1}{R^3} \Rightarrow R = 1.37\times10^{-8} = 0.137\ nm$$

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Simple crystal $a = 2R$

HCP $\Rightarrow V_c = 6R^2 c\sqrt{3}$ $\quad R = \frac{a}{2} \Rightarrow a = 2R$

9) Calculate the radius of (Cr) given that it is BCC, density 16.6 g/cm³, and an atomic weight of 180.9 g/mol.

$$16.6 = \frac{180.9 \times 2}{6.022\,(4R/\sqrt{3})^3} \Rightarrow 2.76\times10^{22} = \frac{1}{64R^3/3\sqrt{3}}$$

$$\frac{1}{R^3} = 3.40\times10^{23} \Rightarrow R = 0.1432\,nm$$

10) A hypothetical metal has the simple cubic structure. If it's atomic weight is 74.5 g/mol. and atomic radius is 0.145 nm compute it's density.

$$\rho = \frac{nA}{V_C N_A} = \frac{1 \times 74.5}{6.022\times10^{23}(2\times0.145\times10^{-9})^3} = \frac{1.23\times10^{-22}}{2.4389\times10^{-23}} = 5.04\ g/cm^3.$$

11) Ti has an HCP structure and a density of 4.51 g/cm³.

(a) What is the volume of it's unit cell in cubic meters?

$$A_{Ti} = 47.87 \Rightarrow 4.51 = \frac{6\times47.87}{6.022\times10^{23} V_c} \Rightarrow V_c = 1.05\times10^{-22}$$

(b) If the c/a ratio is 1.58 compute the value of c and a.

$$V_c = 6R^2 c\sqrt{3}$$

$$1.05\times10^{-22} = 6\left(\frac{a}{2}\right)^2 c\sqrt{3} = \frac{3\sqrt{3}\,a^2 c}{2}$$

$$1.05\times10^{-22} = \frac{3\sqrt{3}\,(1.58)a^3}{2} \Rightarrow a = 2.94\times10^{-8}$$

$$c = 4.59\times10^{-8}$$

12) Mg has an HCP and a density of 1.74 g/cm³.

(a) What is the volume?

$$1.74 = \frac{6\times24.305}{6.022\times10^{23} V_c} \Rightarrow V_c = 1.39\times10^{-22}$$

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(b) If c/a is 1.624 find a and c.

$$1.39\times10^{-22} = 6(a^2)c\sqrt{3}$$

[13] Nb has an atomic radius of 0.1430nm and a density of 8.57g/cm³. Determine whether it has an FCC or BCC.

FCC $\Rightarrow \rho = \frac{4 \times 92.906}{6.022\times10^{23} \times (2\sqrt{2} \times 0.1143\times10^{-9})^3} = \frac{6.172\times10^{-22}}{6.61\times10^{-22}} = 9.33\ g/cm^3$

BCC $\Rightarrow \rho = \frac{2 \times 92.906}{6.022\,(4(0.143\times10^{-9})/\sqrt{3})^3} = \frac{3.08\times10^{-22}}{3.601\times10^{-22}} = 8.57\ g/cm^3$

Then it has BCC structure.

[14] If A has an atomic weight of 43 n and density of 6.4g/cm³ it's atomic radius is 0.122 nm. Determine it's FCC, BCC or SC

FCC $\rho = \frac{4\times43.1}{6.022\times10^{23}(2\sqrt{2}\times0.122\times10^{-9})^3} = \frac{2.86\times10^{-22}}{4.1\times10^{-22}} = 6.9\ g/cm^3$

BCC $\rho = \frac{2\times43.1}{6.022\times10^{23}(4\times0.122/\sqrt{3})^3} = \frac{1.43\times10^{-22}}{2.28\times10^{-22}} = 6.41\ g/cm^3$

Then it has BCC

If B has atomic weight 184.4 and density 12.3g/cm³ it's radius is 0.146nm.

FCC $\rho = \frac{4\times184.4}{6.022\times10^{23}(2\sqrt{2}\,0.146\times10^{-9})^3} = \frac{1.22\times10^{-21}}{7.04\times10^{-22}} = 17.3\ g/cm^3$

BCC $\rho = \frac{2\times184.4}{6.022\times10^{23}(4\times0.146\times10^{-9}/\sqrt{3})^3} = \frac{6.12\times10^{-22}}{3.83\times10^{-22}} = 15.9\ g/cm^3$

SC $\rho = \frac{184.4}{6.022\times10^{23}(2\times0.146\times10^{-9})^3} = \frac{3.06\times10^{-22}}{2.48\times10^{-22}} = 12.3\ g/cm^3$

Then it is SC

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15] The unit cell for (V) has symmetry with a cubic & C lattice parameters of 0.286, 0.587 and 0.495 nm. If it's density, atomic weight and atomic radius are 19.05 g/cm³, 238.03 g/mol and 0.1385 nm. Compute the atomic packing factor.

$$APF = \frac{V_S}{V_C}$$

$$19.05 = \frac{n \times 238.03}{6.022\times10^{23} \times (0.286\times0.587\times0.495)\times10^{-9}} \Rightarrow \boxed{n = 4 \text{ atoms}}$$

$$APF = \frac{4 \times \frac{4}{3}\pi (0.1385\times10^{-9})^3}{(0.286\times0.587\times0.495\times10^{-27})} = 0.5355.$$

$(0.286\times0.587\times0.495\times10^{-27}) \rightarrow 8.3\times10^{-23}$

16] Be has an HCP unit cell for which c/a is 1.568. If the radius is 0.143 nm.

(a) Determine the the unit cell volume:-

$$V_C = \sqrt{3}\,6R^2c \qquad \boxed{a = 2R}$$

$$V_C = 6\sqrt{3}\left(\frac{a^3}{4}\right)(1.568) = 4.87\times10^{-23} \text{ cm}^3/\text{unit cell}$$

(b) Calculate the density of Be.

$$\rho = \frac{nA}{N_A V_C} = \frac{6 \times 9.01}{6.022\times10^{23}(4.87\times10^{-23})} = 1.849 \text{ g/cm}^3$$

17] Co has an HCP crystal, an atomic radius of 0.1253 nm and a c/a ratio of 1.623. Compute the volume.

$$V_C = 6\sqrt{3}R^2c \qquad a = 2R$$
$$c = a(1.623)$$
$$= 6\sqrt{3} \times 2R^3(1.623)$$
$$= 6.63\times10^{-29}$$

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18] Iron upon heating transformation from BCC to FCC. $R_{BCC} = 0.12584\ nm$ to $R_{FCC} = 0.12894\ nm$ and A in addition change in density and volume. Compute the change in volume.

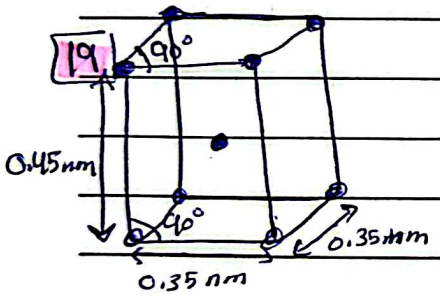
R_{BCC} $\rho = \frac{nA}{N_A V_c} = \frac{2 \times 55.85}{6.022 \times 10^{23} V_c}$ $a = 4R/\sqrt{3}$

$= 7.55\ g/cm^3$

R_{FCC} $\rho = \frac{4 \times 55.85}{6.022 \times 10^{23} (2\sqrt{2}R)^3} = 7.64 \times 10^{24}\ g/cm^3$

$\rho_{FCC} > \rho_{BCC}$

$V_{BCC} > V_{FCC}$

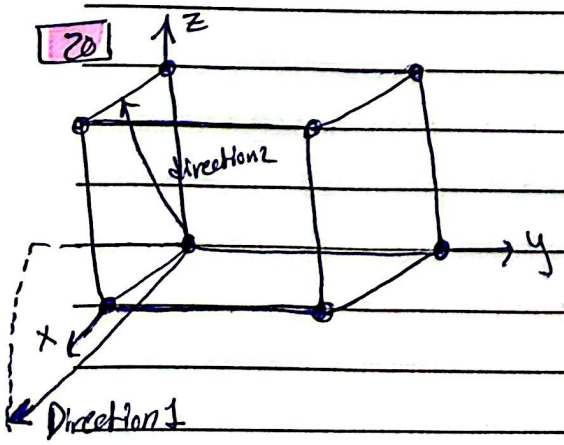
19] 

(a) To which crystal system does this unit cell belong? tetragonal

(b) To which crystal structure does belong? BCC

(c) Compute density? (weight 141 g/mol)

$\rho = \frac{2 \times 141}{6.022 \times 10^{23} \times (0.35)^2 (0.45)}$

20] 

	x	y	z	
direction 1 ⇒	1	-0.5	-1	⇒ $[2\bar{1}\bar{2}]$
	x	y	z	
direction 2 ⇒	0.5	0	1	⇒ $[102]$

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[2] What are the direction indices for a vector that passes from point $\frac{1}{4}\ 0\ \frac{1}{2}$ to point $\frac{3}{4}\ \frac{1}{2}\ \frac{1}{2}$ in a cubic unit cell?

$\frac{3}{4} - \frac{1}{4} = \frac{2}{4} = \frac{1}{2}$

$\frac{1}{2} - 0 = \frac{1}{2}$

$\frac{1}{2} - \frac{1}{2} = 0$

$[110]$

[2] For tetragonal crystals, cite indices of directions that are equivalent to each of the following:-

(a) $[011]$ (b) $[100]$

~~Sol Tetragonal~~ $a = b \neq c$

Sol $[0\bar{1}0]$

$[010]$

$[0\bar{1}\bar{1}]$

$[\bar{1}0\bar{1}]$

$[10\bar{1}]$

$[0\bar{1}1]$

$[\bar{1}01]$

[3] Convert $[110]$ and $[00\bar{1}]$ into four index.

~~$u = \frac{1}{3}(2-1) = \frac{1}{3}$~~

$V = \frac{1}{3}(2-1) = \frac{1}{3}$

$t = -(\frac{2}{3})$

$w = 0$

$[11\bar{2}0]$

$[00\bar{1}]$ $u = 0$

$V = 0$

$t = 0$

$w = \bar{1}$

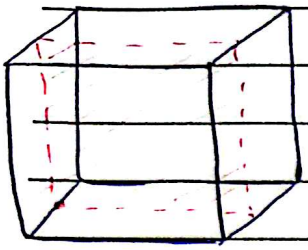
$[000\bar{1}]$

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Planes
يعني اقلب

24 Draw a plane with (200)

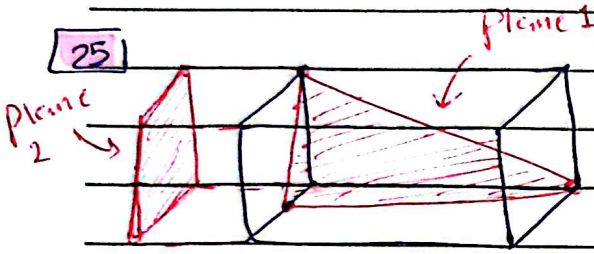


$a = \frac{1}{2}$

$b = \infty$

$c = \infty$

25

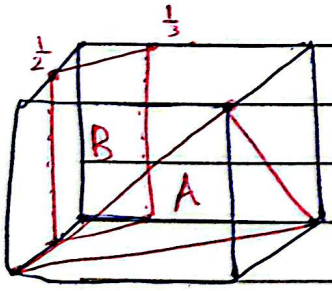


Find indeces for each plane?

Plane 1 ⇒ $a = \frac{1}{2} = 2$, $b = 1$, $c = 1$ (211)

Plane 2 ⇒ $a = \infty = 0$, $b = -0.5 = -2$, $c = \infty = 0$ ($0\bar{2}0$)

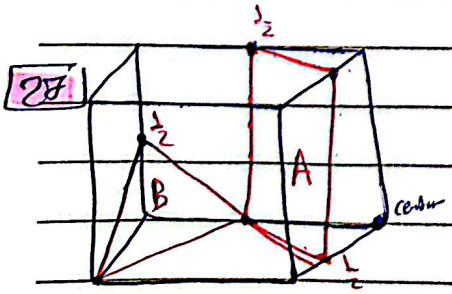
26 Determine the Miller indices for the planes shown:-



A ⇒ 1, 1, $\bar{1}$ ($11\bar{1}$)

B ⇒ $\frac{1}{2} = 2$, $\frac{1}{3} = 3$, 0 (230)

27



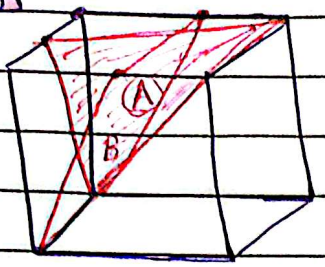
في الصورة في أسهل تخرج

A ⇒ $\frac{1}{2}$ ⇒ 2, $-\frac{1}{2}$ ⇒ $\bar{2}$, 0 ($2\bar{2}0$) or ($1\bar{1}0$)

B ⇒ 1, $\frac{1}{2} = 2$, 1 = 2 (122)

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28 Centred



غير المركز لأنه يعرف

الخلية A ⇒ $\frac{1}{2}$ = 2

1 (2 1 $\bar{1}$)

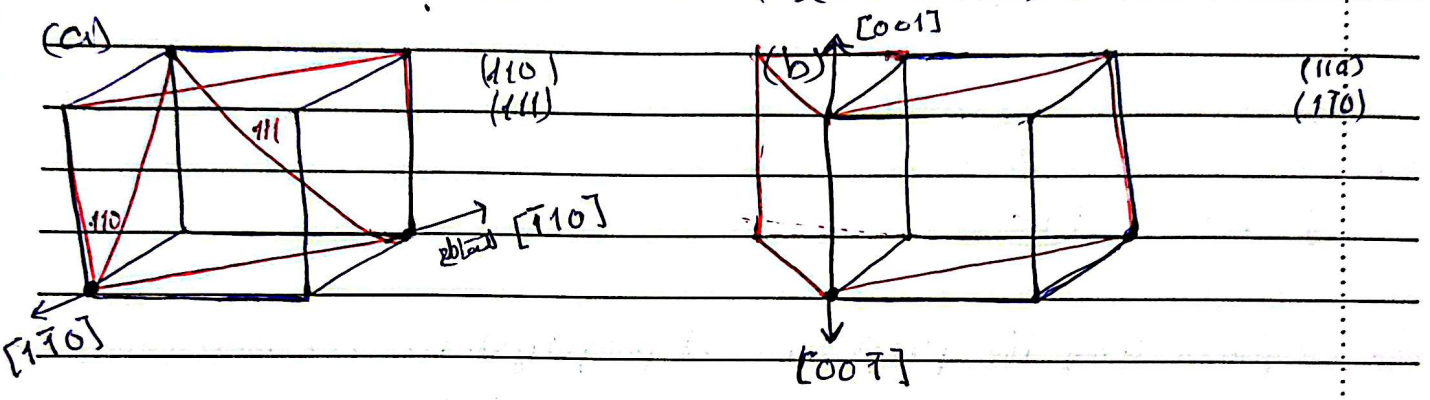
-1

غير المركز B ⇒ ∞ = 0

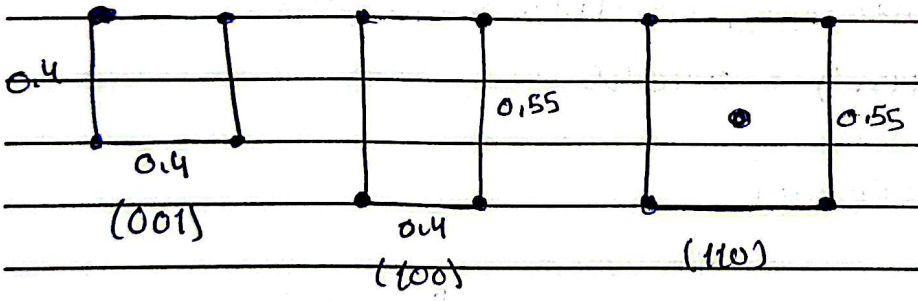
$\frac{1}{2}$ = 2 (0 2 $\bar{1}$)

-1

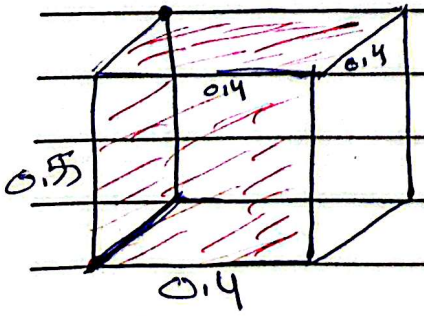
29 Draw the intersection between (a) (110) and (111) (b) (110) and (1 $\bar{1}$ 0)



30 Three different planes as shown.



(a) To what crystal system does the unit system belong?



a = b ≠ c tetragonal

with BCC structure.

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planes

31 Convert the (111) and (0$\bar{1}$2) to Four indices.

h = 1
k = 1 $\quad i = -(k+h) = -2$
L = 1

(1121)

h = 0
k = $\bar{1}$ $\quad i = -(-1+0) = \bar{1}$
L = 2

(01$\bar{1}$2)

32 3.56
p. 130

33 Explain why the properties of polycrystalline are most often isotropic? If the grain have random orientations - - -

34 Al, compute the interplanar for (110) set of planes.

$a = 2\sqrt{2}R = 2\sqrt{2}(0.1431) = 0.4045\,nm$

$d = \frac{a}{\sqrt{h^2+k^2+l^2}} = 0.2860\,nm$

35 Determine the expected diffraction angle from (111) set for FCC(Ni) when the radius is 0.1937nm.

$a = 2\sqrt{2}R = 0.3524\,nm$

$d = \frac{a}{\sqrt{h^2+k^2+l^2}} = 0.2035\,nm$

$d = \frac{n\lambda}{\sin\theta} \Rightarrow \sin\theta = \frac{n\lambda}{d} = 0.476$

$\sin^{-1}(0.476) = 28.42°$

$2\theta = 56.84°$

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FCC ⇒ Peaks are (111) (200) (220)

BCC ⇒ Peaks are (110) (200) (211)

36) For which set of crystallographic planes will a first order diffraction peak at angle 44.53° for FCC (Ni), radius 0.1542nm?

$$d = \frac{n\lambda}{\sin\theta} = \frac{1 \times 0.1542 \times 10^{-9}}{\sin(22.27)} = 0.2035\,nm$$

$$\frac{a}{d_{hkl}} = \sqrt{h^2+k^2+l^2} \Rightarrow \frac{2\sqrt{2}R}{0.2035} = (1.73)^2 = \boxed{3}$$

37) Would you expect a material in which the atomic bonding is ionic in nature to be more or less likely to form a noncrystalline than covalent? ionic are less likely because covalent are directional

(LD) لـ

	[100]	[110]	[111]
FCC (LD)	$\frac{1}{2\sqrt{2}R}$	$\frac{1}{2R}$	$\frac{1}{2\sqrt{6}R}$
BCC (LD)	$\frac{\sqrt{3}}{4R}$	$\frac{\sqrt{3}}{4\sqrt{2}R}$	$\frac{1}{2R}$

(PD) لـ

	[100]	[110]	[111]
FCC (PD)	$\frac{1}{4R^2}$	$\frac{1}{8\sqrt{2}R^2}$	$\frac{1}{2R^2\sqrt{3}}$
BCC (PD)	$\frac{3}{16R^2}$	$\frac{3}{16\sqrt{2}R^2}$	$\frac{\sqrt{3}}{16R^2}$

HCP (0001) ⇒ $\frac{3}{6R^2\sqrt{3}}$

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Chapter (4).

Imperfections in solides :- (made according to geometry of defects)

1. Point defects (associated with one or two atomic positions)
2. Dislocations
3. Interfacial defedets
4. Bulk / Volume.

(1) Vacancy : the simplest of the point (atom is missing) by thermodynamics

$$N_v = N \exp\left(\frac{-Q_v}{kT}\right)$$

(Q_v ← energy; N ← atomic sites; k = 1.38×10^{-23} J/atom or 8.62×10^{-5} eV/atom; T → should be in kelvins + 273°)

(2) Self interstitial : an atom from the crystal that is crowded into an interstitial site (larger than the interstitial position) It is not common (exists in very small consentrations)

Ex. Calculate the equilibrium number of vacancies at 1000°C. The energy for vacancy formation is 0.9 eV/atom. the atomic weight and density for copper are 63.5 g/mol and 8.4 g/cm³ respectively.

Sol

$$N_v = N e^{\left(\frac{-Q_v}{kT}\right)}$$

$$\rho = \frac{N_A}{N_A V_c} \Rightarrow \frac{\rho \cdot N_A \cdot V_c}{A} = N$$

$$N = \frac{8.4 \times 6.022\times10^{23} \times 10^6}{63.5} = 8\times10^{28}$$

$$N_v = 8 e^{\left(\frac{-0.9}{8.62\times10^{-5}\times1273}\right)} = 2.18\times10^{25}$$

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(3) Impurities (one type of atom (foreign))

Alloys are used in metals to improve mechanical strength and corrision

→ solute

Solvent (greatest amount)

homogenous solution ⇒ the impurity atoms are randomly and uniformly dispersed within the solid.

