

Lecture

COURSE DESCRIPTION:

Study of atomic and crystal structures of materials; energy bands in solids; imperfections and atomic motion in materials; phase equilibria and transformation; boundaries; heat treatment of metals; study of metallic and nonmetallic materials; mechanical, physical and chemical properties of materials.

OBJECTIVES:

1. To learn the engineering language for materials.
2. To learn the nature of mechanical, physical, and chemical properties.
3. To learn the behavior of selected materials of engineering importance.
4. To learn the primary considerations in the selection of materials for engineering uses.
5. To learn the basic concepts of physical metallurgy.
6. To learn the correlation between physical metallurgy and properties of selected engineering materials.

TEXT: Guy, Physical Metallurgy for Engineers

REFERENCES:

- 664
6734e ← Guy, Elements of Physical Metallurgy
- Committer on Metallurgy, Engineering Metallurgy
- Samans, Engineering Metals and Their Alloys
- Barrett, Structure of Metals — *Switlin's = max* → 669 S187e
- Young, Materials and Processes → 539.2
- Sinnott, The Solid State for Engineers → 5617s Young
- Murphy, Properties of Engineering Materials → 620.1 M978.2
- Hausner and Roboff, Materials for Nuclear Power Reactors
- Practical, Principles of the Properties of Materials → 669 R473p 473m2
- Phase Diagrams in Metallurgy
- Van Vlack, Elements of Materials Science
- Jastrabekski, Nature and Properties of Engineering Materials 620.1 J39N

ASSIGNMENTS:

Reading assignments will be made from the text and the references.
Written assignments will be submitted on one side only of 8 1/2 x 11 paper.
Problems will be assigned in class.

EXAMINATIONS:

Four one-hour exams will be given during the term. The dates of these exams appearing in the class schedule. Three of these exams will cover lecture material, the fourth will cover laboratory material. Quizzes of five or ten minutes duration may be given unannounced at any class session. A final examination covering the entire course content, both lecture and laboratory will be given. Anyone missing an announced test without an authorized excuse will receive a zero for that particular test. There will be no make-up for short quizzes.

GRADING:

- 3 one-hour lecture examinations
- Final Examination
- Quizzes, reports and questions
- Laboratory work (including lab examination)

42.5%
22.5%
10.0%
25.0%

Labs 1/4 of grade
No labs this week.

Lecture

Lecture No.	Date	Lecture Topic	Reading (Guy)
1	9-17	Introduction	pp. 1-3
2	9-19	Atomic Structure, Principles of Atomic Theory	pp. 28-31 Supplementary Van Vlack Chapter 2 or Sinnott Ch. or Library Texts on Atomic Physics
3	9-21	" " " " "	" " " "
4	9-24	Electron energies in solids	" " " "
5	9-26	Bonding in solids	pp. 28-36
6	9-28	Space lattices and Crystal systems	pp. 36-50 Suppl. Van Vlack pp. 47-6
7	10-1	Space Lattices and Crystal systems	or Barrett or Committee on Met.
8	10-3	Imperfections in crystal structures	pp. 50-60
9	10-5	" " " "	pp. 50-60
10	10-8	Properties: resistivity and semi-conductors	pp. 168-191 also Van Vlack Ch. 14
11	10-10	Thermoelectric effects - magnetic properties	" " " "
12	10-12	EXAM NO. 1	
13	10-15	Elasticity - Stress-Strain relations	pp. 198-205
14	10-17	" " " "	" " " "
15	10-19	Plasticity, Stress-strain relations	pp. 205-219
16	10-22	Plasticity - Hardness	pp. 205-219
17	10-24	Fracture - Impact behavior	pp. 223-24
18	10-26	Fatigue strength and damping capacity	pp. 224-26
19	10-29	Crimp and stress rupture strength	pp. 226-32
20	10-31	Wear resistance and bearing properties	pp. 234-38
21	11-2	Corrosion and oxidation	Ch. 11
22	11-5	Corrosion and Oxidation	Chapter 11
23	11-7	Diffusion in Metals	pp. 241-250
24	11-9	Recovery, recrystallisation, grain growth	pp. 251-264