- Impurities are found as: 1) Substitutional, 2) Interstitial

1) Substitutional (foreign atom replace the host atom) rules:-

- difference in radius should be less than ±15%. (Atomic size factor)
- Crystal structure must be the same
- Electronegativity factor.
- Valences (التكافؤ)

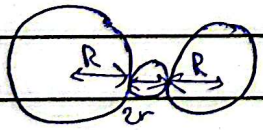
ex. Cu in Ni

2) Interstitial:- (foreign atom smaller than the host atoms)

the maximum concentration ≤ 10%

ex. C in Fe.

ex. Compute the radius of an impurity atom that just fits into a BCC site in terms of the atomic radius R of the host atom.



$$\text{unit cell edge length} = 2R + 2r = \frac{4R}{\sqrt{3}}$$

$$2r = \frac{4R}{\sqrt{3}} - 2R \Rightarrow \left(\frac{2}{\sqrt{3}} - 1\right)(2R)$$

$$r = 0.155R$$

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* Is it possibe for three or more elements to form a solid solution?
Yes it is possible provided that they satisfy the four rules.

* Explain why complete solid solubility may occur for substitutionals not for interstitial?
Interstitial are smaller than the host..

* How point defects affect prop:-
- Mechanical ⟹ Increase material hardness
- Electrical ⟹ enhance conductivity
- Diffusion ⟹ increases diffusion rate
- density ⟹ Decreases with increasing number of defects.

* Compositions (Concentrations) Wt%, at%

[1] weight percent

$$C_1 = \frac{m_1}{m_1 + m_2} \times 100\%$$

(الموضوع السابق)

[2] atom percent

$$n = \frac{m}{A} \quad \text{(atomic weight)}$$

$$C = \frac{n_1}{n_2 + n_1} \times 100\%$$

[3] Conversions (wt% ⟷ at%)

إذا عندك نسبة وبدك ذرية

$$C'_1 = \frac{C_1 A_2}{C_1 A_2 + C_2 A_1} \times 100\%$$

إذا عندك ذرية وبدك نسبة

$$C'_2 = \frac{C_2 A_1}{C_1 A_2 + C_2 A_1} \times 100\%$$

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4 Weight fraction ← Weight in detail

$$C_1 = \left(\frac{\frac{C_1}{\rho_2}}{\frac{C_1}{\rho_2} + \frac{C_2}{\rho_2}} \right) \times 10^3$$

5 Weight percent ← ρ avg

$$\rho_{avg} = \frac{100}{\frac{C_1}{\rho_1} + \frac{C_2}{\rho_2}}$$

6 atom percent ← ρ avg

$$\rho_{avg} = \frac{C_1' A_1 + C_2' A_2}{\frac{C_1' A_1}{\rho_1} + \frac{C_2' A_2}{\rho_2}}$$

7 Atomic weight

$$A_{avg} = \frac{100}{\frac{C_1}{A_1} + \frac{C_2}{A_2}} \quad , \quad A_{avg} = \frac{C_1' A_1 + C_2' A_2}{100}$$

Ex Determine the composition in atom percent of an alloy that consists of 97 wt% Al and 3 wt% copper.

$$C_{Al} = \frac{(97)(63.55)}{(97)(63.55) + 3(26.98)} = 98.7 \text{ at\%}$$

$$C_{Cu} = \frac{(3)(26.98)}{3(26.98) + (97)(63.55)} = 1.30 \text{ at\%}$$

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(الموضوع التالي)

[2] Dislocations :- Is a linear or one dimensional defect around where some of the atoms are misaligned — edge, screw, mixed

edge : linear defect that centers on the line that is defined along the end of the extra half plane of atoms causes dislocation line is perpendicular to the page. (The magnitude decrease with distance) (1) Burgers Vector
effects : atoms above (squeezed together)
atoms below (pulled apart)
reduced the slight curvature

Screw : formed by Shear Stress.
upper front region of the crystal is shifted one atomic distance to the right (C) is parallel Burger vector

Mixed : combination of edge and screw (neither parallel nor perpendicular)

Burger Vector : is the magnitude and direction of the lattice distortion, is the same for all points along it's lines
(TEM)
- Solidifications during phase deformation as a consequence of thermal and stresses that results from rapid cooling.

(الموضوع الرابع)

[3] Interfacial :- two dimensions and separate regions of materials that have different crystal structure. — external grain boundaries, phase boundaries, twin, Stacking

- External Surfaces : Which the crystal structure terminates.
Surface atoms are not bonded to the maximum number of nearest neighbors
energy (J/m^2 or erg/cm^2)
try to reduce energy
liquids have spherical area but it is not possible for solids.

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- grain boundaries : separating two small grains or crystals having different orientations in polycrystalline.
* Atoms at grain boundaries are less regularly bounded, leading to higher energy than inside.
* The degree of misorientation between grains affects the energy :-
  Small angle → lower energy
* effects on material prop :-
  - Strengthening : impede dislocation motion, making it stronger.
  - Diffusion : faster diffusion
  - Segregation : reduce energy
  - Grain size : smaller grains → more boundaries → stronger

Fine grained have more grains than Coarse

grain growth at temperature grain boundary reduce

- Phase : exist in multiphase materials (each phase has it's own physical and chemical prop).
These play a key role in determining mechanical behavior of alloy and composites.
* found in materials with more than one phase
* each side has a different crystal structure.
* important in metal alloys. for strength, ductility..

- Twin : Symmetry defects (mirror).
* enhance mechanical prop.
* Common on stainless steel and brass
* Improve resistance
* types of twins :-
① mechanical twins (formed by shear stress) occurs with metals BCC and HCP
② Annealing twins (formed during thermal) occurs with FCC like brass and Stainless steel

* Crystallographic Nature is specific
* appears as straight parallel regions. //

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- Miscellaneous defects :-

① Stacking Sound in FCC is ABCABC.. ~
affects mechanical prop like ductility and strength

② Domain Walls found in ferromagnetic or ferrimagnetic
have high energy than other defects.

* The interfacial energy is greatest for external surfaces and least for domain walls.

* The surface energy of a single crystal depends on orientation. Does its surface energy increase or decrease with increasing in planer density?
Decrease. (atoms are more closely packed)

④ Bulk or Volume :- are three dimensional found in solids.
They include → Pores (empty spaces)
→ Cracks (splits)
→ foreign phases (unwanted)
→ Other phase (different structure)

* Usually happened during welding or sintering, affect mech prop.

* Atomic Vibrations (Atoms in solid Vibrate constantly)
- non uniform
- temperature depend
- Occurs at highly frequency (10^{13})
- have a small amplitude

- they influence:
melting and thermal conductivity, specific heat, diffusion

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(الموضوع السابع)

* Concepts of microscopy:- is essential for examining the structural elements and defects that affects prop.
- Some features are visible like grain shape and size, surface texture
- Microscopes are: optical / electron (Scanning)

* photomicrographs (Images captured)

(1) Optical: uses light.
* for opaque materials (metals, ceramics, poly) only surface observed
* reflection mode
* Image comes from differences in reflectivity. It is called Metallography
* Surface must be ground and polished, then it is etched with chemical
* photomicrographs shows grain constract
* When a polycrystalline etched grain boundaries becomes grooves because atoms are more chemically active than inside grains. these grooves appeares as dark lines.
* When examining two phase alloy a specific method is chosen this helps differentiate between the phases base on: reflectivity / Surface texture / Etching response.

(2) Electron microscopy:-
Why use it?? The max magnification of optical is ×2000 which is not enough

How it works? • uses electron beams (magnetic lenses)
• according to quantum mech fast moving electrons behave like waves
• The wavelength of electron $\propto \frac{1}{\text{velocity}}$
• When accelerated by high voltage (0.003nm) much shorter than light → higher resolution

- (TEM) transmission electron.
- electron beam passes through an ultra thin.
- differences in electron scattering
- because solids absorb electrons strongly it must be less than 0.1 μm
- The transmitted electrons are projected onto a fluorescent screen or film
- Magnifications up to 10^6 useful for dislocations and internal defects.

- (SEM) Scanning:
- using electron beam
- the reflected or back scattered electrons are controlled on CRT screen
- Surface features
- must be electrically conductive (non conductive require thin metallic coating)
- from x10 up to x50000

(3) Scanning probe (SPM): is used to examine surface features at atomic scale.

How it works??

- Sharp probe tip for scanning
- As the tip moves it experiences deflections measured using piezoelectric
- the result is highly detailed (temperature, fluid flow, topography)
- up to $x10^9$ better resolution than others
- Can operate in different environments (liquids, air, Vacuum)
- useful for nano, bio, semi

* Grain size determination:- (تحديد حجم الحبيبات)
* Grain size is an important factor for determining mech prop
* Two common techniques:-

1. Linear method:-
- set of straight test lines is drawn.
- Count the number of grain boundaries
- Measure the total length using $\bar{l} = \frac{L_T}{P_M}$ (L_T: total length; P_M: magnification; total intersection)

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2) Comparison method :-

- Compare the grain structure in photomicrograph with standard grain size charts
- These charts are calibrated at x100 magnification and linked to ASTM grain size number (G).

ASTM : American Society for testing and materials.

How it works ??

- A set of standard charts shows grain structure at x100
- each chart is grain-size number (G) from 1 to 10
- Compare and choose the most closely matches.

$$n = 2^{G-1}$$ (If $M = x100$)

n = number of grains

as G increases → grains get smaller →

n increase → more grains.

(If M is not 100)

$$n_M \left(\frac{100}{M}\right)^2 = 2^{G-1}$$

If ($\bar{\ell}$ in mm) $G = -6.64 \log \bar{\ell} - 3.29$

If ($\bar{\ell}$ in in) $G = -6.635 \log \bar{\ell} - 12.6$

* It helps to convert between visual grain and actual grain.

To Calculate magnification :-

$$M = \frac{\text{Measured Scale } (\mu)}{\text{actual length } (\mu)}$$

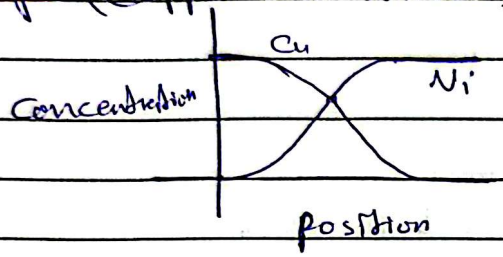
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Chapter (5)

* Diffusion: is the movement of atoms from a region with high concentration to low concentration.

* Why it is important?
- Controls heat treatment, electrical and phase transformation
- Affects mech prop and corrosion resistance.

* Example (Copper and Nickel) Each one migrate into the other.



* Interdiffusion (Impurity diffusion) ⇒ Occurs when atoms of one meter diffuse into another. ex Cu into Ni

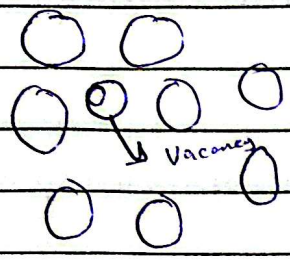
* Self - diffusion ⇒ Occurs within pure metal where atoms change position without composition (No concentration gradient) but atomic movement still happenes (Can be monitored using radioactivity)

* Diffusion mechanism :- diffusion is the step by step migration of atoms from one lattice site to another.

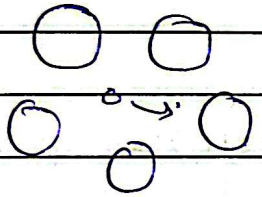
⇒ Conditions for atomic movement:
① There must be an empty site
② The atom must have enough energy to break bonds
This energy is vibrational and only a small fraction of atoms have it.

Types of Diffusion:-

[1] Vacancy: atom moves from it's normal position to a vacant sites
- atom and vacancy exchange positions.
- applies to both self-diffusion and interdiffusion.



[2] Interstitial diffusion: atom moves from one interstitial to another.
- Common for small impurity atoms like (H C N)
- Faster than Vacancy because atoms are smaller and interstitial sites are more than vacancy



- Host atoms or substitutional impurities rarely use this mechanism. because they are too large to fit between lattice atoms.

- It is important in metal alloys.

Fick's First law (steady-state) where the rate is constant.

$$J = \frac{M}{At}$$

J: diffusion flux the amount of material passing through a unit area.

M: total mass

A: area

t: time

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$J = -D \frac{dc}{dx}$ ⇒ concentration gradient (change in concentration over distance) $\frac{\Delta C}{\Delta x}$

Concentration from high to low

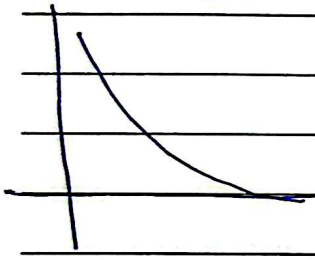
* $\frac{\Delta C}{\Delta x}$ gives constant flux because the gradient is uniform (slope)

* Driving force is what causes atoms to move. (Concentration gradient)

* $D = 3 \times 10^{-11}\ m^2/s$,

* Fick's second law:-

$$\frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial x^2}$$ — over time concentration become more uniform,



— Semi-infinite : It's such that species doesn't reach the far end during the process

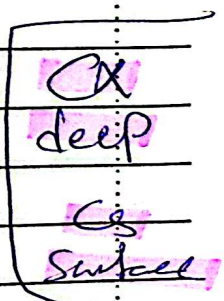
* ① at $t = 0$ (initial), concentration is uniform $C = C_0$ قيمة ثابتة

② at $x = 0$, concentration is held constant $C = C_s$ ثابتة

③ Deep inside $x \to \infty$, concentration remains at initial value $C = C_0$.

* gas phase is an example like hydrogen in metals.

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



$$erf(z) = \frac{2}{\sqrt{\pi}} \int_0^z e^{-y^2} dy$$ error describes how concentration smoothly transitions from C_s to C_0 deep inside.

Example p. 177.

$\frac{x_0^2}{D t_1} = \frac{x_0^2}{D t_2}$

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Final

Chapter (5)

Factors that influence diffusion:-

① diffusion species : the magnitude of D is indicative of the rate at which atoms diffuse. (الذرات الصغيرة تنتشر بسرعة أكبر)

② Temprature (كلما زادت درجة الحرارة زادت الحركة)

$$D = D_o \exp\left(\frac{-Q_d}{RT}\right)$$

D معامل الانتشار عند درجة حرارة معينة
D_o ثابت لا يعتمد على الحرارة
Q_d طاقة التنشيط
R ثابت الغاز $R = 8.31\ J/mol\text{-}K$
T درجة الحرارة بالكلفن

- كلما زادت T زادت D
- كلما زادت Q_d قلت D

③ host medertes

④ microstructure

⑤ type of diffusion.

* Table 5.2 page 168:-

① interstitial diffusion.

γ-Fe and α-Fe يحدث غالبًا في الحديد

في C و N

② self diffusion.

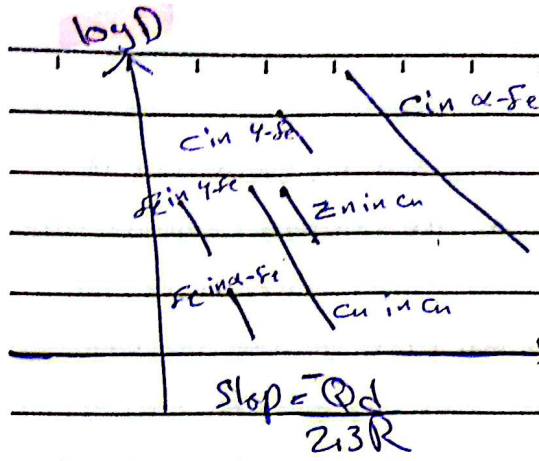
- يحدث في ذرة تنتشر في داخل نفس المعدن
- يعتمد على التركيب البلوري (BCC, HCP, FCC)
- لاحظ أن المعادن ذات FCC لها طاقات تنشيط أقل وأسرع انتشار

③ Vaccancy diffusion (interdiffusion)

- يحدث بين ذرتين مختلفتين داخل شبكة
- يعتمد على وجود الفراغات

* نختار Q_d و D_o حسب نوع الفلزات والمعادن

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- الخطوط ذات الميل الأكبر تمثل Qd أعلى.
- الخطوط الأعلى في الرسم تمثل D أكبر عند نفس درجة الحرارة.
- كل الخطوط مستقيمة بين أنها تتبع قانون أرينيوس.

* Rank the magnitude of diffusion coefficient from greatest to least for the following systems:- N in Fe at 700°C
Cr in Fe at 700°C
N in Fe at 900°C
Cr in Fe at 900°C

Note that radii for Fe, Cr and N are 0.124, 0.125 and 0.065 nm.

Sol
N in Fe at 900°C — الأكبر حيث أسرع انتشار
Cr in Fe at 900°C — ثانية، أسرع انتشار
N in Fe at 700°C
Cr in Fe at 700°C

* Using Table 5.2 compute the diffusion coefficient for Mg in Al at 550°C

Sol
$$D = (1.2\times10^{-4}) \exp\left(\frac{-130000}{8.31(550+273)}\right) = 6.7\times10^{-13}$$

Questions

① The wear resistance of a steel gear is to be improved by hardening its surface. This is to be accomplished by increasing the carbon content within an outer surface layer as a result of carbon diffusion into steel, the carbon is to be supplied from an external carbon rich gaseous atm at elevated temp. The initial carbon is 0.2 wt%, the surface concentration is at 1 wt%. a carbon content of 0.6 wt% must be established at a position 0.75mm below the surface. Specify the heat treatment in terms of temp and time between 900 and 1050°c. Use table 5.2 for diffusion carbon in γ-iron.

Sol

$C_o = 0.2 wt\%$

$C_s = 1 wt\%$

$C_x = 0.6 wt\%$

$$\frac{0.6-0.2}{1-0.2} = 1 - erf\left(\frac{x}{2\sqrt{Dt}}\right)$$

$$0.5 = \frac{x}{2\sqrt{Dt}}$$

$$0.4747 = \frac{x}{2\sqrt{Dt}}$$

$$Dt = 6.24 \times 10^{-7}\ m^2$$

$$6.24 \times 10^{-7} = 2.3 \times 10^{-5} \exp\left(\frac{-148000}{8.31\,(T)}\right)\ (K)$$

at 900°c $t = 106400\ s$

at 950°c $t = 57200\ s$

at 1000°c $t = 32300\ s$

at 1050°c $t = 19000\ s$

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(2) Cite the values of the diffusion coefficient for carbon in both α-iron and γ-iron at 900°C. Which is larger.

$$D = D_o \exp\left(\frac{-Q_d}{RT}\right)$$

$$D_\alpha = (1.1\times10^{-6}) \exp\left(\frac{-87400}{8.31(1173)}\right) = 1.4\times10^{-10}$$

$$D_\gamma = 2.3\times10^{-5} \exp\left(\frac{-148000}{8.31(1173)}\right) = 5.86\times10^{-12}$$

The D in BCC is larger because Atp is smaller than FCC. so there is more space in it.

(3) Using the data compute the value of D for the diffusion of nitrogen in FCC iron at 950°C.

$$D = (9.1\times10^{-5}) \exp\left(\frac{-168000}{8.31(950+273)}\right) = 6\times10^{-12}$$

(4) At what temperature will the diffusion coefficient for the zinc in copper have a value of $2.6\times10^{-16}\ m^2/s$?

$$2.6\times10^{-16} = (2.4\times10^{-5}) \exp\left(\frac{-189000}{8.31\,T}\right)$$

$$-23.24 = \frac{-189000}{8.31\,T}$$

$$T = 901.09\ °K$$

(5) The activation energy for the diffusion of copper in silver is 193000 J/mol. Calculate the diffusion coefficient at 1200K, given that D at 1000K is 1×10^{-14}

$$D_o = 1\times10^{-4} \exp\left(\frac{193000}{8.31\times1000}\right)$$

$$D_o = 1.22\times10^{-4}$$

$$D = 1.22\times10^{-4} \exp\left(\frac{19300}{8.31\times1200}\right) = 4.8\times10^{-13}$$

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(6) The diffusion coefficient for nickel in iron.

T(K)	D(m²/s)
1473	2.2×10^{-15}
1673	4.8×10^{-14}

(a) Determine the value of D_0 and the activation energy Q_d.

$$2.2\times10^{-15} = D_0 \exp\left(\frac{-Q_d}{8.3\times1473}\right) \Rightarrow D_0 = 2.2\times10^{-15}\exp\left(\frac{Q_d}{8.3\times1473}\right)$$

$$4.8\times10^{-14} = D_0 \exp\left(\frac{-Q_d}{8.3\times1673}\right)$$

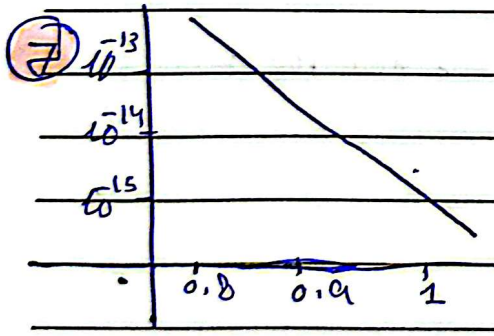
$Q_d = 315700$ J/mol $\Rightarrow$ $\log D = \log D_0 - 2.3R\left(\frac{\log D_1 - \log D_2}{\frac{1}{T_1} - \frac{1}{T_2}}\right)$

$D_0 = 3.5\times10^{-4}\ m^2/s$

(b) What is the magnitude of D at 1573 K?

$$D = 3.5\times10^{-4}\exp\left(\frac{-315700}{8.3\times1573}\right) = 1.1\times10^{-14}$$

(7)



$$\text{Slope} = \frac{-Q_d}{2.3R}$$

$$Q_d = -2.3R\,\frac{\log D_1 - \log D_2}{\frac{1}{T_1} - \frac{1}{T_2}}$$

$$= -2.3(8.31)\left(\frac{-14.68 - -(13.52)}{1\times10^{-3} - 0.9\times10^{-3}}\right)$$

$$Q_d = 212200$$

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(8) Carbon is allowed to diffuse through a steel plate 10mm thick. The concentrations of carbon at the two faces are 0.85 and 0.4 kgC/m³ Fe, which are maintained constant. D_o and Q_d are 5×10^{-5} m²/s and 77000 J/mol. Compute the temperature at which the diffusion flux is 6.3×10^{-10} kg/m²s.

Sol $J = -D\frac{\Delta C}{\Delta x}$

$$J = -D_o \frac{\Delta C}{\Delta x} \exp\left(\frac{-Q_d}{RT}\right)$$

$$\ln J = \ln\left(-D_o \frac{\Delta C}{\Delta x}\right) - \frac{Q_d}{RT}$$

$$T = \frac{Q_d}{R}\left(\frac{1}{\ln\left(\frac{-D_o \Delta C}{J \Delta x}\right)}\right) \Rightarrow \left(\frac{77000}{8.3}\right)\left(\frac{1}{\ln\left(\frac{-5\times10^{-5}(0.4-0.85)}{6.3\times10^{-10}\times 10\times10^{-3}}\right)}\right) = 884\,K$$

(9) The steady state diffusion flux through a metal plate is 7.8×10^{-8} kg/m²s at a temperature of 1200°C (1473) and when the concentration gradient is −500 kg/m⁴. Calculate the diffusion flux at 1273 K for the same concentration gradient and Q_d is 145000 J/mol.

$$J = -D\frac{\Delta C}{\Delta x}$$

$$D_o = -J\frac{\Delta x}{\Delta C}\exp\left(\frac{Q_d}{RT}\right) \rightarrow -7.8\times10^{-8}\left(\frac{1}{-500}\right)\exp\left(\frac{145000}{8.3\times1473}\right)$$

$$D_o = 2.18\times10^{-5}$$

$$J = -2.18\times10^{-5}(-500)\exp\left(\frac{-145000}{8.31\times1273}\right) = 1.21\times10^{-8}$$

(10) At approximately what temp would a specimen for α-iron have to be carburized for 4h to produce the same diffusion result as carburization at 1000°C for 12h?

$$DT = DT$$

$$D_{1000} = 2.3\times10^{-5}\exp\left(\frac{-148000}{8.3\times1273}\right) = 1.93\times10^{-11}$$

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$1.93\times10^{-11} \times 12h = 4h\, D_T$

$D_T = 5.79\times10^{-11}$

$$T = \left(\frac{-Q_d}{R(\ln D_0 - \ln D)}\right) = \frac{-148000}{8.31\left(\ln(5.79\times10^{-11}) - \ln(2.3\times10^{-5})\right)} = 1381\,K$$

(11) Calculate the diffusion coefficient for magnesium in Al at 450°C

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

$$D = 1.2\times10^{-4} \exp\left(\frac{-130000}{8.31 \times (450+273)}\right) = 4.81\times10^{-14}$$

Then what time will be required at 550°C to produce the same diffusion result for 15h at 450°C?

$$D_{T_{450}}\,{}_{15} = D_{T_{550}}$$

$$D_{550} = 1.2\times10^{-4} \exp\left(\frac{-130000}{8.3\,(550+273)}\right) = 6.67\times10^{-13}$$

$$t_{550} = \frac{4.81\times10^{-14}\times 15h}{6.67\times10^{-13}} = 1.08h$$

(12) A copper-nickel diffusion after a 500-h heat treatment at 1000°C the concentration of Ni is 3wt% at the 1mm position. At what temp should the diffusion couple be heated to produce the same conc at a 2mm after 500h? D_0 is 1.9×10^{-4} and Q_d is 230000 J/mol

$$\frac{x^2_{1000}}{D_{1000}} = \frac{x^2}{D_T}$$

$$D_{1000} = 1.9\times10^{-4} \exp\left(\frac{-230000}{8.3\times1273}\right) = 6.68\times10^{-14}$$

$$D_T = \frac{D_{1000} \times x^2}{x^2_{1000}} = \frac{6.68\times10^{-14}\times(2\times10^{-3})^2}{(1\times10^{-3})^2} = 2.74\times10^{-13}\ m^2/s$$

$$T = \frac{230000}{(8.31)\left(\ln(1.9\times10^{-4}) - \ln(2.74\times10^{-13})\right)} = 1360\,K$$

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(13) Consider the diffusion of some metal Y into Z at 950°C after 10h at 5mm position, is 2wt%. At what position will the concentration also be 2wt% Y after 17.5h at 950°C? assume D_o is 4.3×10^{-4} and Q_d is 180000 J/mol.

$$\frac{x^2}{t} = \frac{x^2}{t} \Rightarrow \frac{(5\times10^{-3})^2}{10h} = \frac{x^2}{17.5}$$

$$x = 0.66mm$$

(14) An FCC iron-carbon alloy initially containing C_o 0.1 wt% is carburized at an temp. which the surface concentration is C_s 1.1wt%. After + 48h the concentration of carbon is C_x 0.3 wt% at a position x 3.5 mm below the surface; determine the temp at which treatment was carried out.

$$\frac{C_x - C_o}{C_s - C_o} = \frac{0.3-0.1}{1.90-0.1} = 0.12 = 1 - erf\left(\frac{x}{2\sqrt{Dt}}\right)$$

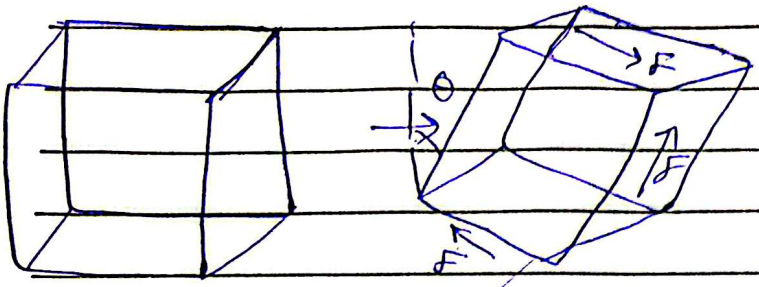
$$0.8 = erf\left(\frac{x}{2\sqrt{Dt}}\right)$$

$z = 0.9063$ (from table) $\Rightarrow 0.9063 = \frac{x}{2\sqrt{Dt}} \Rightarrow D = \frac{x^2}{4t(0.9063)^2} = 2.16\times10^{-11} m^2/s$

$$T = \frac{-Q_d}{R(\ln D_o - \ln D)} = \frac{-148000}{8.31(\ln(2.3\times10^{-5}) - \ln(2.16\times10^{-11}))} = 1283K$$

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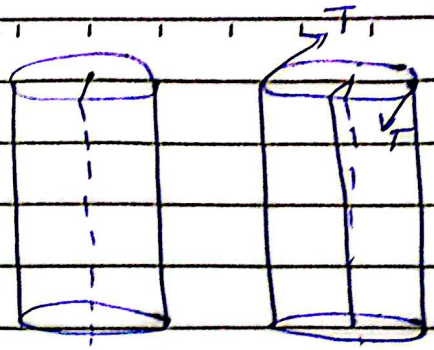
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Shear Strain

two opposing forces act

$\tan(\theta) = \gamma$ (3)



Torsion - Angle of twist

When a torque is applied to a material (cylindrical)

(4)

* Engineering Strain *

$$\epsilon = \frac{L_i - L_o}{L_o} = \frac{\Delta L}{L_o}$$

* Engineering Stress *

$$\sigma = \frac{F}{A_o}$$

* Compression test: In this test, above compresses the material and this type is taken as negative because it shortens the specimen (Tensile more common and easier than compression)

* Shear and Torsional tests: $\tau = \frac{F}{A_o}$

* Geometric considerations of the stress state:

* Normal and Shear Stress components:-

When analyzing a plan within a material at an angle θ, the stress splits into:-

- Normal stress: acts perpendicular to the plane
- Sheen stress: acts parallel to the plane.

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Normal stress

$$\sigma' = \sigma \cos^2\theta = \sigma\left(\frac{1+\cos 2\theta}{2}\right)$$

Shear stress $\tau' = \sigma \sin\theta \cos\theta = \frac{1}{2}\sigma \sin 2\theta$

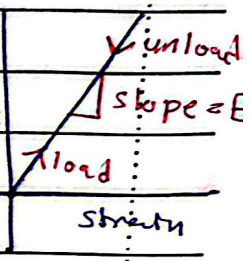
Hooke's law:-

$$\sigma = E\varepsilon$$

The Stress σ is directly prop to strain ε with constant elasticity E

* Modulus of elasticity (E): it measures the stiffness of a material

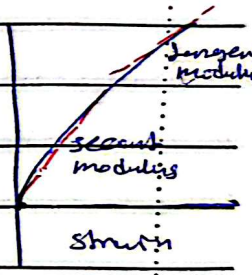
* Elastic deformation (nonpermenant): عند ازالة الاجهاد تعود للحالة الاولية



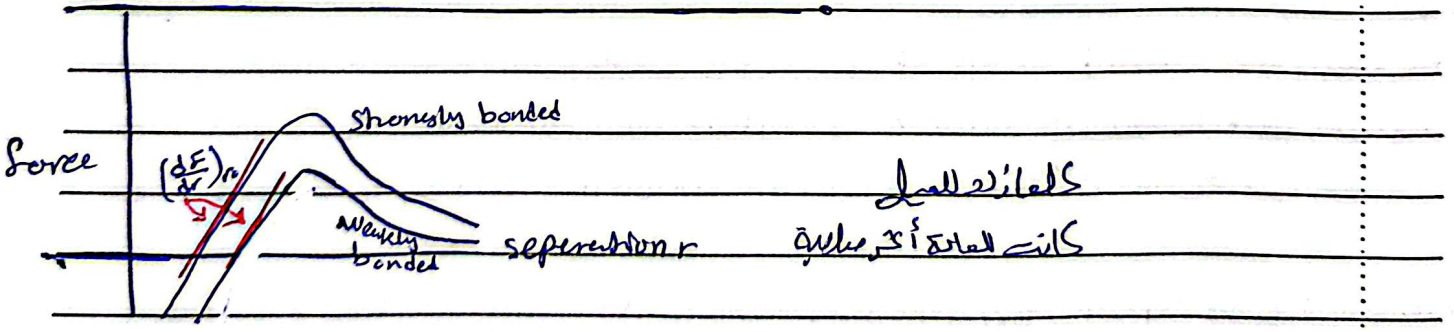
↳ Types of elastic behaviour:-

① linear elastic: when the load removed the material returns to it's original shape (slope = E)

② Non linear elastic: the stress strain curve is curved have Tangent: slope at a specific point and Secant: slope between origin and point



* The modulus is an important design parameter for computing elastic



كلما زاد الميل كانت الطاقة أكثر مثالية

* Materials exhibit elastic behaviour under compressive, shear and torsional stresses

$\tau = G\gamma$

Shear stress ← Shear strain

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* Modulus of elasticity decreases with increasing temp.
- Tungesten : highest modulus, slight decrease
- Steel : Moderate modulus, gradual decrease.
- Aluminium : lowest modulus, sharp decrease

* Elastic deformation is time-independent (it happens instantly when force is applied).
* In some materials especially polymers there is a time dependent called anelasticity.
* Viscoelastic behaviour : In polymers there are both elastic and time dependent

ex A piece of copper originally 305mm (12in) long is pulled in tension with a stress of 276MPa. If the deformation is elastic, what will be the resultant elongation?

$$\sigma = \epsilon E = \left(\frac{\Delta l}{l_o}\right) E$$

$$\Delta l = \frac{276 \times 305 \times 10^{-3}}{110 \times 10^3} = 0.77\text{mm}$$

* Poisson's ratio: $\nu = \frac{-\epsilon_x}{\epsilon_z} = \frac{-\epsilon_y}{\epsilon_z}$ $\left(\frac{\epsilon_z}{2} \frac{\Delta l_z/2}{\Delta l_z}\right)$ $\left(\frac{\epsilon_x}{2} = \frac{\Delta l_x/2}{\Delta l_x}\right)$

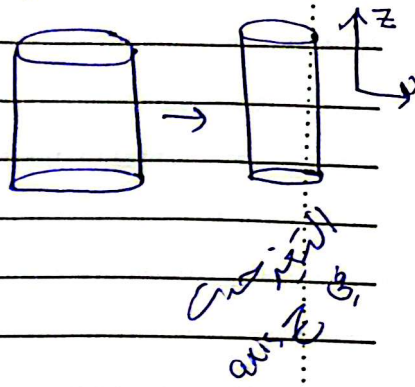
When tensile stress is applied to a material it elongates in the direction of the force (z), but it also contracts in the lateral directions x and y.

$E = 2G(1+\nu)$ * This equation applies to isotropic materials meaning that their elastic prop are the same in all directions

* Theoretical value of poisson's ratio is 0.25
* Max value of ν is 0.5
ν typically ranges between 0.25 – 0.35

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Ex: A tensile stress is to be applied along the long axis of a cylindrical brass rod that has a diameter of 10mm. Determine the magnitude of the load required to produce a 2.5×10^{-3} mm change in diameter if the deformation is elastic.



$$\epsilon_x = \frac{\Delta d_o}{d_o} = \frac{-2.5 \times 10^{-3}\,mm}{10\,mm} = -2.5 \times 10^{-4}$$

$$\epsilon_z = \frac{-\epsilon_x}{\nu} = 7.35 \times 10^{-4}$$

$$\sigma = \epsilon_z E = (7.35 \times 10^{-4})(97 \times 10^3) = 71.3\,MPa$$

$$F = \sigma A_o = \sigma \left(\frac{d_o}{2}\right)^2 \pi = 71.3 \times 10^6 \times \left(\frac{10^{-2}}{2}\right)^2 \pi = 5600\,N$$

Plastic deformation

- In most metals elastic deformation lasts only 0.005
- after this point, stress is no longer prop to strain, so hooke's law breaks down
- This marks the begening of plastic deformation which is permenent
- bonds between ordginal atoms break and new bonds form
- atoms shift permenently and don't return to their origin

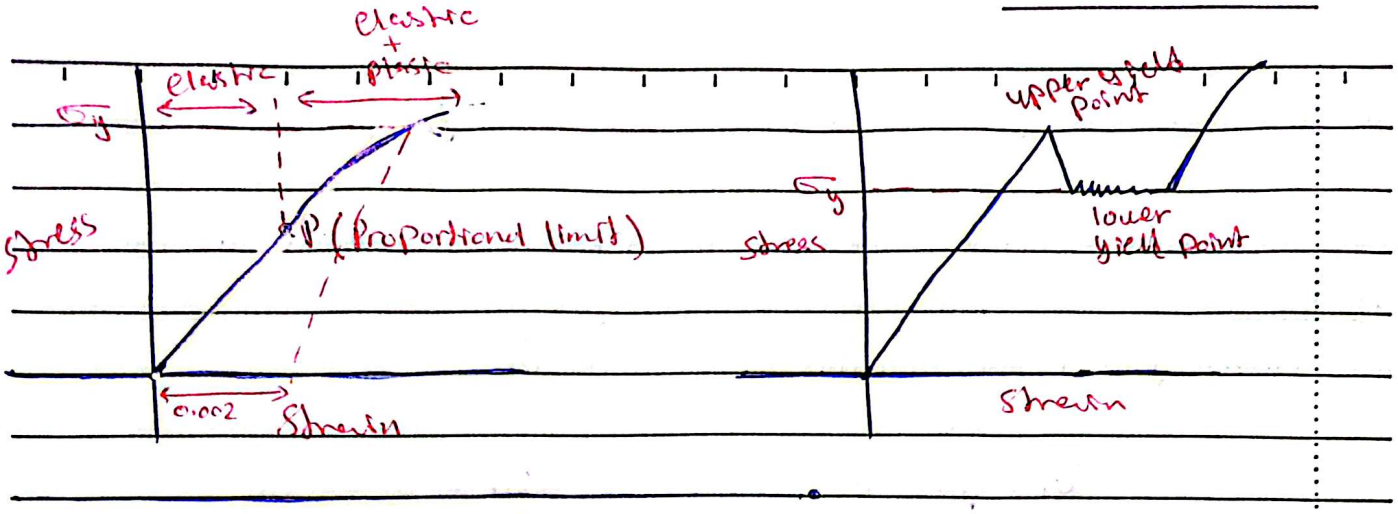
In Crystaline solids deformation occurs via SLIP.

In amorphous deformation happens through viscous flow.

Yielding and yield strength

- Yielding: is the point where a material starts to deform plastically
- Engineers dessign structures to stay within the elastic region
- Yield strength: the stress level at which yielding begins.

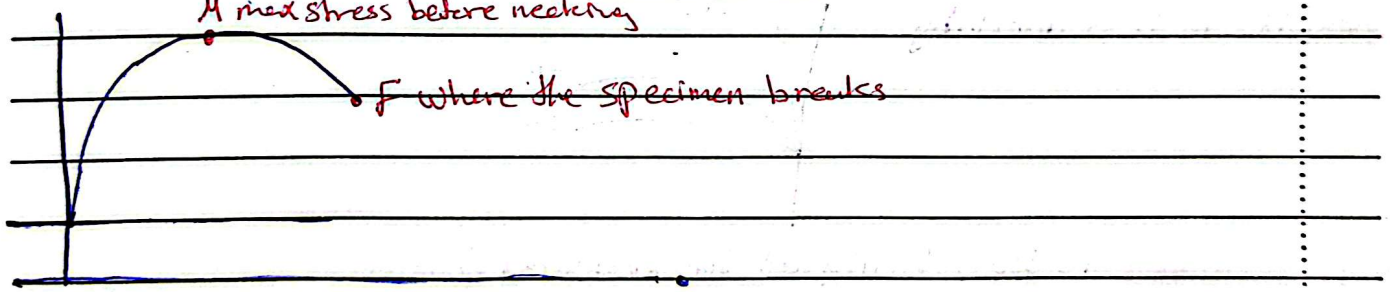
Some steels show a distinct yield point with a sudden drop from an upper yield point to a lower yield point.



* Proportional limit: the first deviation from linearity in the stress-strain

* Tensile Strength: after yielding the stress needed to continue plastic deformation increases until it reaches a max point (TS) before it starts to neck

* Necking :-
  - at the tensile strength point, a localized constriction (neck) forms
  - All further deformation happens in this necked region until fracture occurs.
  - this behavior is typically in [ductile metals]



* Ductility: is the ability of a material to undergo plastic deformation before breaks.
  - materials that fracture with little or no plastic deformation called brittle

$$\%EL = \left(\frac{L_f - L_o}{L_o}\right) * 100\%$$ percent elongation

$$\%RA = \left(\frac{A_o - A_f}{A_o}\right) * 100\%$$ Reduction in area

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* Materials like copper and brass are highly ductile.

* Resilience: is the ability of a material to absorb energy during elastic deformation and release it upon unloading.
the related prop. is the modulus of resilience U_r

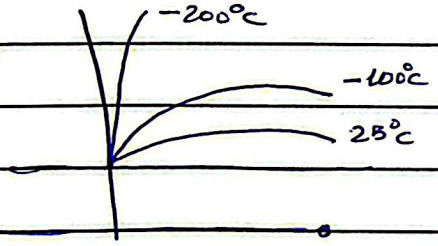
$$U_r = \int_0^{\varepsilon_y} \sigma \, d\varepsilon \qquad U_r = \frac{1}{2} \sigma_y \varepsilon_y$$

(General) area under the stress-strain (for linear-elastic)

$$U_r = \frac{1}{2} \sigma_y \varepsilon_y = \frac{\sigma_y^2}{2E}$$

U_r: is the energy a material can absorb elastically and release upon unloading.