Lecture No.	Date	Lecture Topic	Reading (Qty)
	11-12	Veteran's Day - Holiday	
25	11-14	EXAMINATION NO. 2	
26	11-16	Phases in Metal Systems, Phase <u>Rules</u>	Chapter 4
27	11-19	Phases in Metal Systems, the Solid Phase	Chapter 4, pp. 60-62
28	11-21	Phase diagrams; solid solution systems	" "
	11-23	THANKSGIVING HOLIDAY	
29	11-26	Phase Diagrams - Eutectic Systems	Chapter 4
30	11-28	Phase Diagrams - Intermediate Phases Peritectics	"
31	11-30	Non-Equilibrium Cooling	"
32	12-3	Age Hardening	Chapter 9
33	12-5	Iron-Carbon Diagram - Cast Irons and Steels	Ch. 5, pp. 136-151
34	12-7	Steel Heat Treatment	Chapter 10
35	12-10	Steel Heat Treatment	Chapter 10
36	12-12	Hardenability	"
37	12-14	EXAMINATION NO. 3	
		CHRISTMAS HOLIDAY	
38	1-2	Alloying Elements in Steel	<i>Chap 5</i> Chapter 5 pp. 151-55 pp. 157-166, pp. 170-171
39	1-4	Copper Alloys	
40	1-6	Light Metal Alloys	
41	1-7	Light Metal Alloys	pp. 278-281
42	1-9	Heavy and Refractory Metals	Samans
43	1-11	Nuclear Materials	pp. 192-196

Lecture No.	Date	Lecture Topic	Reading (Qty)
44	1-14	Ceramic Materials	Van Vlack Ch. 5
45	1-16	Organic High Polymers	Van Vlack Ch. 6

FINAL EXAMS START THURSDAY

Zuhar Munir - 5212 Office Hrs: MWF 2³⁰-3³⁰
TuTh 1³⁰-2³⁰

Exams will be based on the lectures, primarily.

ATOMIC STRUCTURE

Atomic weight: gram/gram atom

gram atom $\equiv 6.02 \times 10^{23}$ atoms = Avogadro's No. $\equiv N$

Wt. of 1 atom = atomic wt. / N

Outer shell electrons influences

1. chemical properties
2. inter atomic bonding (which in turn influences mech. prop's.)
3. atomic size.
4. electrical conductivity.
5. optical characteristics.

Electrons occupy fixed orbits (shells)

1st shell \equiv K shell

2nd " \equiv L "

M, N, O, P, Q,

Shell : Max. No. of e^-

K 2

L 8

M 18

N 32

O 50

CLASSICAL TREATMENT OF THE ATOM.

9/2/62

The Bohr Atom.

Bohr's

Assumptions

1. Orbits around nucleus have fixed energies.
2. Changes in energy's are governed by:

$$\Delta E = h\nu$$

ν = radiation freq.

h = Planck's constant

ΔE = energy change.

K.E. of Hydrogen electron = $e^2/2r$ \circ

Centrifugal force balances attractive force (electro-static) to keep e^- in equilibrium.



$$C-S \text{ force} = K \frac{e^- \cdot \text{proton}^+}{r^2} = K \frac{e^2}{r^2}$$

$$\text{Centrifugal force} = \frac{mv^2}{r}$$

m = electron mass

e^- = " charge

r = dist. of e^- from nucleus (radius of orbit).

$$\frac{e^2}{r^2} = \frac{mv^2}{r}, \text{ since } KE = \frac{1}{2}mv^2$$

$$\frac{e^2}{2r} = \frac{mv^2}{2r}; \quad KE = \frac{e^2}{2r}$$

P.E. of hydrogen atom:

Define P.E. = 0 when e^- at $r = \infty$.

∴, set P.E. = 0 at $r = \infty$.

$$PE = \int_{\infty}^r F \cdot dr \quad (F \text{ is the } C-S \text{ force})$$

$$F = \frac{e^2}{r^2}$$

$$PE = \int_{\infty}^r \frac{e^2}{r^2} dr = e^2 \int_{\infty}^r \frac{dr}{r^2} = -\frac{e^2}{r} \Big|_{\infty}^r$$

$$PE = -\frac{e^2}{r}$$

$$E_{\text{TOTAL}} \text{ of } e^- = KE + PE = \frac{e^2}{2r} - \frac{e^2}{r} = -\frac{e^2}{2r}$$

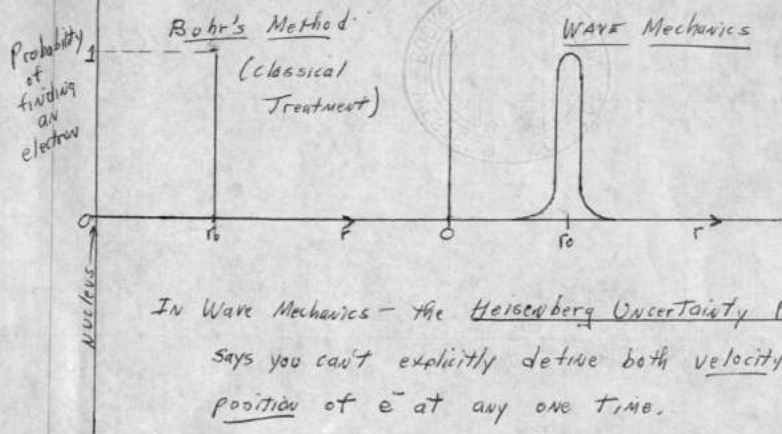
$$E_T = -\frac{e^2}{2r}$$

WAVE MECHANICS

Electrons behave as if they were light waves.
 \therefore We must treat the e^- as both a particle or corpuscle and a wave mechanism.

Schrodinger developed a function for describing the e^- anywhere in space.

Plotting probability vs. radius we find the differences between the Bohr model & Wave Mech theory.



In Wave Mechanics - the Heisenberg Uncertainty Principle says you can't explicitly define both velocity and position of e^- at any one time.

QUANTUM NOS.

NOS:
 n = principle Q.N. (levels of energy)
 l = orbital Q.N.
 m_l = magnetic Q.N.
 m_s = spin Q.N.

Values of Q.N.'s:

$n = 1, 2, 3, \dots, \infty$
 $l = 0, 1, 2, \dots, n-1$
 $m_l = \pm l$ i.e., $(-l, -l+1, -l+2, \dots, 0, 1, 2, \dots, +l)$
 $m_s = \pm 1/2$

Pauli Exclusion Principle: No 2 e^- can have the same set of Quantum Nos.

As n increases, energy increases.

Ground state and lowest energy level is at $n=1$.

n is a measure of the total energy of the e^- .

H: $n=1; l=0, m_l=0, m_s = +1/2$

He: $1s^2 e^-: n=1, l=0, m_l=0, m_s = +1/2$

$2s^2 e^-: n=1, l=0, m_l=0, m_s = -1/2$

<u>Li</u>	<u>3rd e^-</u>	<u>4th e^-</u>
$n=2$	$n=2$	$n=2$
$l=0, 1$	$l=0$	$l=0$
$m_l=0, -1, +1$	$m_l=0$	$m_l=0$
$m_s = \pm 1/2$	$m_s = +1/2$	$m_s = -1/2$

s, p, d, f, ...

Any e^- whose $l=0 \equiv s$ electron (state)

" $l=1 \equiv p$ " "

" $l=2 \equiv d$ " "

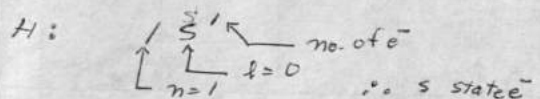
" $l=3 \equiv f$ " "

S state has $l=0, \therefore m_l=0, m_s = \pm 1/2$
 so 2 possible e^- .

P state has ~~$l=0$~~ $l=1 \therefore m_l = -1, 0, 1, m_s = \pm 1/2$
 so 6 possible e^- .

deriv for H.W. { d state has 10 possible + " " 14 "

n, l essentially determine the total energy of the e^- .

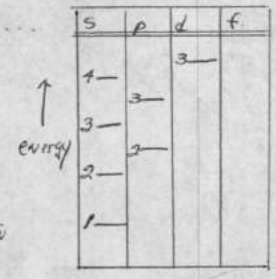


He: $1s^2$ Li: $1s^2, 2s^1$

Order: 1s, 2s, 2p, 3s, 3p, 4s, 3d, ...