* Stress negatively affects the stress-strain of iron
the iron becomes more malleable and brittle at lower temp, but this results in less ductility



* Toughness: is the ability of the material to:-
(1) absorb energy (2) undergo plastic deformation (3) Resist fracture

→ Types:-

1] Fracture:-
- measures resistance to crack propagation.
- Imp for structural materials.

2] Notch:-
- Relevant under dynamic loading.
- measured using impact tests.

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[3] Static toughness (from tensile test)

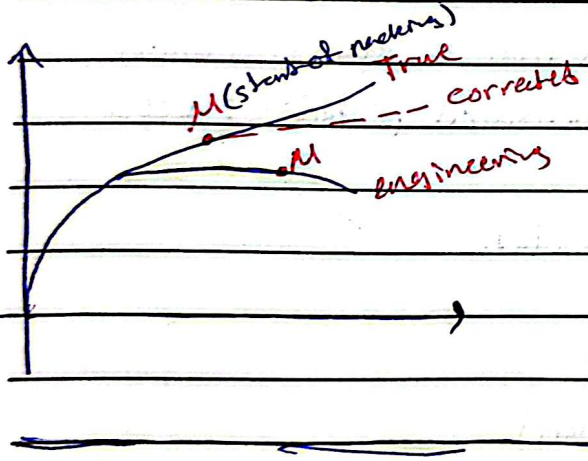
- for low loading conditions.
- Calculated as the area under the stress-strain curve.
- Requires both strength and ductility.

✱ Note: even if a brittle metal has high yield and tensile strength it may still have low toughness because it lacks of ductility. (i.p. toughness)

✱ True stress and strain ✱ this imp after necking and we use it because engineering value use initial dimensions

$$\sigma_T = \frac{F}{A_i} \quad (\text{actual area})$$

$$\sigma_T = \frac{l_i}{L_o} \qquad (A_i l_i = A_o l_o)$$



$$\sigma_T = \sigma(1+\epsilon)$$

$$\epsilon_T = \ln(1+\epsilon)$$

$$\sigma_T = K \epsilon^n$$

$$n = \frac{\log \sigma_T - \log K}{\log \epsilon_T}$$

✱ Elastic recovery after plastic deformation ✱

- When the load is removed the total strain is recovered elastically.
- The unloading path follows a straight line and is parallel to the original e
- When the load is reapplied the material follows the same elastic back
- yielding will occur at the same stress level
- it explain springback in metal forming.

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* Deformation in metals:- metals can undergo plastic deformation not only tensile loads, but also under:-

- Compressive
- Shear
- Torsional

* Compression Vs. Tension.

No necking occurs in compression, so there is no neck stress point like in tension.

* Hardness: is a material's resistance to localized plastic deformation like dents and scratches

- early hardness testing based on natural minerals scratching each other
- Modern testing a small indenter is pressed into the material under controlled load, then the size of depth is measured (softer → deeper)

Note: Hardness value are relative not absolute

- Why hardness tests are popular??

① Simple and inexpensive (no special specimen)
② Nondestructive (no structure damages)
③ useful for estimating other mean prop

1 * Rockwell hardness test:

- the most common method used today
- Involves pressing a steel ball/cone into the surface (measures deepth)
- How is measured??

a minor load is applied first to improve accuracy then a major is applied the difference in depth is the hardness number

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• Types of Rockwell tests :-

① Standard → minor 10kg ± 1 in ball
→ major 60, 100 or 150 kg
diamond diamond

② Superficial → minor 3kg
→ major 15, 30 or 45 kg
used for thin specimen

• How to report hardness (HR)

e.g. 80 HRB ⇒ Rockwell hardness of 80 on the B scale

e.g. 80 HR 30W ⇒ Rockwell of 60 on the 30W scale

(Note:) Values above 100 or below 20 on any scale may be inaccurate + make sure testing on smooth, flat surface

[2] Brinell hardness test as follows (ASTM)

• How it works??

- a hard spherical indenter (made of tungsten) is pressed into the surface of the metal. (10mm sphere)
- a standard load between 500 and 3000 kg is applied
- the load is held for a specific time typically (10 to 30 s)
- the diameter of the indenter is low-power
- the diameter is then converted to a Brinell hardness numb (HB or BHN)

• Why using it??

- it is ideal for bulk metals and rough surfaces.
- provide larger indentation.
- used for casting, forgings and large components.

(!)

TS (psi) = 500 ×

TS (MPa) = 3.45 × H

[3] Knoop (HK) and Vickers (HV) designed for small region, thin materials like (ceramics)

- smaller than the two methods before

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* Hardness is not defined prop and test methods vary so conversions are not exact.
depends on: ① Material type (steel dies) → steel → tungsten → ceramics
② surface condition
③ test method

* Variability in materials prop
- elastic modulus is material prop
- Critical prop depend largely on sample flaws. (large to variability)
- Statistics.

$$\text{Mean } \bar{x} = \frac{\sum x}{n}$$

$$\text{Standard deviation } S = \left[\frac{\sum (x_i - \bar{x})^2}{n-1}\right]^{1/2}$$

* Design or safety factors * We don't push the limits

$$\sigma_{working} = \frac{\sigma_y}{N}$$

N ← factor of safety (1.2 – 4)

Choosing it depends on:
① material type
② load ✓
③ applications ✓
④ frequency ✓

Design Stress $\sigma_d = N a \sigma_a$ → max
↓ ↓
1 to 5 ± ?

using it helps to:-
① durability
② safety

Want to make sure $\sigma_d > \sigma_y$

Safe or working stress $\sigma_w = \frac{\sigma_y}{N}$

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Questions

(1) At what angle is the shear stress and normal stress equal??

$\sigma' = \sigma \cos^2\theta$ ($\theta = 0°$) Normal

$\tau' = \frac{1}{2}\sigma \sin 2\theta$ ($\theta = 45°$) Shear.

(2) A specimen of copper having a rectangular cross section 15.2mm x 19.1mm is pulled in tension with 44500N, producing only elastic deformation Calculate the resulting strain.

Sol $\sigma = E\varepsilon$

$$\frac{F}{A_o E} = \varepsilon \Rightarrow \varepsilon = \frac{44500}{(2.9\times10^{-4})(110\times10^{9})} = 1.39\times10^{-3}$$

(3) A cylindrical rod of nickel alloy having elastic deformation of 270GPa and an original diameter of 10.2 mm. experience only load of 8900N. Compute the maximum length of the specimen before deformation if the max allowable elongation is 0.25mm.

Sol

$$\sigma = E\varepsilon \Rightarrow \frac{F}{A_o} = E\frac{\Delta L}{L_o} \Rightarrow L_o = \frac{270\times0.25\times10^{-3}\times81.71}{8900} = 0.47m$$

(4) An aluminum 125mm long having a square cross section 16.5mm on an edge is pulled in tension with load of 66700N and elongation 0.43mm, assuming that deformation is elastic, calculate modulus of elasticity.

$\sigma = E\varepsilon$

$$\frac{F}{A} = E\frac{\Delta L}{L_o}$$

$$\frac{66700}{(16.5)^2\times10^{-6}} \times \frac{125\times10^{-3}}{0.43\times10^{-3}} = E \Rightarrow E = 71.2\,GPa$$

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(5) Consider a cylindrical wire 2 mm in diameter 3×10^4 mm long. Calculate its elongation when a load of 300 N is applied. Assume the deformation is elastic.

$$\sigma = E\varepsilon$$

$$\frac{F}{A} = E\frac{\Delta L}{L_o} \Rightarrow \Delta L = \frac{FL_o}{AE} = \frac{300\times 30}{\pi\left(\frac{2\times10^{-3}}{2}\right)^2\times 207\times10^9} = 13.8\text{ mm}$$

(6) For a brass alloy, the stress at which plastic deformation begins is 345 MPa and the modulus of elasticity is 103 GPa.

(a) What is the max load that can be applied if area is 130 mm²?

$$\sigma = E\varepsilon \quad // \quad \sigma = \frac{F}{A} \Rightarrow F = 345\times130\times10^{-3} = 44850\text{ N}$$

(b) The max length at which the sample may be without plastic is? ($L_o = 76$ mm)

$$L_i = L_o\left(\frac{\sigma}{E}+1\right)$$

$$= 76\times10^{-3}\left(\frac{345\times10^6}{103\times10^9}+1\right) = 76.25\text{ mm}$$

(7) A cylindrical rod of steel ($E = 207$ GPa) having a yield strength of 310 MPa is to be subjected to a load of 11100 N. If the length of the rod is 500 mm, what must be the diameter to allow an elongation of 0.38 mm?

$$\sigma = \frac{F}{A} \Rightarrow E\varepsilon = \frac{F}{A} = A = \frac{F_a L_o}{E\Delta L}$$

$$\pi\left(\frac{d}{2}\right)^2 = \frac{11100\times500\times10^{-9}}{207\times0.38\times10^{-3}} \Rightarrow d = \sqrt{\frac{4\times500\times10^{-9}\times11100}{207\times0.38\times10^{-3}\times\pi}} = 9.5\text{ mm}$$

(8) Consider a cylindrical specimen of a steel alloy 8.5 mm in diameter and 80 mm long that is pulled in tension. Determine its elongation when load of 65250 N is applied.

$$\sigma = E\varepsilon$$

$$\frac{65250\times80\times10^{-3}}{\pi\left(\frac{8.5\times10^{-3}}{2}\right)^2\times207} = \Delta L$$

$$\Delta L = 0.143\text{ mm}$$

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(9) Using Materials data, rank the magnitude of E?

	A	B	n
X	1.5	7×10^{-6}	8
Y	2	1×10^{-5}	9
Z	3.5	4×10^{-6}	7

$$E_X = \frac{2(1.5)}{\left(\frac{1.5}{8\times7\times10^{-6}}\right)^{3/(1-2)}} + \frac{8(9)(7\times10^{-6})}{\left(\frac{1.5}{8\times7\times10^{-6}}\right)^{(10)/-7}} = 830$$

$E_Y = 683$

$E_Z = 7425$

(10) A cylindrical specimen of steel having a diameter of 15.2mm and length of 250mm. is deformed elastically with a force of 48900N. Using data -- . determine:

(a) The amount by which it will elongate?

$$\sigma = E\varepsilon$$

$$\frac{F}{A_o} = E\frac{\Delta L}{L_o} \Rightarrow \Delta L = \frac{FL_o}{E * A_o} = \frac{48900 * 250\times10^{-3}}{207\times10^{9} * \pi\left(\frac{15.2\times10^{-3}}{2}\right)^2}$$

$\Delta L = 0.325mm.$

(b) The Change in diameter of the specimen: Will the diameter increase or decrease?

$$\nu = -\frac{\varepsilon_x}{\varepsilon_z} \Rightarrow \nu = -\frac{\Delta d/d_o}{\Delta L/L_o}$$

$$\Delta d = \frac{\nu \Delta L}{L_o} d_o = \frac{(0.3)(0.325\times10^{-3})(15.2\times10^{-3})}{250\times10^{-3}} = -5.9\times10^{-3}mm$$

decrease.

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(11) A cylindrical bar of aluminum 19mm in diameter is to be deform. elastically by force along the bar axis. Determine the force that produces an elastic reduction of 2.5×10^{-3} mm in the diameter

$$F = \frac{-d_o \Delta d \pi E}{4V} = \frac{-19\times10^{-3} \times 2.5\times10^{-6} \times \pi \times 69\times10^{9}}{4 \times 0.33}$$

$$F_i = +8.00\,N$$

(12) A cylindrical of a metal alloy 10mm in diameter is stressed elastically in tension. A force of 15000 N produces a reduction in diameter of 7×10^{-3} mm. Compute the poisson's ratio if it's E is 100 GPa.

$$F_z = \frac{-d_o \Delta d \pi E}{4V}$$

$$V = \frac{-d_o \Delta d \pi E}{4F} = \frac{-10\times10^{-3} \times 7\times10^{-3} \times \pi \times 100}{4 \times 15000} = 0.367$$

(13) A cylindrical of metal alloy is stressed in compression. If it's original and final diameters are 30 and 30.04 mm, and it's final length is 105.2×10^{-3} m, Compute it's original length if the deformation is totally elastic. The elastic and shear moduli are 65.5 and 25.4 GPa respectively.

$$\epsilon_x = \frac{\Delta d}{d_o} = \frac{30.04 - 30}{30} = 1.33\times10^{-3}$$

$$\epsilon_z = \frac{-\epsilon_x}{V} \qquad \left(V = \frac{E}{2G} - 1 = 0.289\right)$$

$$\epsilon_z = -4.6\times10^{-3}$$

$$-4.6\times10^{-3} = \frac{\Delta L}{L_o}$$

$$L_o = \frac{105.2\times10^{-3}}{1 - 4.6\times10^{-3}} = 105.69\,mm$$

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(14) Consider a cylindrical of metal alloy has a diameter of 10mm A tensile force of 1500 N produces an elastic reduction in diameter of 6.7×10^{-4} mm. Compute elastic modulus given that poisson's ratio is 0.35

$$1500 = -\frac{10\times10^{-3} \times 6.7\times10^{-4}\times10^{-3} \times \pi \times E}{4 \times 0.35}$$

$$\boxed{E = 10^{11}\ GPa}$$

(15) Note: $\epsilon_{(test)} < \epsilon_{(yield)}$ then test is possible

but if $\epsilon_{test} > \epsilon_{yield}$ it is not possible.

(16) A cylindrical metal 10.70mm in diameter and 95mm long is to be subjected to a tensile force of 6300 N at this force level, the resulting deformation is elastic

(a) If the final length must be less than 95.04mm, which of the metals are suitable candidates? $E \frac{\Delta L}{L_o} = \frac{F}{A_o}$

$$E = \frac{6300 \times 95\times10^{-3}}{\pi\left(\frac{10.7\times10^{-3}}{2}\right)^2 \times (95.04-95)\times10^{-3}} = 167\ GPa.$$

(17) Consider brass alloy for which the stress-strain behavior. 10mm in diameter and 101.6 mm long is pulled in tension with a force of 10000 N. If it is known that this alloy has a value for poisson's of 0.35 compute

(a) The elongation (b) the reduction in diameter.

$$\epsilon = E\epsilon$$

$$\frac{F}{A} = E\frac{\Delta l}{L_o}$$

$$\Delta l = \frac{10000 \times 101.6\times10^{-3}}{\pi\left(\frac{10\times10^{-3}}{2}\right)^2 \times} = 0.15mm$$

$$\Delta d = d_o\epsilon_x = -d_o\nu\epsilon_z = -10\times10^{-3} \times 0.35 \times 1.5\times10^{-3}$$

$$= -5.25\times10^{-3}\ mm$$

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Given that $\sigma = 335 MPa = 335 \times 10^6$

(18) A cylindrical of brass alloy having a length of 100mm must elongate only 5mm when 120000N is applied. Under these what must be the radius?

$$\varepsilon = \frac{\Delta l}{L} = \frac{5 \times 10^{-3}}{100 \times 10^{-3}} = 5 \times 10^{-2}$$

$$\sigma = \frac{F}{A} = \frac{10^6}{\pi (r)^2} \Rightarrow r = \sqrt{\frac{F}{\sigma \pi}} = 0.0097m$$

(19) A load of 140000N is applied to a steel alloy that has a diameter of 10mm, given that the figure is 6.22.

(a) Will the specimen experience elastic or plastic deformation?

$$\sigma = \frac{F}{A} = \frac{140000}{\pi \left(\frac{10^{-2}}{2}\right)^2} = 1782 MPa$$

(ii) After the load is released will be there a net deformation if it was only elastic? No

(21) A cylindrical metal having a diameter of 12.8mm and gauge length of 50.8mm. The diameter is 8.13 mm and gauge length is 74.17mm. Calculate the ductility in percent reduction in area and elongation

$$\%EL = \left(\frac{74.17 - 50.8}{50.8}\right) \times 100\% = 46\%$$

$$\%RA = \left(\frac{\pi \left(\frac{12.8}{2}\right)^2 - \pi \left(\frac{8.13}{2}\right)^2}{\pi \left(\frac{12.8}{2}\right)^2}\right) = 60\%$$

(22) A steel alloy to be used for a spring have a modulus of resilience at least 2.07 MPa. What must be the yield strength?

$$U_r = \frac{\sigma_y^2}{2E}$$

$$\sigma_y = \sqrt{2 E U_r} = \sqrt{2 \times 207 \times 207 \times 10^3} = 926 MPa$$

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(23) A tensile test, it is found that true strain of 0.16 is produced when a true stress of 500 MPa is applied for the same metal, the value of k is 825 MPa. Calculate the true strain that make true stress of 600 MPa.

$$n = \frac{\log \sigma_T - \log k}{\log \epsilon_T} = \frac{\log 500 - \log 825}{\log 0.16} = 0.273$$

$$\sigma_T = k \epsilon^n \Rightarrow \epsilon^{0.273} = \frac{600}{825} \Rightarrow \epsilon_T = 0.34$$

(24) For some metal alloy, true stress of 345 MPa produces true strain of 0.02. How much this material elongate when a true stress of 415 MPa is applied, if the original length is 500mm? Assume a value of 0.22 for the strain hardening (n).

$$\sigma_T = K \epsilon^n \Rightarrow k = \frac{345}{(0.02)^{0.22}} = 816 \text{ MPa}$$

$$\epsilon_T = \left(\frac{\sigma_T}{k}\right)^{1/n} = 0.0463$$

$$\epsilon_T = \ln \frac{L_i}{L_o} \Rightarrow e^{\epsilon_T} * L_o = L_i$$

$$L_i = 523.7 \text{ mm}$$

$$\Delta l = 523.7 - 500 = 23.7 \text{ mm}$$

(25) A brass alloy 10mm in diameter and 120 mm long is pulled in tension with a force of 11750 N computer. Find the final length.

السؤال لم E يعطى

$$\sigma = \frac{11750}{\pi \left(\frac{10^{-2}}{2}\right)^2} = 150 \text{ MPa}$$

$$L_i = 120 \times 10^{-3} \left(\frac{150 \times 10^6}{1.25} + 1\right) = 121.44 \text{ mm}$$

(26) A steel alloy having a rectangular dimensions 19mm x 3.2mm has the stress-strain behaviour. the force is 110000 N.

(a) Determine the elastic and plastic strain values.

$$\sigma = \frac{F}{A_o} = 1.81 \times 10^9 \Rightarrow \epsilon = \frac{\sigma}{E} = 0.0087$$

$$\epsilon_{plastic} = \epsilon_{total} - \epsilon_e = 0.02 - 0.0087 = 0.0113.$$

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(27) Cite five factors that lead to scatter in measured material prop?

① test method ② operator bias ③ material differences ④ variation in specimen

(28) Upon what three criteria are factors of safety based?

① failure ② previous experiences ③ accuracy ④ economics.

Chapter (7)

Dislocations and plastic deformation (difference between real and theoritical forces)

- dislocation: line defect disrupts the regular arrangements of atoms.
- They see it by (electron microscope)
- two basic types of dislocations:-
  - Edge dislocation: by an extra half plane of atoms (⊥) (dislocation line) or mixed
  - Screw dislocation: by shear dislocation

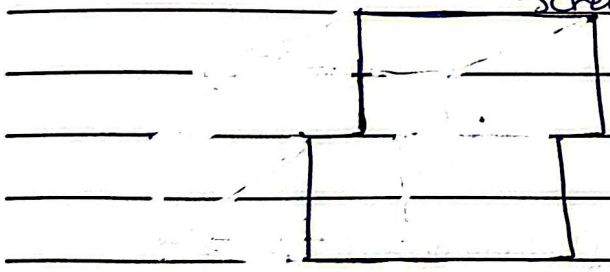
Both make it easier for atoms to move so, real materials deform easily than perfect crystals.

Slip: Plastic deformation happens when many dislocations move under shear stress

dislocations motion is like (caterpillar)

Direction of motion

- edge (the same as force) ⇒ extra half
- screw (perpendicular) ⇒



Dislocation density is measured as:-

- Total dislocation length per unit volume
- Or number of dislocations per unit area

Pure metals ~ $10^3\ mm^{-2}$

Heavily metals ~ $10^{10}\ mm^{-2}$

Heat treatment ~ $10^5 - 10^6\ mm^{-2}$

Ceramics ~ $10^2 - 10^4\ mm^{-2}$

Silicon ~ $0.1 - 1\ mm^{-2}$

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✱ Characteristics of dislocations ✱

1. Strain fields around dislocation
   - Compressive strain : above the dislocation line
   - Tensile strain : below the " "
   - Shear strain : around edge , screw has pure shear

2. Stored energy during plastic deformation :-
   - About 5% of energy is retained as strain energy due to dislocations
   - The rest is dissipated as heat.