Be: 1s², 2s²

Fl 9: 1s², 2s², 2p⁶
 Ne 10: 1s², 2s², 2p⁶
 Mg 12: 1s², 2s², 2p⁶, 3s²



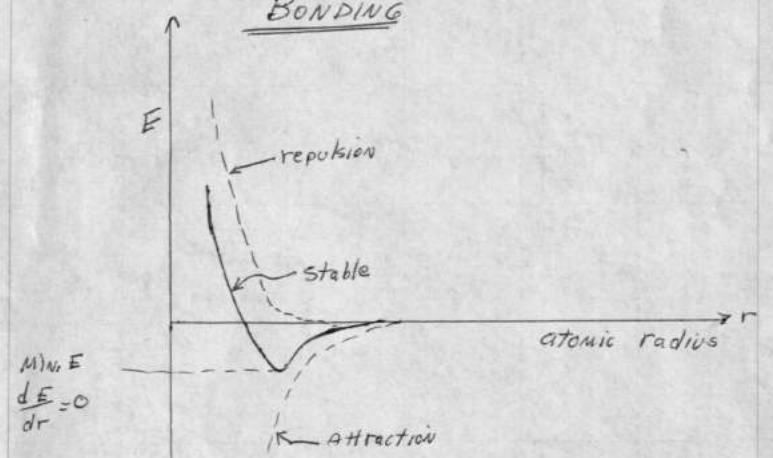
2nd Problem: Write e⁻ configurations (in spdf notation) for elements 1-19.

Box configuration:

1s²: $\uparrow\downarrow$

1s² 2s² 2p⁶: $\uparrow\downarrow$ $\uparrow\downarrow$ $\uparrow\downarrow\uparrow\downarrow\uparrow$
 1s 2s 2p

BONDING



Bond Types:

1. Ionic
2. Covalent
3. Metallic
4. Van der Waals

BONDING:

$$E = \frac{A}{r^a} - \frac{B}{r^b}, \quad A, B, a, b \text{ are constants}$$

$\frac{A}{r^a}$: energy of attraction.

$\frac{B}{r^b}$: energy of repulsion.

At E min, $\frac{dE}{dr} = 0$, we can solve for constants.

TYPES OF BONDS:

1. Ionic
2. Covalent
3. Metallic
4. Van der Waals

A. IONIC BONDING:

Non-directional
 bond of ions
 ions attract & repel each other until equilibrium is reached.

Properties, e.g.:

1. Hardness	BeO	MgO	CaO	SiO
inter atomic dist (A-x)	1.65 Å	2.10	2.40	2.57
hardness	9.0	6.5	4.5	2.5

Moh scale: diamond = 10, Quartz = 7, Gypsum = 2, Talc = 1

BeO has the stronger bond (because shorter bond distance).

2. Melting pt:	NaF	NaCl	NaBr	NaI
(A-x)	2.31	2.79	2.94	3.18
M.P.	988	801	740	660 °C.

3. Thermal Expansion: Volume change due to heat.
 linear exp.: change of length per unit length per unit temp.

$$\alpha = \frac{1}{l} \frac{dl}{dt}$$

l = length before heating
 dl = " change
 t = temp
 dt = " change.

(A-x)	NaF	NaCl	NaBr	NaI
$\alpha \times 10^6$	39	40	43	48

α large \Rightarrow material easy to expand w/ heat, \therefore weaker bond.

Munir

Ionic Bonds:

A. electrical prop:

Ionic crystals are non-conductors.

Bond strength	→
radius	←
melting pt.	→
hardness	→
thermal exp. (very slight)	→

B. COVALENT BONDING (electron sharing)

10/1/62

Molecules stay together in melt - no ions.
Strong bond; Barium nitrate, diamond, ex. gr.

Coordination No. = No. of nearest atoms in the crystal.

C. van der Waals:

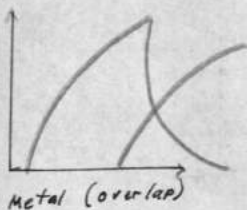
An induced dipole in every atom.
The bond is a dipole - dipole interaction.

Inert gases in solid state have van der Waal's bonds.

D. METALLIC BONDING:

Valence e^- devoted to a cloud.
The Coulombic force between the e^- cloud and the now-positively charged nuclei hold material together.

Metal energy bands constantly E overlap, $\therefore e^-$ are free to move in outer bands.



Property	Ionic	Covalent	Metallic	van der Waals
Mechanical	Strong, giving hard crystals	Strong, giving hard crystals	Variable strength gliding common	Weak, giving soft crystals
Thermal	Fairly high M.P. Low coeff. of expansion. Ions in melt	High M.P. Low coeff. of expansion. Molecules in melt.	Variable M.P. Long liquid interval	Low M.P. Large coeff. of expansion
Electrical	Moderate insulators Conduction by ions in melt	Insulators in solid and melt	Conduction by electron transport	Insulators
Structural	Non-directional Structures of high coordination.	Directional Structures of low coordination and low density	Non-directional Structures of very very high coordination and high density.	Analogous to metallic bond

CRYSTAL SYSTEMS - SPACE LATTICES

primitive cell:

cell which has only 1 total atom associated with it.