3. Interaction between dislocations :-
   - When dislocations are close
     - repulsion (Same sign) تنافر
     - Attraction and annihilation (opposite sign) إنجذاب وتلاشي

✱ New dislocation form from :-

- existing ones
- grain boundaries
- Internal defects عيوب داخلية
- Surface scratches

✱ Slip systems ✱

- **Slip plane** : plane with highest atomic packing density
- **Slip direction** : the direction with highest linear atomic density.
- **Slip system** = Slip plane + Slip direction.

	Plane	direction	
FCC	{111} 4 family	⟨110⟩ 3 family	⇒ Cu, Al, Ni, Ag, Au → ...
BCC	{110}	⟨111⟩	⇒ Fe, W, Mo → ...
	{211}		⇒ Fe, W ⇒
	{321}		⇒ Fe, K ⇒
HCP	{0001}	⟨11$\bar{2}$0⟩	⇒ Cd, Zn, Mg, Ti, Be → ...
	{10$\bar{1}$0}		⇒ Ti, Mg, Zr, ⇒ ...
	{10$\bar{1}$1}		⇒ Ti, Mg → ...

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Burgers Vector

FCC = $\frac{a}{2}\langle 110 \rangle$

BCC = $\frac{a}{2}\langle 111 \rangle$

HCP = $\frac{a}{3}\langle 11\bar{2}0 \rangle$

Ex: Which of the following slip system for simple cubic structure?

$\{100\}\langle 110 \rangle$, $\{110\}\langle 110 \rangle$, $\{100\}\langle 010 \rangle$, $\{110\}\langle 111 \rangle$

$\{100\}\langle 010 \rangle$ → Simple cubic

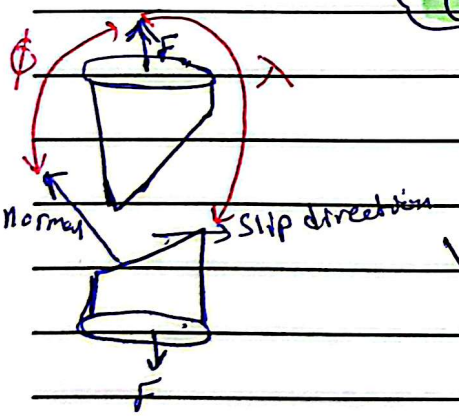
Slip in single crystals

even if the applied stress is purely tensile or compressive it creates shear components.

Dislocations moved in response to resolved shear stress

$\tau_R = \sigma \cos\phi \cos\lambda$

- $\cos\phi$: between Stress direction and slip Plane normal
- $\cos\lambda$: between Stress direction and slip direction



In general $\phi + \lambda \neq 90°$

CRSS: is the minimum resolved shear stress in single crystal

$$\sigma_{yield} = \frac{\tau_{crss}}{(\cos\phi \cos\lambda)_{max}}$$

$\phi = \lambda = 45° \Rightarrow \sigma_y = 2\tau_{crss}$

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- Under continued tensile stress:-
slip lines and steps increses
In FCC and BCC a second slip system may activate.

- In HCP few slip systems available.
and if stress axis is perpendicular ($\lambda = 90°$) or ($\phi = 90°$) then $\tau = 0$ no slip and fracture occurs.

Q: What the difference between τ_{Real} and τ_{crss}:-
τ_{Real} ⇓ reduced
τ_{crss} ⇓ minimum

Q: Consider a BCC along [010] direction.
(a) Compute resolved shear stress along a (110) plane in a $[\bar{1}11]$ direction when a tensile stress of 52 MPa is applied.

$$\phi = \cos^{-1}\left[\frac{1\times0 + 1\times1 + 0\times0}{\sqrt{2}}\right] = 45°$$
[010] (110)

$$\lambda = \cos^{-1}\left(\frac{1}{\sqrt{3}}\right) = 54.7°$$
$[\bar{1}11]$ (010)

$$\tau_R = 52 \times \cos45 \cos 54.7 = 21.3 \text{ MPa}$$

* Plastic deformation of polycrystalline materials
- Polycrystalline = grains with random orientations (slip direction varies)

- Slip occurs along the most favorably slip system and slip lines appears as intersecting sets.

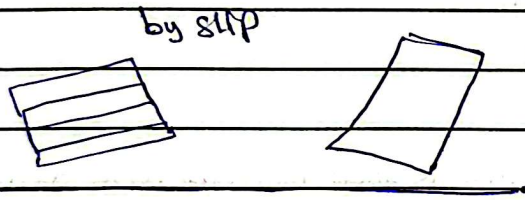
- Grain boundaries remain the same, each grain deforms via slip two sets of slip per grain.

- Even if one grain oriented for slip it can't slip unless neighboring grains also slip
- poly are stronger than single crystals.

Twinning is a plastic deformation where atoms shift in a mirror displacement increases with distance from the plane.

Comparison

Feature	Slip	Twinning
Atomic movement	Irregular	Symmetrical
Crystal reorientation	No	Yes
Displacement size	Multiples of atomic packing	Less than atomic packing
Preferred conditions	Normal temp	low temp, high strain
Crystal type	FCC, BCC, HCP	BCC, HCP (No FCC)
Deformation amount	large	small
Engineering role	Main deformation mode	Enables new slip system



Mechanisms of strengthening in Metals

- Easier dislocation motion → softer metal

- Strengthening for (single phase) Metals:-

① Grain size reduction: more grain boundaries block dislocation motion.

② Solid solution Alloying: solute atoms distort the lattice and hinder

③ strain hardening: deformation increases dislocation density, making motion harder

1 | Grain size reduction:- → (Crystallographic boundaries)

In Polycrystalline grain boundaries hinder due to:-

① Crystallographic misorientation: dislocations must change direction when crossing into a (different oriented grain.)

② Atomic disorder at boundaries: (slip planes are discontinuous) across grain boundaries.

* Smaller grain size ⇒ more obstacles to dislocation motion ⇒ Stronger metal

$\sigma_y = \sigma_0 + k_y d^{-1/2}$ — Hall-Petch equation (العلاقة بين الحجم والخضوع)

σ_y: yield strength — σ_0: base resistance — d: diameter

Smaller d ⇒ higher σ_y ⇒ Stronger metal

2- Solid-solution strengthening:-

means adding impurity atoms to metal's crystal lattice.

- Substitutional: impurity replaces host atom.
- Interstitial: impurity fits between host atoms.

(a) ⇒ Tensile strength ⇒ increases

(b) ⇒ Yield strength ⇒ Increases

(c) ⇒ Ductility ⇒ Decreases

* Impurity atoms create local lattice strains that interact with dislocations and hinder their motion.

Types of strain:-

① Smaller impurity atoms ⇒ Tensile

② larger " " ⇒ Compressive

* Impurities tend to segregate near dislocations to reduce strain energy:-

Smaller atoms ⇒ above slip plane

larger atoms ⇒ below slip plane

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[3] Strain hardening:- (Cold Working) when the metal is plastically deformed :-

- dislocation density increases
- dislocations block each other → metal becomes stronger

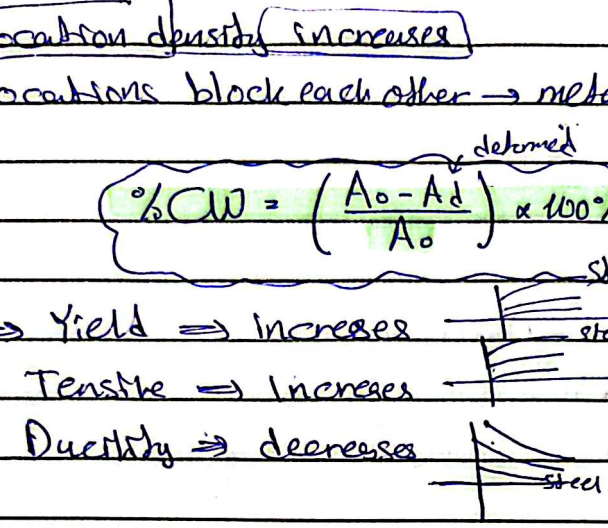
$$\%CW = \left(\frac{A_o - A_d}{A_o}\right) \times 100\%$$

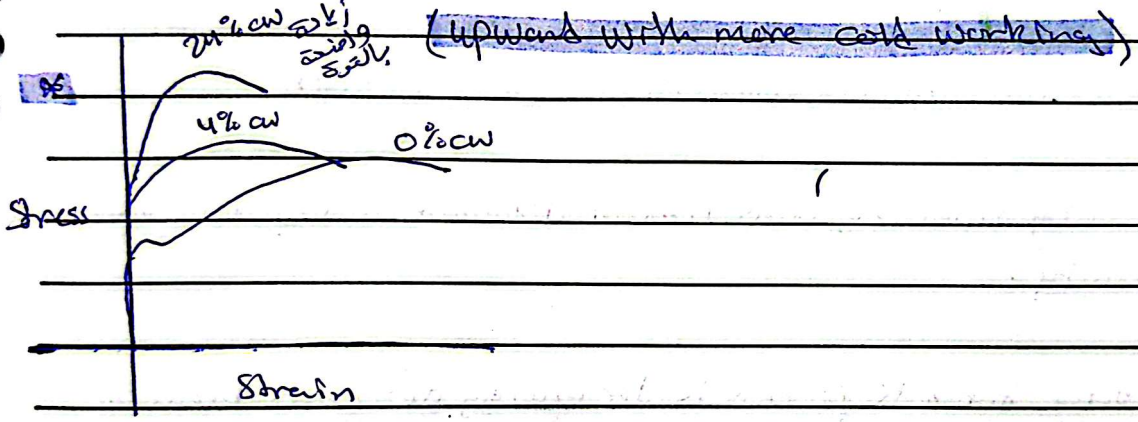
(A_d: deformed)

(a) ⇒ Yield ⇒ increases

(b) ⇒ Tensile ⇒ increases

(c) ⇒ Ductility ⇒ decreases





Q: Would you expect a crystaline ceramics material to strain harden?

No, they are brittle and lack of dislocations

Q: Compute the tensile strength and ductility of a crystaline copper rod if it is cold worked such that the diameter is reduced from 15.2mm to 12.2mm :-

$$\%CW = \frac{\pi\left(\frac{15.2mm}{2}\right)^2 - \pi\left(\frac{12.2mm}{2}\right)^2}{\pi\left(\frac{15.2mm}{2}\right)^2} \times 100 = 35.6\%$$

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* Recovery, Recrystallization and grain growth

- plastic deformation at low temp causes:-

1. grain shape change
2. Strain hardening
3. Increased dislocation
4. Stored strain energy.

So, annealing restores prop via three steps:-

[1] Recovery: occures at elevated temp, dislocation rearrange with external stress, strain energy is partially relieved (No change in grain structure and mech

[2] Recrystallization:- forms new, free strain with low dislocation and equal dimension density, it restores ductility and softens the metal after cold work

(b) after the recovery stage, grains remain deformed and contain high dislocation density.

- The driving force for this process is the energy differences between the deformed and undeformed material.

- Mechanical effects: softer ⟷ less mechanically strong
  more ductile.

- Therefore, some heat treatments are intentionally used to induce recrystallization in order to improve ductility.

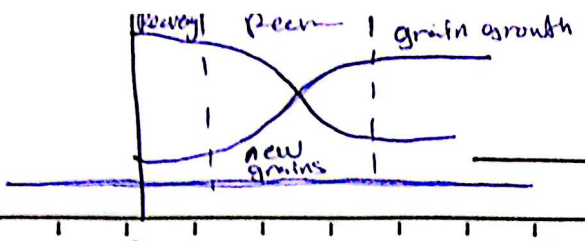
* Recrystallization temp:- means that rec.-- complete within one hour typically between one-third to one-half of melting temp of the meter.

Factors:-

1. CW% higher ⇒ faster rec.- ⇒ low temp

At high deformation levels, the temp reaches constant min value

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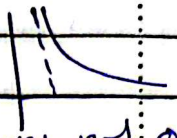


② Metal purity ⇒ pure ⇒ faster ⇒ lower temp ($0.4\,T_m$)

↓

Commercial alloy ⇒ higher temp ($0.7\,T_m$)

③ Minimum cold work:- (critical deformation)



If cold work is less than 2% to 20%, recrystallization may not occure

* Impurity atoms tend to gheather boundaries ⇒ slow down recr. and high temp.

Q Why do some metals like lead and tin Not strain harden at room temp?

• Room temp is higher than their melting points

3 Grain growth:-

After nyrda :- If metal remains at high temp, grain growth occurs.

- large grains → less boundary area → lower total energy → grain growth
- It happens (grain boundaries) via short-range atomic diffusion.

$$d^n - d_o^n = Kt$$

n: growth exponent

higher time or temp ⇒ large grains

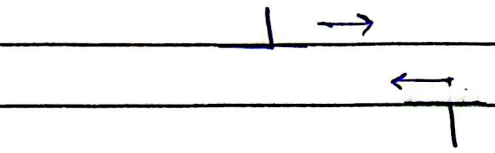
* Note: polycrystalline don't have to go at first to recrystallization

Questions

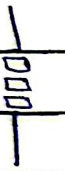
1) Consider a metal specimen with a density of $10^5 mm^{-2}$. Suppose all dislocations in $10^3 mm^3$, How far would this chain extend?

$$\left(10^5 \frac{m}{m^2}\right)\left(10^3 mm^3\right) = 10^8 mm$$

2) Consider two dislocations of opposite sign and having slip planes that are seperated by several distances, describe the defect that results when they aligned with each other.



Sol



planer region with vacancies

3) Is it possible for two screw dislocation of opposite sign to annihilate each other?

Yes if they are parallel

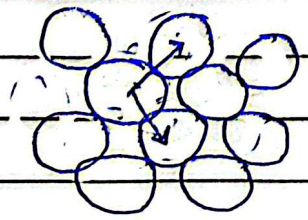
4) For each edge, screw and mixed cube the relationship between the direction of the applied shear stress and the direction of dislocation line motion.

edge – parallel

screw – perpendicular

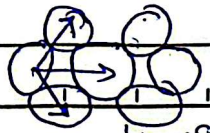
mixed – neither parallel nor perpendicular

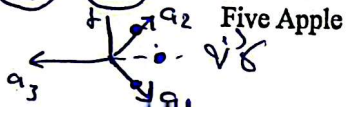
5) One slip for BCC is $\{110\}\langle 111\rangle$ sketch on $\{110\}$ then use arrows for $\langle 111\rangle$



HCP

$\{0001\}\langle 11\bar{2}0\rangle$





6) Determine the value of |b| for copper (R = 0.1278nm)

Sol

$$|b| = \frac{a}{2}(u^2+v^2+w^2)^{1/2} \qquad Cu \Rightarrow FCC \langle 110 \rangle$$

$$a = 2\sqrt{2}R = 0.3615nm$$

$$= \frac{0.3615\times10^{-9}}{2}(1+1)^{\frac{1}{2}} = 0.2556nm$$

7) Consider a single crystal oriented such that the normal plane is at angle of 60° and 35° for direction. If the critical resolved stress is 6.2 MPa will an applied stress of 17 MPa cause the single crystal yield?

$$\tau_R = \sigma \cos\phi \cos\lambda$$

$$6.2 = \sigma \cos 60 \cos 35$$

$$\sigma = 15.1 MPa$$ will not yield!

8) A single crystal of Zinc such the plane angle is 65°. Three possible directions make angles of 30°, 48°, 78°.

(a) Which of these is most favored?

Angle 30° makes the maximum.

(b) If plastic deformation begins at stress of 2.5 MPa. Determin resolved

$$\tau_R = 2.5 \cos 65 \cos 30 = 0.914 MPa$$

9) Consider single crystal of nickel such that stress is [001] and Plane on a (111) and in a [$\bar{1}$01] direction and the stress of 13.9 MPa Compute the resolved shear stress.

[001] (111)

$$\phi = \cos^{-1}\left[\frac{0+0+1}{\sqrt{(1)(1+1+1)}}\right] = 54.7$$

[001] [$\bar{1}$01]

$$\lambda = 45°$$

$$\tau_R = 13.9 \cos 54.7 \cos 45 = 5.68 MPa$$

Five Apple

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10 The critical resolved shear stress for cu is 0.48MPa. Determine maximum possible yield strength

$\sigma_y = 2\,\tau_{crss} = 2 \times 0.48 = 0.96\,MPa$

11 Explain why small angle grain boundaries are not as effective in interfering with slip process.

Because the crystallographic misalignment

12 Why HCP are more brittle than FCC and BCC??

because of slip numbers in HCP they are fewer.

13 The lower yield point for iron has an average diameter of 10^{-2} mm is 230MPa. At a grain diameter of 6×10^{-3} mm the yield point increases to 275MPa. At what grain diameter will the lower yield point be 310MPa?

Sol

$$230 = \sigma_0 + (10)k_y$$
$$275 = \sigma_0 + (12.91)k_y$$ } Divide

$k_y = 15.46$ & $\sigma_0 = 75.4$.

$$310 = 75.4 + 15.46\, d^{-1/2}$$

$d = 4.34 \times 10^{-3}$ mm

14 If the stress of 415MPa corresponds to a strain of 0.15. Determine the cold work.

$$\%CW = \left(\frac{\epsilon}{\epsilon+1}\right) \times 100 = \left(\frac{0.15}{0.15+1}\right) \times 100 = 13\,\%CW$$

15] Two previously undeformed of a strain hardening alloy for one specimen the initial and deformed radii are 15 and 12 mm. The second specimen with initial radius of 11mm must have the same hardness as the first. Compute the second radius after deformation.

$$\%CW = \left(\frac{\pi(15mm)^2 - \pi(12mm)^2}{\pi(15mm)^2}\right)\times 100 = \boxed{36\%\ CW}$$

$$r_d = 11mm\sqrt{1 - \frac{36\%}{100}} = 8.8mm$$

$$_{0.36}$$

16] For copper the resolved shear stress is 0.69 MPa at a density of $10^4 mm^{-2}$. If τ_0 is 0.069 MPa compute τ_{crss} at a density of $10^6 mm^{-2}$

$$0.69 = 0.069 + A\sqrt{10^4 mm^{-2}}$$

$$A = 6.21\times 10^{-3}$$

$$\tau_{crss} = 0.069 + 6.21\times 10^{-3}\sqrt{10^6 mm^{-2}} = 6.28\ MPa$$

17] What is the ~~rate~~ driving force for grain growth? reduction in grain boundary as the total grain boundary area decreases.

18] Consider a material has a grain diameter of $2.1\times 10^{-2} mm$. After a heat treatment at 600°C for 3h, the diameter increases to $7.2\times 10^{-2} mm$. Compute grain diameter when a specimen of this material ($d_0 = 2.1\times 10^{-2} mm$) is heated for 1.7h at 600°C. Assume $\boxed{n=2}$.

$$d^n - d_0^n = kt$$

$$(7.2\times 10^{-2} mm)^2 - (2.1\times 10^{-2} mm)^2 = k(3)$$

$$k = 1.58\times 10^{-3} mm^2/h$$

$$d = \sqrt{d_0^2 + kt} = 5.59\times 10^{-2} mm$$

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19] Plastically deforming a metal at room temp leads to?
Increased tensile strength and decreased duethity.

20] The atoms in screw experience which kind of strain?
Shear

21] dislocation formed by adding extra half plane of atoms is?-
Edge dislocation.

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Chapter (8)

Fundamentals of fracture

- Fracture (simple) : seperation of a body into parts due to (impact) or stress
- Fracture can also result from:-
  - Fatigue → (cyclic loading)
  - Creep → time dependent (at high temp)

- Types of fracture :-

1) Ductile fracture :- → plastic deformation, high energy absorption, slow crack growth
   - stable crack → twisting
2) Brittle fracture → no plastic deformation, low energy abs.
   - unstable crack → Rapid and sudden fracture

- Fracture process involves :-
  1) crack formation
  2) crack propagation

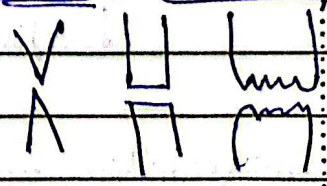
Note: Ductile is prefered because they gives warning before fracture and requires more energy (toughter)

1) Ductile fracture :-

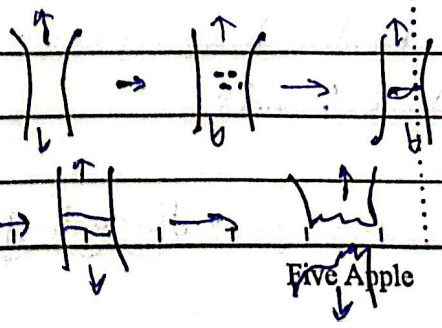
* Ductile surfaces show distinct features at both micro and macro

* Macro profiles :-

- Found in extremely soft like pure gold and lead at room temp.
- Also in poly and glasses at high temp.
- Nearly 100% reduction in area.



- Most common tensile for ductile
- Occures after moderate necking
- Fracture happenes in multiple stages.



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(a) Ductile fracture – Cup and cone في الشد:-
- Plastic deformation before breaking
- Warning sign

(spherical) كرة
at 45° → C shape (Pure shear)

(b) Brittle fracture – In mild steel:-
- Flat and perpendicular
- Sudden



* To understand we use fractographic studies using Scanning electron microscopy (SEM) because it is deeper than optical and reveals topographical.
they help to analyze ← fracture mode, stress state, crack site

(2) Brittle fracture:-
- Crack direction is nearly perpendicular to tensile stress
- Fracture surface is smooth and flat

* Distinctive surface patterns:-
① Chevron marks
- V-shaped. • point back toward the origin • common in steel

② Fan like patterns:-
- lined or ridges radiating from origin • fan shape

Both help to crack site, fracture mode, stress.

* Transgranular fracture (عبر الحبيبات)
- In brittle fracture occurs by cleavage (الانشقاق) which is repeated breaking of atomic bonds
- Cracks pass through grains, not between.
- fracture appears grainy

!! In amorphous like ceramics, fracture surface is smooth. In very hard, fine-grained Five Apple fracture pattern visible

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Intergranular fracture

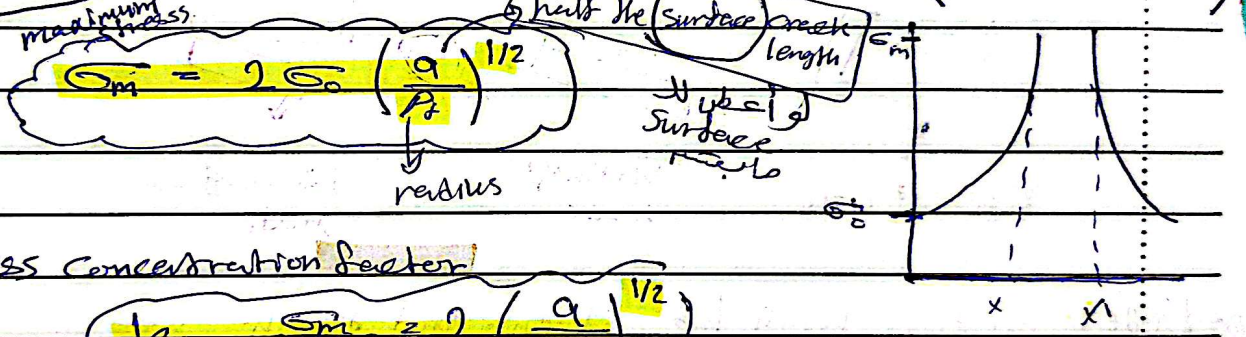
- In some alloys, cracks are along grain boundaries, not through
- results from weaken or brittle grain boundaries such as:-
  - Intergranular alloying
  - Thermal degradation
  - Improper alloying

Principle of fracture mechanics

- to understand brittle materials.
- it allows:-
  - Quantifying relationship between material prop, stress, flaws, crack propagation
  - Anticipating and preventing failures in design.

1 Stress Concentrations:-

- Measured strength is much lower than theoretical. Because of micro cracks and it makes fracture easier called (stress raisers)



Stress Concentration factor:

$$K_t = \frac{\sigma_m}{\sigma_o} = 2\left(\frac{a}{\rho_t}\right)^{1/2}$$

Critical Stress for Crack propagation

$$\sigma_c = \left(\frac{2Ey}{\pi a}\right)^{1/2}$$

(E: modulus)

- All brittle have small cracks with various sizes.

When tensile stress tip is larger than σ_c, a crack form leading to fracture. Micro are the reason of all of this.

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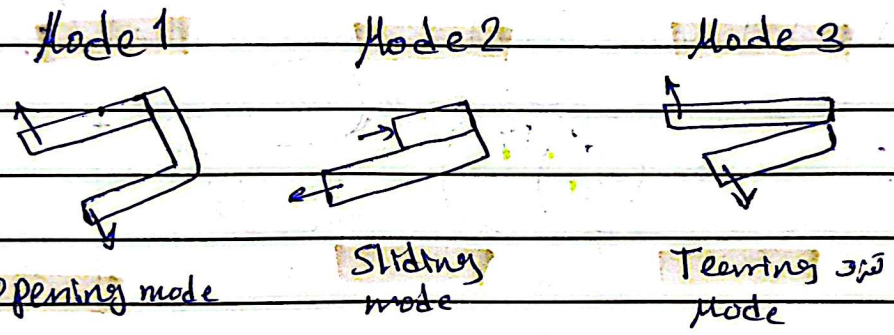
[2] Fracture toughness :-

$$K_c = Y \sigma_c \sqrt{\pi a}$$

- For short cracks in wide specimens → $Y \simeq 1$
  Ex: infinite or semi-infinite

- Thin specimens → K_c depends on thickness
- Thick → K_c independent, thus called (plane strain) and toughness is lower. (K_c is much than crack size)

- This equation is commonly used because it reflects Mode 1 crack opening.



Note: Metals high K_c, strong and tough
Ceramics very low K_c, brittle
Poly low to moderate K_c

[3] Design using fracture mechanics :-

- Three factors determine fracture risks :-
  1. toughness K_c → prop
  2. Applied stress σ → operating
  3. Flaw size a → service

} two are known, the third becomes fixed

$$\sigma_c = \frac{K_c}{Y\sqrt{\pi a}}$$

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Nondestructive Testing (NDT) :-

(اختبارات ومنها العيوب السطحية والداخلية)

- Techniques :-

① SEM Surface ② Dye Surface ③ Ultra Subsurface ④ optical Surface ⑤ Visual Surface ⑥ Acoustic Surface Subsurface ⑦ x-ray Surface

Fracture (toughness) testing

- In US → ASTM standards.
- The specimens contain sharp crack.
- Then it is loaded

⇒ ASTM E399 → K_c

ASTM E561 → R-R curves

ASTM E1290 → CTOD (crack tip opening)

Impact testing Techniques

→ Impact tests were developed before mechanics under fast loading.

→ conditions : (low) temp, (high) strain, stress

→ Chenpy : Specimen supported at both ends (horizontal, opposite, USA)

Izod : specimen clamped at one end (Vertical, Top or notch, UK, Canada)

→ energy absorbed from height difference (notch) toughness)

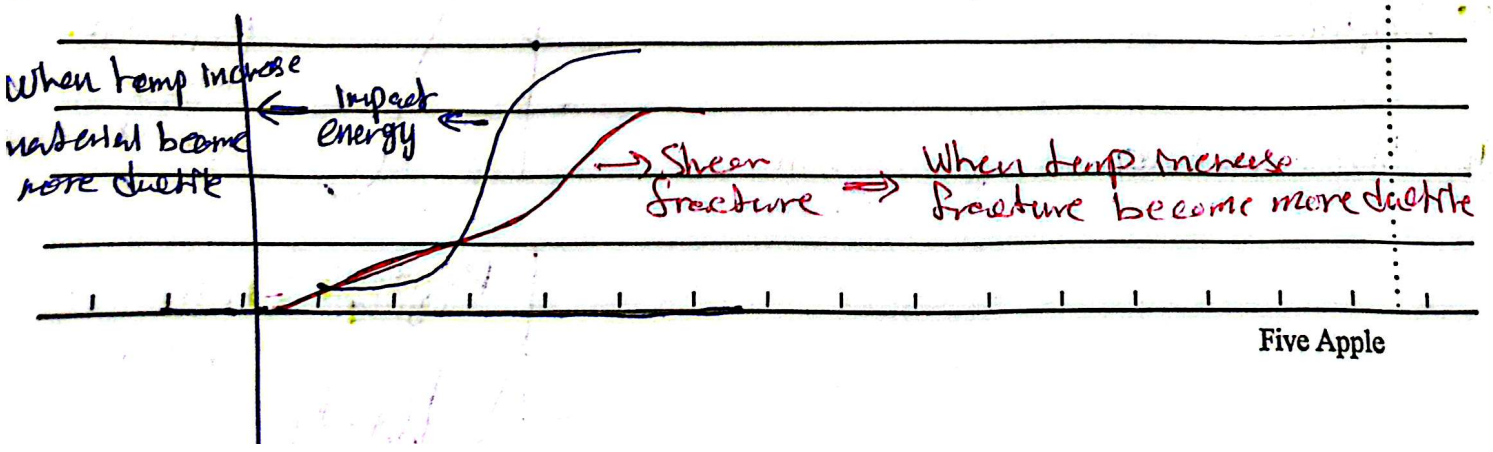
→ Impact tests are equivalative used for (comparison) not precise.

Ductile to Brittle Transition

2025

→ Chenpy and Izod help as (temp) decrease

→ Some metals behave ductile at high temp and brittle at low



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- Three general behaviour:-

Upper curve ⇒ low strength FCC or HCP metals (Al, Cu) ⇒ No transition (high temp)

Middle " ⇒ low strength BCC steels ⇒ Clear transition

Lower " ⇒ High strength steels (Ti) ⇒ Always brittle, low energy

- Smaller grain → lower transition temp → improve toughness
- More carbon → rises strength but rises temp → brittleness

* Effect of carbon effect:-

Higher carbon → lower energy ✓
Higher carbon → higher temp ✓
} Never require grain growth

Toughness decrease but strength increases.

* Fatigue * is a failure due to repeated stresses below yield strength

⇒ Accounts for ~90% of metallic failures

⇒ Affect polymers and ceramics.

⇒ It is Brittle and sudden

* Cycle stress equations *

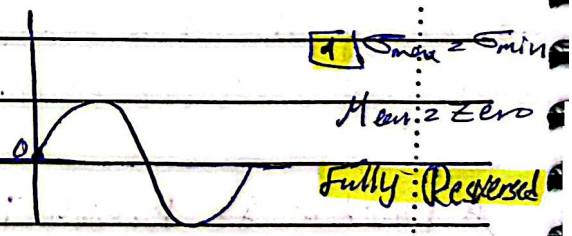
are essential for engine analysis and predicting material life.

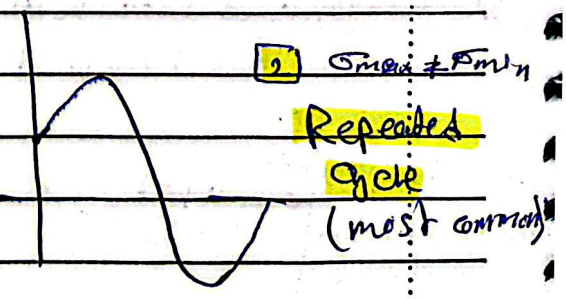
(1) Mean stress $\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2}$

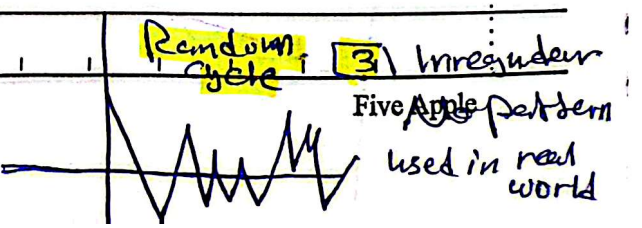
(2) Range $\sigma_r = \sigma_{max} - \sigma_{min}$

(3) Amplitude $\sigma_a = \frac{\sigma_r}{2}$

(4) Stress ratio $R = \frac{\sigma_{min}}{\sigma_{max}}$







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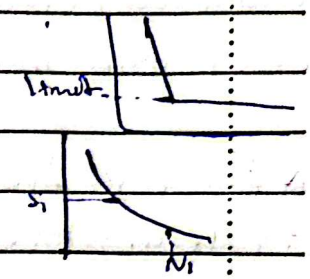
S-N curve:-

S: stress level , N: number of cycle failure

- How it is tested?

using rotating beam, alternating tension and compression (R=-1), record cycles.

- Types:-

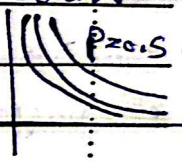


① With fatigue limit → high N → steel, titanium

② Without fatigue → keeps dropping → Al, cu, poly

- Fatigue limit: stress below which failure won't occure, no matter how many cycles. (max stress with infinite life)

- Fatigue strength: stress causing failure at a set of cycle count used for nonferrous alloys.



- Fatigue life: number of cycles to failure at a given stress

Crack initation and propagation

- Fatigue crack stages:-

① Crack initation ⇒ small crack (usually surface)

② Crack propagation ⇒ crack grows with each cycle

③ Final failure ⇒ (sudden)

- Crack origin:- starts at surface (scratches, threads, dents, fillets)

- Fracture surface features:-

① Beachmarks ⇒ Macro ⇒ growth during operation ⇒ visible

② Striations ⇒ Micro ⇒ each line = crack ⇒ seen by SEM/TEM

Thousands of striations may exist within one beachmark.

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- Why ↑ medians ??

① Reveals crack origin ② growth direction ③ fatigue life

- Fracture surface analysis :-
  - Beachmarks and Striations confirm failure.
  - Not all metals show striations.
  - Corrosion may erase them

✱ Factors that affect fatigue life ✱

1| Mean Stress σ_m

- S-N usually $\sigma_m = 0$
- Increases ↑ → reduces life

2| Surface effects :-

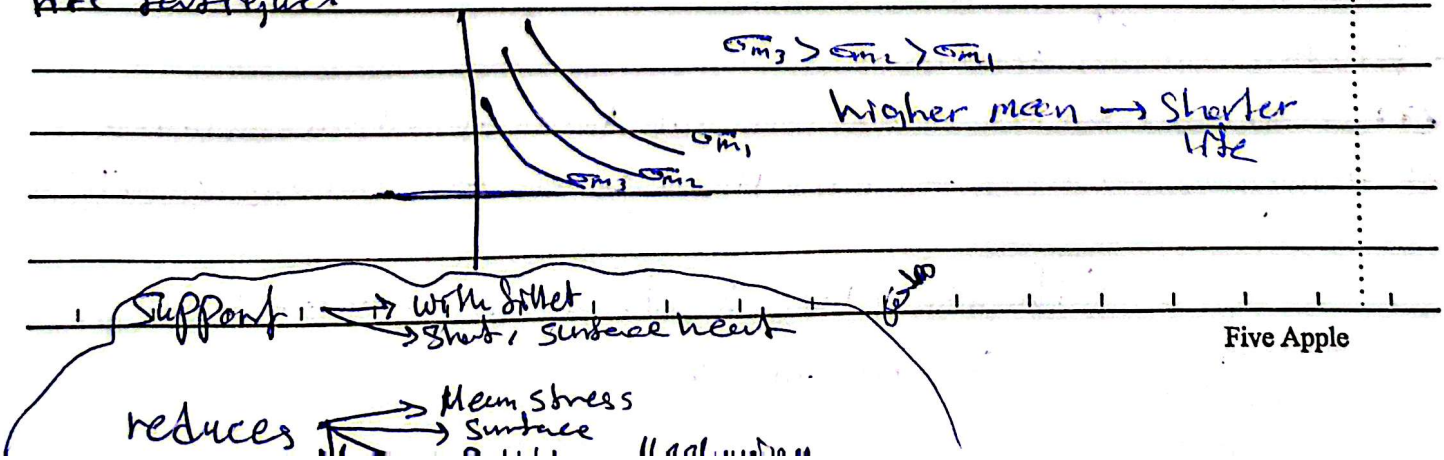
- Max stress often at the surface
- Improving ↑ → enhances fatigue resistance.

✱ Design factors ✱

- Sharp → Stress raisers → crack sites (without fillet) — reduces life
- Rounded fillets → reduces stress → improve life (with fillet)

✱✱ Surface treatments ✱✱

- Machining scratches reduce life
- polishing improve surface
- best method residual compressive stress (shot, surface heat) Key supp
  (peened)
  life fatigue.



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For 1&2

[1] Residual compressive stress:- → Reduce stress and delay crack
→ Via localized plastic deformation
→ Shot peening
→ Induces compressive stress ($\frac{1}{4} - \frac{1}{2}$) diameter

[2] Case hardening:- → methods are carburizing or Nitriding
→ high temp
Higher hardness — Produces 1mm outer layer and residual compressive stress

Environmental effects

- Thermal fatigue: Caused by cyclic temp changes at high temp. with no external mech stress.

$$\sigma = \alpha E \Delta T$$

Note: low thermal temp will not dimensional changes

- Corrosion fatigue: Caused by chemical attack and crack growth at weak surface so accelerates crack growth.

- Creep: Time-dependent permenent deformation under constant loads. (unlike fatigue creep develops gradually)

- When does it matter? For metals at $T > 0.4\,T_{melting\ temp}$
For amorphous poly creep occurs even at moderate temp.

- Creep testing must be at → constant stress, constant temp

- Measures Strain Vs. time used to determine → service life, Deformation rate
Rupture point

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- Creep Curve :-

① primary creep → starts immediately → decreasing rate → Strain hardening

② Secondary → longest phase → constant rate → balance hardening

③ Tertiary → Near failure → accelerating rate → cracks / necking → rupture

- Steady state creep rate $\dot{\epsilon} = \frac{\Delta\epsilon}{\Delta t}$ for long term

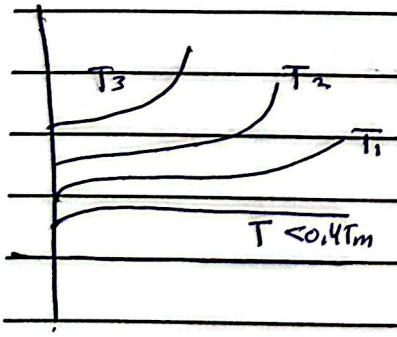
- Testing methodes → Metals (uniaxial tension)
  Brittle (uniaxial compression)
  Specimens (Cylinders or parallelpiped (length/diameter = 2÷4))

Note! Creep prop are mostly independent of direction.