Assignment Probs 3.9, p. 68
10/3/62

Bravais Lattices - 14 types

Cubic:

1. primitive or simple: $8(\frac{1}{8}) = 1 \text{ atom}$



2. Body-centered cubic (BCC)

simple + 1 atom in middle of cube = 2 atoms e.g. Fe



3. Face-centered cubic (FCC)

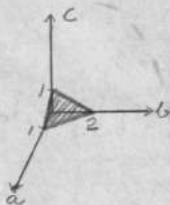
simple + $\frac{1}{2}$ of 1 atom on each face:
 $8(\frac{1}{8}) + 6(\frac{1}{2}) = 4$
e.g. Cu



Hexagonal Close-Packed (HCP):
e.g. Mg

MILLER INDICES:

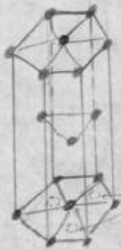
Intercepts of a plane: 1, 2, 1
Reciprocals of intercepts: $1, \frac{1}{2}, 1$
X thru to get whole nos, 2, 1, 2



$\therefore (2 \ 1 \ 2)$ planes

() \equiv set of planes

100: i.e. Miller indice alone means a particular plane.
Negative intercept, say $-3, 1, 1$ is written as $\frac{1}{3}, 1, 1 \Rightarrow \frac{1}{3} \ 1 \ 1$



Projections of 3 middle atoms on base.

Directions in a crystal:

Start line at origin, pick a pt. on line. Say coord. of pt. are 3, 2, 2.

We say line direction is 3:2:2.
(line MUST start at origin).

Type of Imperfection

I. Point defects:

- a. Interstitial
- b. Schottky defects (VACANCY)
- c. Frenkel defects (atb)



Description of Imperfection

Extra atom in an interstitial site.
Atoms missing from correct sites. (migrates to surface)
Atoms displaced to interstitial site creating nearby vacancy.



II. Line defects:

- a. edge dislocation $\vec{B} \perp$ to dis line
- b. screw dislocation $\vec{B} \parallel$ to dis line

Row of atoms marking edge of a crystallographic plane extending only part way in crystal.
Row of atoms about which a normal crystallographic plane appears to spiral.

III. Plane defects:

- a. Lineage boundary
- b. Grain boundary
- c. Stacking fault

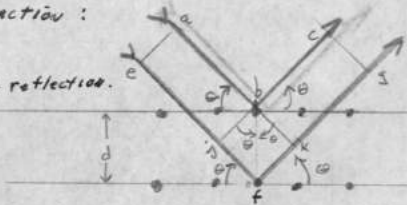
Boundary between two adjacent perfect regions in the same crystal that are slightly tilted with respect to each other.
Boundary between two crystals in a polycrystalline solid.
Boundary between two parts of a closest packing having alternate stacking sequences.

Zn/mn	1b. Schottky	favored when atoms are similar in size (NaCl)
	1c. Frenkel	are very different in radius (when size of ion are substantially different) (AgBr, AgI , etc) (generally neg ion is larger)

METHODS OF STUDYING CRYSTAL STRUCTURE

X-ray Diffraction:

\angle incidence = \angle reflection.



$ae = bf$
 $cg = dk$
 $ab = cd$
 $bc = dk$
 $efg - abc - jfk$
 $jfk = 2d \sin \theta$

For 2 waves to be in phase, the difference in the distance they travel (jfk) must be = to a multiple of the wave length, or:

BRAGG'S LAW: $2d \sin \theta = n\lambda$

Page of notes missing referring to Schottky & Frankel crystal defects.

CRYSTAL IMPERFECTIONS

10/5

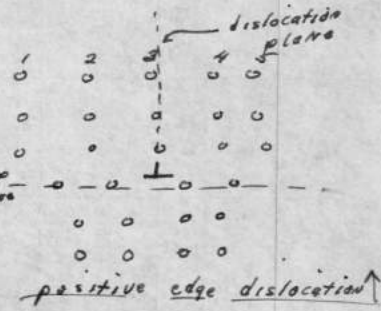
$n \approx$ number of point defects $\propto e^{-\Delta H/RT}$, where
 $e =$ base nat. logs
 $\Delta H =$ heat of formation of a defect
 $R =$ gas constant
 $T =$ temperature ($^{\circ}$ Kelvin)

ex. NaCl: For Schottky defects, $\Delta H \sim 2ev$

$n \approx n_{\text{Schottky}} \approx 10^6$ defects/cm³ at 800 $^{\circ}$ K (room temp)

LINE DEFECTS:

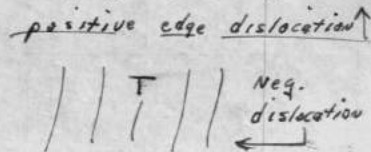
Edge Dislocation:



Plane 2 stops at dislocation line denote by \perp . Planes 1, 2, 3 try to straighten things out.