Stress and temp effects

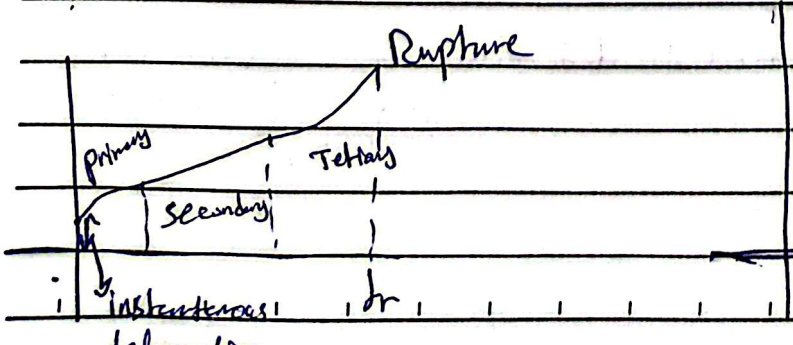
- At $T < 0.4T_m$, with increasing stress or temp:- Creep rate $G_s = K_1 \sigma^n$

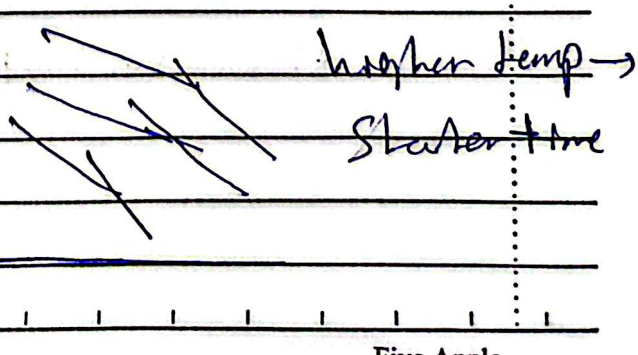
effects	results
higher stress/temp	more instantaneous stress
↑ ↑ / ↓	higher steady-state creep
↓ ↓ / ↑	shorter rupture lifetime



$T_3 > T_2 > T_1$

$\sigma_3 > \sigma_2 > \sigma_1$





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When temp is included $\dot{\varepsilon}_s = K_2 \sigma^n \exp\left(\frac{-Q_c}{RT}\right)$ steady state creep

Constant

— Creep Mechanisms:-

- stress induced Vacancy diffusion
- Dislocation motion
- Grain boundary sliding

Each one yields a different exponent (n)

— Deformation mechanism maps:-

- Show stress–temp zones for each mech
- used to predict behaviour under specific conditions

✱ Data extrapolation (Miller) ✱

When using long term creep data

$$M = T(C + \log t_r)$$

constant

✱ Alloys for high temp ✱

— factors affects (creep resistance)

- melting temp → higher → better resistance
- Elastic modulus → higher → less deformation
- Grain size → larger → less grain boundary → better resistance

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Questions

1] What is the magnitude of the max stress that exist at an internal Crack having a radius of 1.9×10^{-4} mm and a crack length of 3.8×10^{-2} mm. When a tensile stress of 140 MPa is applied?

$$\sigma_m = 2\sigma_c \left(\frac{a}{\rho}\right)^{1/2} = 2 \times 140 \left(\frac{\frac{3.8 \times 10^{-2}}{2}}{1.9 \times 10^{-4}}\right) = 2800 \text{ MPa}$$

2] Estimate the theoretical fracture strength of a brittle ~~M~~ material known shaped surface crack of length 0.5mm and tip radius of curvature of 5×10^{-3} mm. When a stress of 1035 MPa is applied.

$$\sigma = 2 \times 1035 \times \left(\frac{0.5}{5 \times 10^{-3}}\right)^{1/2} = 2.07 \times 10^4 \text{ MPa}$$

3] If the specific surface energy for Al oxide is 0.9 J/m² compute the critical required for the propagation of an internal crack of length 0.4mm. ($E = 393$ GPa)

$$\sigma_c = \left(\frac{2E\gamma_s}{\pi a}\right)^{1/2} = \left(\frac{2 \times 393 \times 0.9}{\pi \left(\frac{0.4}{2}\right)}\right)^{1/2} = 33.6 \times 10^6 \text{ MPa}$$

4] An MgO component must not fail when a tensile stress of 13.5 MPa is applied. Determine the max allowable surface crack length if the surface energy of MgO is 1 J/m².

$$a = \frac{2E\gamma_s}{\pi \sigma^2} = \frac{2 \times 225 \times 10^9 \times 1}{\pi (13.5)^2} = 0.79 \text{ mm}$$

5] A specimen of a 4340 steel alloy with a plane strain fracture toughness of 54.8 MPa$\sqrt{m}$ is exposed to a stress of 1030 MPa. Will this experience fracture if the largest crack is 0.5 mm long? Assume that $Y = 1$.

$$\sigma_c = \frac{K_c}{Y\sqrt{\pi a}} = \frac{54.8}{1\sqrt{\pi (0.5)}} = 1380$$

Will not occur because it is greater than the applied stress of

$\sigma_c > \sigma_{yield}$ ⇒ Would occur

6) Al alloy has a plane strain fracture toughness of 40 MPa$\sqrt{m}$. It has been determined that fracture results at a stress of 300 MPa when the max internal crack length is 4 mm. For this component will fracture occur at a stress level of 260 MPa when the max internal crack length is 6 mm?

$$300 = \frac{40\sqrt{m}}{Y\sqrt{\pi(\frac{4}{2})}} \Rightarrow Y = 1.68$$

$$K_c = 1.68 \times 260 \times \sqrt{\pi(\frac{6}{2})} = 42.4 \text{ MPa}\sqrt{m}$$

fracture will occure since is greater than K_c

7) A structural component has a plane toughness of 62 MPa$\sqrt{m}$. It has been determined that this component fails at a stress of 250 MPa when the max length of a surface is 1.6 mm. What is the max surface length for this same component exposed to a stress of 250 MPa and made from another alloy that has a 51 MPa$\sqrt{m}$ toughness.

$$62 = Y\, 250\sqrt{\pi(1.6)} \Rightarrow Y = 3.5$$

mm

$$250 = \frac{51}{3.5\sqrt{\pi a}} \Rightarrow a = 1.08 \text{ mm}$$

8) A large plate is fabricated from a steel alloy that has a plane strain fracture toughness of 82.4 MPa$\sqrt{m}$. If the plate is exposed to a tensile stress of 345 MPa during service use, determine the min length of a surface that will lead to fracture. Assume $Y = 1$.

$$\sigma_c = \frac{K_c}{Y\sqrt{\pi a}} \Rightarrow 345 = \frac{82.4}{\sqrt{\pi a}} \Rightarrow a = 18.2$$

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9) A fatigue test was conducted in which the mean stress was 70MPa and the amplitude was 210MPa :-

(a) Compute the max and min stress.

$70 = \frac{\sigma_{max} + \sigma_{min}}{2}$, $210 = \frac{\sigma_{max} - \sigma_{min}}{2}$

$140 = 420 + 2\sigma_{min}$ ⇐ $420 + \sigma_{min} = \sigma_{max}$

$\sigma_{min} = -140\ MPa$

$\sigma_{max} = 280\ MPa$

(b) Compute the stress ratio.

$R = \frac{-140}{280} = -0.5$

(c) Compute the stress range.

$\sigma_r = 280 + 140 = 420\ MPa$

10) A cylindrical bar of cast iron (S-N) if the bar diameter is 9.5mm, determine the max cyclic load that may be applied to ensure the part won't occur. Assume factor of safety is 2.25 and that the distance between load is 55.5mm.

$F = \frac{220 \times 10^6 \times \pi \times (9.5 \times 10^{-3})^3}{16\,(2.25)(55.5)} = 297\ N.$

11) A cylindrical rod the diameter is 12mm. Calculate the max load amplitude. Assume factor of safety is 3

$F = \frac{\sigma \pi d_o^2}{4N} = \frac{(170 \times 10^6)(\pi)(12)^2}{4\,(3)} = 6400\ N.$

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12] Five factors that may lead to scatter in fatigue life data.
① Mean stress ② surface ③ frequency ④ test apparatus

13] Give the approximate temp at which creep deformation becomes an imp for each following: iron, gold, zinc
For Fe → $0.4T_m = 0.4(1538+273) = 724K$
For Au → $0.4(1064+273) = 535K$
For Zn → $0.4(420+273) = 277K$

14] A specimen 975mm long is to be exposed to a tensile stress of 300MPa at 730°C. Determin elongation after 4h. Assume that the total of both instantaneous and primary creep elongation is 2.5mm.

$$\Delta\varepsilon * G = \Delta G$$

$$300 * 4 = 0.04 = \frac{\Delta L}{L_o} = \frac{\Delta L}{2.5} \Rightarrow \boxed{\Delta L = 39mm}$$

15] Cite three processing techniques that are employed to enhance the creep resistance of metal alloy:-
(1) Solid solution alloying (2) increasing grain size
(3) insoluble second phase.

16] If $m = 19.7$ where equal to $10^3 T(20 + \log t_r)$. Compute the rupture lifetime. T = 1088K

$$m = T(C + \log t_r)$$
$$19.7 = 1088(20 + \log t_r)$$
$$t_r = 1.3 \times 10^{-2} h.$$

17] Which type of metal would experience failure with tensional Brittle fails with no plastic deformation and with flat surface

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Chapter (9):

* Phase diagram shows how microstructure affect mechanical prop.

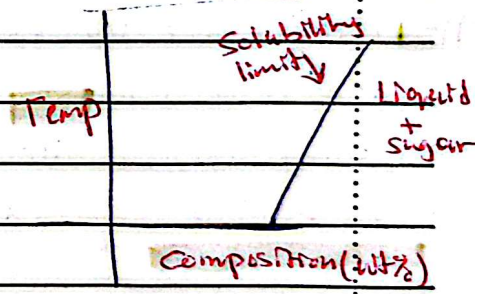
* Component: Pure metal or compound that makes up an alloy. (Cu in Zn)

* System: → specific body of material
  ↓
  Series of possible alloys made from same components.

* Solid solution: Contains atoms of at least two types.
  - Substitutional position: replacing solvent atoms
  - Interstitial position: fitting into spaces between solvent atoms.
  - The crystal structure of the (solvent) remains unchanged.

* Solubility limit: is the max concentration of solute atoms that can dissolve in a solvent from a solid solution at temp.

* exceeding this limit leads to the formation of a new phase or undissolved solute.



* Solubility depends on temp (sugar water)

* Phases: is a homogeneous part of a system with uniform physical and chemical prop.
  - every pure metal is a phase
  - solid, gasses and liquids solutions

* Two phases (different prop) H_2O

* System types: → Single phase: one only (homo)
  ↓
  Multi phase: two or more (mixture) (heterogeneous)

* Note: most metallic alloys, ceramics, poly and composites are

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* Note: The interaction between phases gives unique and often superior prop compared to individual phases.

* Microstructure: It refers to the arrangements and distribution of phases in a material at the microscopic level.

* using electron microscope.

* What affects microstructure? → allowing elements
→ their concentrations
→ heat treatment (temp, time, cooling)

* phase equilibrium: when the system is free energy is at a min under specific conditions (temp, pressure, composition) (Stable)

* Free energy = internal energy + entropy (randomness)

* What if conditions change?
increase free energy and the system shift to a new state with lower free energy.

* In more than one phase all phases are stable and persist over time.

* higher temp → higher solubility → phase equilibrium shifts

* Metallurgy → Phase equilibrium is crucial in metals and alloys
→ It helps control micro through heat and alloy

* Metastable states: are equilibrium state that can persist for a long time. (Al) they are not the lowest energy state.
(not fully stable)

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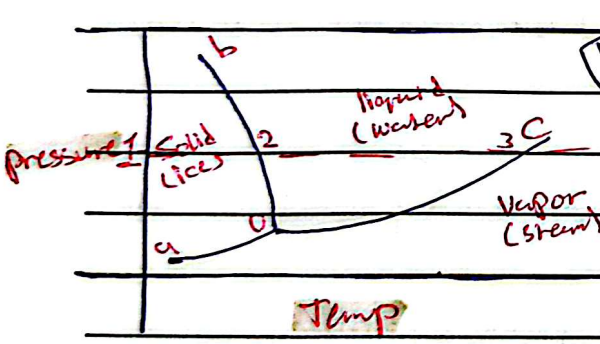
Ques: What the difference between phase equilibrium and Metastability?

Metastability	Phase equilibrium
→ not fully stable	- fully stable
- free energy not min (trapped)	- free energy min (global min)
- like Al	- don't change over time if conditions remain constant
- higher energy	- like sugar in water
	- lowest energy

* One Component (Unary) phase diagrams: H_2O

* What is a phase diagram: graphical tool that shows how phase structure changes with (temp, pressure, composition) equilibrium diagram

* Unary phase diagram:- • for a pure substance (composition constant)
• Variables (temp, pressure)
• 2D plot (P-T diagram)



* Conclusion *
bo ⇒ Melting point (solid - liquid)
bo ⇒ Boiling point (liquid - vapor)
ao ⇒ Sublimation (solid - vapor)
point 2 ⇒ melting at 0°C (intersection with ao)
point 3 ⇒ Boiling at 100°C (intersection with bo)
any point inside region = one phase
any point on a boundary = two phases
(O) Triple point: (Invariant point): is the point where solid, liquid and vapor in equilibrium

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✳ Binary phase diagrams : relationship between temp and composition pressure is constant (1 atm) and used for two components only.

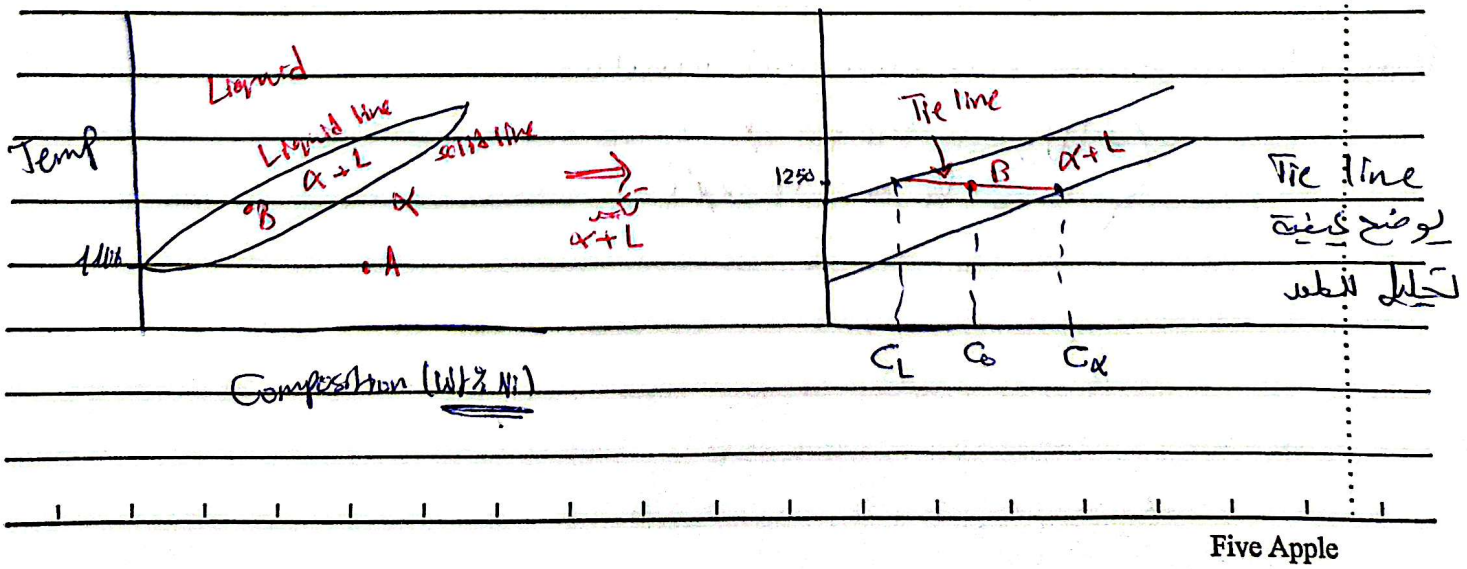
- Why it is imp? ⇒ phase transformation
  - micro and mech prop
  - phase at different temp, comp

✳ Binary Isomorphous System : speeser type of binary diagram where two components completely soluble in each other in liquid and solid no compounds or seperate phases

⇓

⇒ Cu – Ni system :- (isomorphous)

- Three region → Liquid (home of Cu and Ni)
  - → Solid (substitutional solid of FCC structure)
  - → α+L (solid + liquid) (Two phase region in equilibrium)
- Why Cu and Ni fully soluble?
  Same FCC, similar atomic radii, similar electronegativity, Comparable Valence.
- liquid line above it fully liquid / solid line below it fully solid.
- As temp increase, liquid fraction increases



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Interpretation of phase diagrams

- Phase present ⇒ you have to locate the temp – composition point. If the point lies in a single phase only that phase is present, but if it two phase both exist.

- Phase Composition ⇒ In two phase region use the line to find it. Draw the line across α + Liquid then find intersects then drop vertical line to the composition C_L and C_α

- Determination of phase amounts ⇒ We use lever rule to calculate how much of each phase is present :-

Liquid phase fraction (mass fraction) $W_L = \frac{C_\alpha - C_0}{C_\alpha - C_L} \left(\frac{S}{R+S}\right)$

Solid phase fraction $W_\alpha = \frac{C_0 - C_L}{C_\alpha - C_L} \left(\frac{R}{R+S}\right)$

If you know Volumes $V_\alpha = \frac{V_\alpha}{V_\alpha + V_\beta}$

If you know mass fraction and densities

$$V_\alpha = \frac{\frac{W_\alpha}{\rho_\alpha}}{\frac{W_\alpha}{\rho_\alpha} + \frac{W_\beta}{\rho_\beta}}$$

If you know Volume fraction and densities

$$W_\alpha = \frac{V_\alpha \cdot \rho_\alpha}{V_\alpha \cdot \rho_\alpha + V_\beta \cdot \rho_\beta}$$

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* Development of microstructure in isomorphous alloys *

- Equilibrium cooling of Cu–Ni alloy (35 wt% Ni)

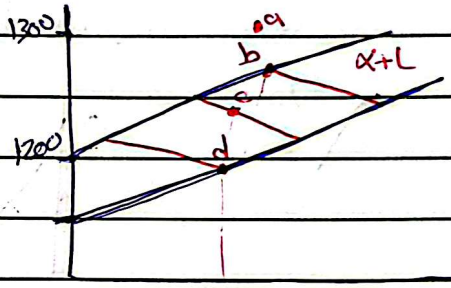
① At 1300°C (point a):-
The alloy is fully liquid (homo)

② Cooling into α + liquid region:-
First solid crystal begin to form they have higher Ni than liquid

③ Further cooling:-
More α forms and liquid shifts toward lower Ni and change composition gradually

④ At solidus line:-
last drop of liquid solidifies, final α phase has uniform.

⑤ Below solidus:-
Entire alloy is solid.



- Nonequilibrium cooling

– Why equilibrium fails?? because solid diffusion only happens at slow cooling. At temp drops liquid and solid phases must adjust to phase diagram. and require diffusion (time-dependent) and slow in solids.

So, In real world cooling is too fast → no time for full adjustment → nonequilibrium

– Why coring happens??

- During fast cooling diffusion in solid is too slow
- As α grains grow the composition changes but the inner parts don't adjust
- This creates composition gradient called coring. (centers high melting (Ni) | boundaries low melting (Cu))

– What is the solution??

Homo heat treatment below solidus temp → allow diffusion even out → eliminates coring and improve prop

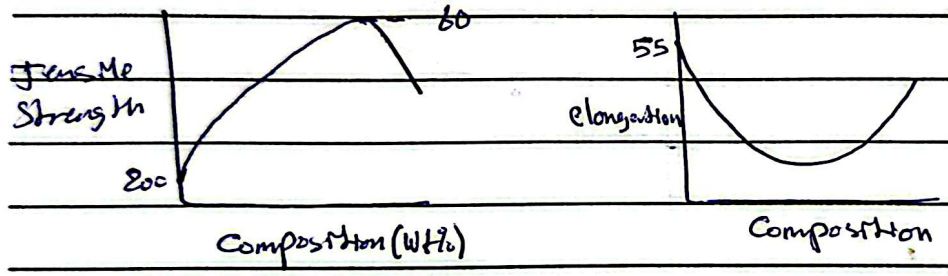
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Mechanical prop of isomorphous alloys

- Below the melting point of the lowest melting component only solid phase exist
- each component strengthens the other via solid solution
- Tensile strength increases with alloying, revealing maximum at intermed.
- Ductility behaves oppositely ⇒ decreases with alloying and reaching min

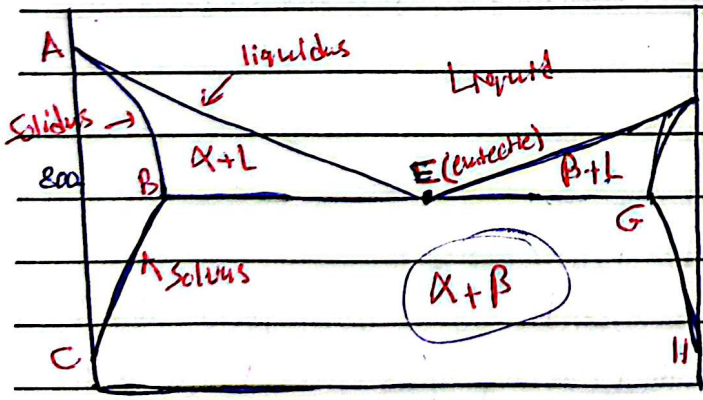
Binary eutectic systems (Cu-Ag)

- Three single-phase regions α, β and L
- α phase ⇒ rich in copper, silver is solute.
- β phase ⇒ rich in silver, copper is solute.
- Eutectic point ⇒ where liquids transform into α+β



Strength increases with Ni addition peaks around 60 then decreases towards pure Ni

Ductility decreases with Ni addition Reaches min around 50wt% of Ni then increases slightly towards pure Ni



Eutectic phase diagram

$$L(C_E) \underset{\text{melting}}{\overset{\text{Cooling}}{\rightleftharpoons}} \alpha(C_{\alpha E}) + \beta(C_{\beta E})$$

- Solvus line: Seperate α or β from two phase (α+β)
- Solidus line: Seperate solid from solid+liquid
- Liquidus line: Seperate L from L+solid
- Point B ⇒ α phase
- Point G ⇒ β phase
- Point A ⇒ melting point of pure Cu
- H-I-[illegible] ⇒ eutectic isotherm

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Summary

- In any phase field only one or two phases can be in equilibrium.
- In eutectic system, three phases can exist only at eutectic isotherm.
- Single phase regions always seperated by two phase.

Microstructure in eutectic alloys

Slow cooling of eutectic alloys leads to different micro depending on composition. using (Pb–Sn) we analyze:-

Case 1 : Near pure component at room temp → for Pb rich solid α phase Sn dissolved in Pb (0–2 wt% Sn)
→ for rich Sn solid β phase Pb dissolved in Sn (pure Sn 100%)

- Solders are metal alloys to join components

Case 2 : alloys with Sn (2–18.3 wt%) Pb rich or 97.8–99 wt% (Sn rich)

① Liquid region Alloy is fully liquid at high temp
② α + L follows liquidus and solidus curves
③ Above solvus line ⇒ micro (α grains with C_2)
④ Crossing solvus line ⇒ α phase exceeds and small β
⑤ final micro ⇒ α matrix with dispated β (Secondary phase precipitation)

Case 3 : At 183°C the liquids transform directly into:-
α (Pb rich) / β (Sn rich) transform is isothermal with no primary phase forms & entire solid reaction is eutectic and final structure is fine and regular (lamellar eutectic)

Case 4 :

- Thermal path:-
  - start at high temp (fully liquid) C_4 at 350°C
  - at 330°C → cross liquidus line → α begins to form
  - In α + L composition follow solidus and liquidus.

- Crossing eutectic isotherm (779°C):
  - Remaining eutectic liquids solidifies into lamellar (α + β)
  - previously formed remains unchanged.

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- Final microst:-
- primary α formed before eutectic
- eutectic α+β formed from eutectic liquid

* Using lever rule for primary α and eutectic:-
- Microconstituents → primary α forms before eutectic temp
  eutectic (α+β) forms from eutectic liquid

fraction weight

$$W_e = W_L = \frac{P}{P+Q}$$

eutectic

$$W_{\alpha'} = \frac{Q}{P+Q} \qquad W_\alpha = \frac{Q+R}{P+Q+R} \qquad W_\beta = \frac{P}{P+Q+R}$$

* Equilibrium diagrams having intermediate phases *
for (Cu-Ag) and (Pb-Sn) α+β ⇒ called terminal solid solution
But In more complex systems like (Cu-Zn) → arranged pattern
despite complex only one or two phases exist
2 terminal α and η
4 intermediate β, γ, δ, ε

* In some alloy systems instead of forming solid solutions we get (intermetallic compounds) like (Mg-Pb)
- these are distinct chemical compounds
- they appear (vertical lines (fixed))
- they don't composition like α or β

* Eutectoid and peritectic reactions *
* eutectoid reaction: occurs at fixed temp. transforming one (solid) phase into two solid (Cu-Zn) it resemble eutectic but occurs in solid st

* Peritectic reaction: occurs at fixed temp (solid + liquid) into a new solid phase.

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Congruent phase transformations

- Occurs without any change in composition
- phases involved retain the same chemical makeup

(Congruent transformation like Mg-P

- Occurs with a change in composition of at least one phase
- resulting phases differ chemically from the original.
- Ex eutectic and peritectic

(In Cong. transform

Ceramics and ternary phase diagrams

- phase diagrams exist for ceramics too.
- Ternary systems (3 components) are shown in 3D.

Gibbs phase rule

$P + F = C + N$ → external variables (usually T & P)

P: num of phases; F: degree of freedom; C: num of components

Ex For a ternary system, three components are present, temp is also variable. What is max num of phases that may be present for a ternary system assuming pressure constant?

$$P = 3 + 1 = 4$$

The Iron – Carbon system ($Fe - Fe_3C$)

- Is the most important binary alloy system in materials science.
- steels and cast irons are iron – carbon alloys
- pure iron undergoes allotropic transformation before melting
- Allotropic changes in iron:-

① room temp → phase: Ferrite (α iron), BCC

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② At 912°C → Austenite (γ-iron) FCC

③ At 1394°C → δ-ferrite (BCC)

④ At 1538°C → iron melts.

Picture page 361 from the Book

[1] Critical temp:-

Transformation	temp	Description
Melting point of pure	1538°C	Iron becomes liquid
End of δ ferrite	1493°C	Transition from δ to liquid
End of austenite γ	1395°C	transforms to δ ferrite.
Start to austenite γ	912°C	α-ferrite transforms to γ-austinite
Eutectoid temp	727°C	$\gamma \rightarrow \alpha + Fe_3C$ (solid → two solids)
Eutectic temp	1147°C	$L \rightarrow \gamma + Fe_3C$ (liquid → two solids)

(α → γ → δ → liquid)

[2] Important compositions (wt% carbon):-

Point	Composition	Meaning
α-ferrite max solubility	0.022 wt% C	Max carbon in ferrite
Eutectoid composition	0.76 wt% C	γ transforms to α + Fe_3C
γ-austinite max solubility	2.14 wt% C	Max carbon in austenite
Eutectic composition	4.3 wt% C	Liquid transforms to γ + Fe_3C
Cementite (Fe_3C)	6.7 wt% C	Fixed composition of Fe_3C

[3] Phase regions:-

Phase	symbol	Structure	Notes
Ferrite	α	BCC	Soft, low carbon solubility
Austinite	γ (non magnetic)	FCC	higher carbon, ductile
Cementite	Fe_3C	Complex	hard and brittle
Liquid	L	—	above melting point
α + γ	—	two solids	transition region
γ + Fe_3C	—	two solids	Found in steels and Five Apples Iron
α + Fe_3C	—	two solids	found below eutectoid point

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Key values to memorize

Property	Value
Cementite composition	6.7 wt% C
Max carbon in ferrite	0.022 wt% C at 727°C
Ferrite becomes magnetic	below 768°C
Ferrite density	7.88 g/cm³

Note: even small amounts of carbon significantly increases strength.

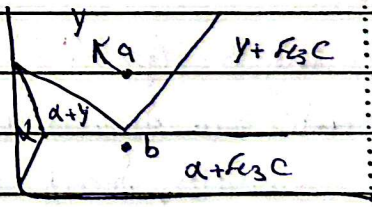
Classification of Iron–Carbon alloys by carbon content

- **Steels:** Iron less than 0.008
  - Carbon 0.008% to 2.14% carbon
  - Typically α (ferrite) and Fe_3C (cementite)
  - Cooling involves passing through the γ austenite
  - In practice carbon content rarely exceeds 1% steels.

- **Cast iron:**
  - Carbon 2.14% to 6.7% carbon
  - Commercial cast iron usually less than 4.5% C

Development of Iron carbon alloys

- Micro depends on (Heat, carbon)
- Focus is on very slow cooling
- Complex phase from γ to $\alpha + Fe_3C$



At 727°C austenite transforms into a structure called pearlite.

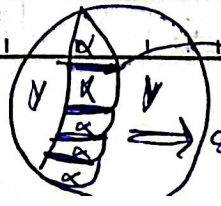
$\alpha + Fe_3C$

Pearlite consists of alternating layers (lamellae) of:-

① Ferrite (α) thick, light (0.022%)

② Cementite thin, dark (6.7%) 8:1 (ferrite to cementite)

Pearlite forms in colonies, each with distinct layer orientation.



FCC

growth direction

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* Hypoeutectoid alloys : alloys with carbon less than 0.76% between 0.022% and 0.76% and they contain less carbon than eutectoid

- When slowly cooled :-

① transforms begins around 875°C $\quad \gamma \rightarrow \alpha+\gamma \rightarrow \alpha+Fe_3C$

② changes in micro follow the vertical line y-y'

③ micro consists of austenite only

* Micro of steel with 0.44% carbon :-

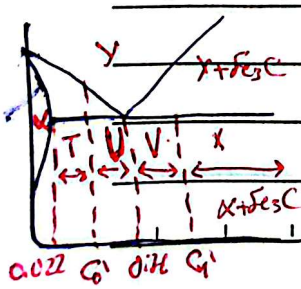
- Proeutectoid ferrite : large dark before eutectoid temp
- Pearlite : alternating light and dark lamellae of ferrite and cementite

* Micro evolution during cooling :- (page 328)

- At around 775°C (point d)
  - C = contains both γ and α
  - F = ferrite forms along original austenite
  - Ferrite composition 0.022% C, Austenite 0.4% C

- Cooling to (point e) above
  - More ferrite forms and grows larger
  - Ferrite 0.022% C, Austenite 0.76% C

- Cooling to (point f) below
  - All eutectoid transforms to pearlite
  - pre-existing ferrite remains unchanged
  - Ferrite types → eutectoid ferrite within pearlite
    → Proeutectoid before eutectoid temp



pearlite fraction $W_p = \frac{T}{T+U} = \frac{C_0' - 0.022}{0.76 - 0.022}$

proeutectoid, fraction $W_{\alpha'} = \frac{U}{T+U} = \frac{0.76 - C_0'}{0.76 - 0.022}$

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[Steels]

Hypereutectoid alloys (0.76% – 2.11% carbon)

Starts at γ only then enters α + Fe_3C produces Cementite then at 727°C (eutectoid temp) remaining γ transforms into pearlite

Note: pro-eutectoid cementite looks similar to ferrite.

Note: Non-equilibrium cooling is preferred because it can happen at room temp that are not show on the phase diagram.

Note: Fe_3C is (metastable compound) not fully stable.

Elements like Cr, Ni, Ti, Mo, Mn, Si, W:- (temp increase, wt% decrease)

Cause changes in iron – carbon they shift phase boundary and shape

These shifts affect → amount of pearlite

→ amount of proeutectoid (ferrite or cementite)

Questions

[1] Cite three variables that determine the micro of an alloy?

heat treatment, alloying, concentrations

[2] What thermodynamics condition must be met for a state equilibrium to exist? free energy min at constant (temp, pressure, composition)

[3] How many (kg) of nickel must be added to 1.75 kg of copper to yield liquids temp of 1300°C??

From figure Cu–Ni at 1300°C Ni is 43wt%

$$43\text{wt}\% = \frac{m_{Ni}}{1.75 + m_{Ni}} \times 100 \Rightarrow m_{Ni} = 1.32\text{kg}$$

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[4] The phases that are present and the phase compositions:

(a) 15 wt% Sn – 85 wt% Pb at 100°C.

From figure

C_β = 98% Sn – 2% Pb

C_α = 5% Sn – 95% Pb

(b) 1.25 kg Sn and 14 kg Pb at 200°C

$$W_{Sn} = \frac{1.25}{1.25+14} \times 100 = 8.2 \text{ wt\%}$$

$$W_{Pb} = \frac{14}{1.25+14} \times 100 = 91.8 \text{ wt\%}$$

(c) 21.7 mol Mg and 35.4 mol Pb at 350°C.

$m_{Mg} = n \alpha A = 527$ g , $m_{Pb} = 7335$ g

C_{Pb} = 93.3 wt% , C_{Mg} = 6.7 wt%

[5] Is it possible to have a copper silver alloy that at equilibrium of β phase of 92 wt% Ag – 8 wt% Cu and also a liquid phase of 71.9% Ag – 28 wt% Cu ? If so, what will be the approximate temp?

from figure yes it is possible at 800°C

[6] A 2 kg specimen of an 85 wt% Pb – 15 wt% Sn alloy is heated to 200°C at this temp it is entirely on α-phase solid solution (figure 9.8) The alloy is to be melted to the extent that 50% of the specimen is liquid the reminder is α.

a) To what temp must the specimen heated?

From the figure it may it be 280°C

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(b) How much (Sn) must be added to the 2kg specimen at 200°C to achieve this state?

From figure C_α = 17wt% Sn – 83wt% Pb

C_L = 57wt% Sn – 43wt% Pb

$$0.5 = \frac{C_0 - (C_L)}{C_\alpha - C_L} = \frac{57 - C_0}{57 - 17} \Rightarrow C_0 = 37 \text{ wt\% of Sn}$$

7] Consider 2.5kg of a 80wt% Cu – 20wt% Ag at 800°C, How much copper must be added to this alloy to cause it completely solidify at 800°C?

$m_{Cu(old)} = 2.5 * 0.8 = 2kg$

$$C_{Cu} = \frac{2 + m_{Cu}}{2.5 + m_{Cu}} \Rightarrow 0.92 = \frac{2 + m_{Cu}}{2.5 + m_{Cu}} \Rightarrow m_{Cu} = 3.75kg$$

8] For alloys of two metals A and B determine the composition of the phase boundary for both α and β at this temp.

Alloy composition	Fraction α phase	β phase
70wt% A – 30wt% B	0.78	0.22
35wt% A – 65wt% B	0.36	0.64

Sol

$$0.78 = \frac{C_\beta - C_0}{C_\beta - C_\alpha} \Rightarrow 0.78 = \frac{C_\beta - 70}{C_\beta - C_\alpha}$$

$$0.36 = \frac{C_\beta - 35}{C_\beta - C_\alpha}$$

$C_\alpha = 88.5$, $C_\beta = 5$

9] A hypothetical A–B alloy of composition 40wt% B – 60% A is found to consist of mass fractions of 0.66 and 0.34 for α and β, if the composition of α phase is 13wt% B – A, what is the composition of β phase?

$$0.66 = \frac{C_0 - C_\beta}{C_\beta - C_\alpha} \Rightarrow 0.66 = \frac{40 - C_\beta}{C_\beta - 13}$$

$C_\beta = 92.9$

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10 (a) Briefly describe the phenomenon of coring?

across grains in polycrystalline alloys with higher concentrations of component having lower melting temp

11 What is the different between a phase and a microconstituent?

⇓ more than one phase (element of micro)

12 At 100°C, what is the maximum solubility of:-

(a) Pb in Sn (b) Sn in Pb

Sol with reference figure 9.8 and the rule

Pb - Sn

⇓ ⇓

α β

⇓ ⇓

Sn 5% Sn 98%

Pb 95% Pb 2%

(a) Pb in Sn ⇒ Pb in β ⇒ 2 wt%

(b) Sn in Pb ⇒ Sn in α ⇒ 5 wt%

13 How many kg of nickel must be added to 5.43 kg of copper to yield solidus temp at 1200°C?

α + L ⇒ Cu ⇒ 70 wt% = $\frac{m_{Cu}}{5.43 + m_{Cu}} \times 100$

m_{Cu} = 12.7 kg

19 A 65 wt% Ni-35 wt% Cu is heated to a temp within α + L region. If the composition of the phase is 70 wt% Ni determine-

(a) The temp of this alloy ⇒ 1345°C

(b) The composition of liquid phase:-

59 wt% of Ni

(c) The mass fraction of both phases:-

$W_\alpha = \frac{65-59}{59-70} = 0.55$, $W_L = \frac{70-65}{70-59} = 0.45$

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[5] A Cu alloy with Ag is heated to 900°C and is consist of α and L phases. If the mass fraction of Liquid phase is 0.68 determ
(a) The composition of both phases, in both weight and atomic percent.

Cu — Ag

↓ α ↓ L

Cu 92% Cu 57%

Ag 8 % Ag 43%

$$C_{a1\%} = \frac{C_1 \infty A_2}{C_1 \infty A_2 + C_2 A_1} \Rightarrow C_{Ag}\,\%(X) = \frac{(8\%)(63.55)}{(8\% \times 63.35) + [92][107]} = 49$$

$$C_{Cu}(\alpha) = 95.1 \text{ at\%}$$

ثم بنفس الطريقة لـ Liquid

[6] Is it desirable to produce a copper-nickel alloy that has a room-temperature cold worked tensile strength of 330 MPa and a ductility of at least 45% EL. Is such an alloy possible? If so, what must be its composition? If this is not possible explain why.

It is not possible depending on Figure 9.6a and 9.6b

[7] A 60 wt% Pb – 40 wt% Mg is rapidly to room temp. is consist of α phase and Mg_2Pb. having mass fractions of 0.42 and 0.58. Determine the temp.

Sol

$$C_\alpha = 0.42 = \frac{C_{Mg_2Pb} - C_0}{C_{Mg_2Pb} - C_\alpha} \Rightarrow 0.42 = \frac{81 - 60}{C_{Mg_2Pb} - C_\alpha}$$

$$C_\alpha = 31 \text{ wt\% Pb}$$

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18] Is it possible to have Mg–lead alloy in which the mass fractions of primary α and total α are 0.6 and 0.85, at 460°C? Why?

From figure

$C_\alpha = 41\%$ ✓ $\quad C_\beta = 67\%$

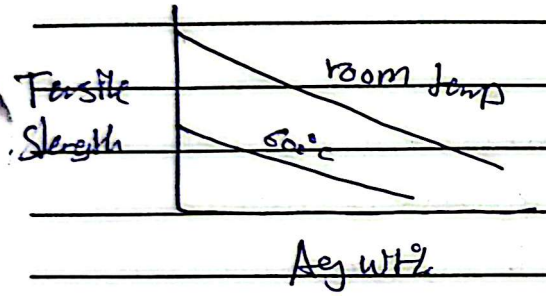
$$W_\alpha = \frac{C_0 - C_\beta}{C_\alpha - C_\beta} = \frac{C_0 - 67\%}{67\% - 41\%} = 0.6$$

$C_{Mg_2Pb} = 81\%$ ✓

$$0.85 = \frac{81 - C_0}{81 - 41}$$

$C_0 = 47\%$ of Pb

19] The room temp tensile strengths of pure copper and pure silver are 209 and 125 MPa. Draw when room temp then at 600°C



600°C أقل
الانخفاض في الـ Tensile
لزيادة تحمل الـ Tensile

20] Two intermetallic compounds A_3B and AB_3, one having 91 wt% A – 9 wt% B / 53 wt% A – 47 wt% B and element A is an identity element B.

A_3B → 75, 25

$$C_B = 25 \text{ at\%} = \frac{(9)(A_A)}{(91)(A_B) + 9(A_B)}$$

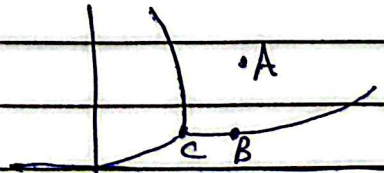
$$A_B = 0.297 A_A = (0.297)(91.22) = 27.09 \text{ g/mol}$$

B ⇒ Al

21] Pressure – temp phase diagram of H_2O. Apply gibbs rule at point A, B, C.

$$P + F = C + N \Rightarrow (2)$$

(1 unary)



at A ⇒ $1 + F = 1 + 2$, $F = 2$ // at B ⇒ $2 + F = 3$, $F = 1$ // at C $F = 0$

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22 | Specify the number of degrees of freedom for the following:-

(a) 20 wt% Ni – 80% Cu at 1300°C

$P + F = C + N$ (Binary) Isomorphous

$F = 3 - 1 = 2$

(b) 71.9 wt% Ag – 28.1 wt% Cu at 779°C

$P + F = C + N$ (Binary)

$F = 3 - 3 = 0$

23 | Compute the mass fraction of α-ferrite and Fe_3C in pearlite:-

$$W_\alpha = \frac{C_{Fe_3C} - C_0}{C_{Fe_3C} - C_\alpha} = \frac{6.7 - 0.76}{6.7 - 0.022} = 0.89$$

$W_{Fe_3C} = 0.11$

24 | What is the difference between hypoeutectoid and hypereutectoid steels?

hypoeutectoid:
- has Carbon less than eutectoid
- above eutectoid temp
- for both 0.022 wt%

hypereutectoid:
- has Carbon greater than eutectoid
- below eutectoid temp
- for both 0.022 wt%

25 | What is the proeutectoid for an iron–carbon alloy in which the mass fraction of total ferrite and total cementite are 0.86 and 0.14?

$$0.86 = \frac{6.7 - C_0}{6.7 - 0.022}$$

$C_0 = 0.96$ wt%

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[26] Consider 3.5 kg of γ containing 0.95 wt% C and cooled to below 727°C.

(a) What is the proeutectoid phase?

α + Fe_3C since 0.95 wt% greater than 0.76

(b) How many kg each of ferrite and cementite form?

$$W_\alpha = \frac{6.7 - 0.95}{6.7 - 0.022} = 0.86 \text{ mass} \times 3.5 = 3 \text{ kg}$$

$$W_{Fe_3C} = \frac{0.022 - 0.95}{6.7 - 0.022} = 0.14 \times 3.5 = 0.49 \text{ kg}$$

(c) How many kg each of pearlite and proeutectoid phase form?

$$W_{Fe_3C} = \frac{0.95 - 0.76}{5.94} = 0.03$$

$$W_p = \frac{6.7 - 0.95}{5.94} = 0.97$$

[27] Compute the mass fractions of proeutectoid ferrite and pearlite containing 0.35 wt% C.

أكبر من 0.76 لأنه أقل من 0.35 لذلك يعتبر أصلاً

α و 0.022 بدلاً من 0.022

$$W_{p(\alpha)} = \frac{C_1 - 0.022}{0.76 - 0.022} = \frac{0.35 - 0.022}{0.74} = 0.44$$

$$W_{\alpha'} = \frac{0.86 - 0.35}{0.74} = 0.56$$

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28) Is it possible to have an iron-carbon alloy for which the mass fractions of total cementite and proeutectoid ferrite are 0.057 and 0.36?

$$W_{\alpha'} = \frac{0.76 - C_0}{0.76 - 0.022} = 0.36 \Rightarrow C_0 = 0.494 \text{ wt\%}$$

$$W_{Fe_3C} = \frac{C_0 - 0.022}{6.7 - 0.022} = 0.057 \Rightarrow C_0 = 0.4 \text{ wt\%}$$

} Different C_0 so not possible.

29) Compute the mass fraction of eutectoid cementite if steel contains 1 wt%.

$$W_{eutectoid} = W_{Fe_3C} - W_{proeutectoid}$$

$$W_{Fe_3C} = \frac{1 - 0.022}{6.7 - 0.022} = 0.146$$

$$W_{Fe_3C} = \frac{1 - 0.76}{5.94} = 0.04$$

$$W_{eutectoid} = 0.106$$

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