Magnitude of dislocations

by means of Burgers Vector



Screw Dislocations:

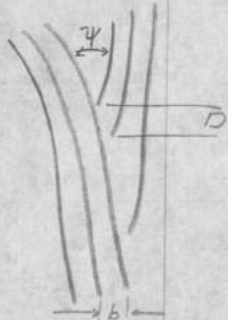
$\vec{b} \parallel$ dislocation line

Major Distinction between edge & screw dislocations:
 Screw: Burger's vector \parallel to dislocation line
 Edge: " \perp " " " " "

Dislocation density: $\rho = L/V$ where
 $L =$ total strength of dislocation
 $V =$ volume of crystal.

PLANE DEFECTS:

Grain Boundary (Most imp. plane defect):
 a grain is a crystal whose surfaces have been distorted.



ψ is small (in radians)

$b \approx D \psi$

STACKING FAULTS:

ABCABC | BCABC

← stacking fault.

If the N^{th} layer is A and the $N^{\text{th}+1}$ layer is C, then there is a stacking fault between the N^{th} and $N^{\text{th}+1}$ layers (assuming the $N^{\text{th}+1}$ layer was supposed to be a B).

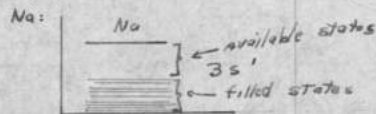
Stacking faults occur thru crystal growth or thru plastic deformation.

ELECTRICAL PROPERTIES OF METALS

10/1/62

Metals:

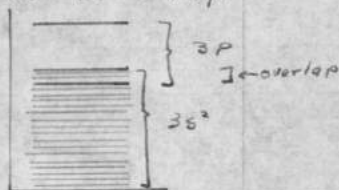
a) monovalent: e.g. Na
low density, high conductivity



CONDUCTORS have available states for e^- to go.

b. divalent; e.g. Mg.

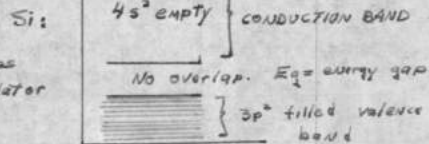
Because of the overlap, when $3s^2$ is full of e^- , the e^- are also at the bottom of $3p$, thus they can go up into the $3p$.



high density, low conductivity
(s bands very large, but p bands very small, \therefore monovalent better conductors than divalent)

Insulators:

Magnitude of E_g determines whether material is an insulator or semi-conductor



RESISTIVITY: ρ (ohm-meters or ohm-cm.)

$$R = \rho l/A$$

Element	E_g (ev)	ρ (ohm-cm at 20°)	
C	6.0	$> 10^8$	insulator
Si	1.1	$2 \cdot 10^4$	semiconductor
Ge	0.7	50	
Sil (grey)	0.08	< 1	

Semi-conductors:

E_g is relatively small (see above diagram)

I. Intrinsic (Natural) Semiconductors, i.e., no impurities added.

e.g. pure Si, Ge, etc.

CONDUCTION OF INTRINSIC SEMICOND. DUE TO:

1. MOTION of e^- IN CONDUCTION BAND
2. " " " " "holes" " valence " "

No. of holes = no. of e^-

n = number of e^- in conduction band.

p = number of holes

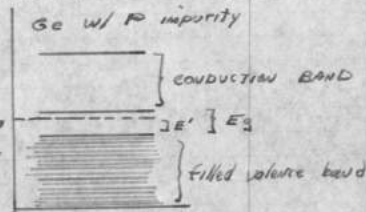
$np = k$ (constant)

Electrical Properties (cont.)

n-type: conduction by e^- . (neg. charges)
p-type: " " holes. (pos. ")

II. EXTRINSIC SEMICONDUCTORS (impurities added)

P^{+5} has one extra e^- . These e^- are at the impurity level E' . Thermal agitation "pushes" them thru remaining E_g into the conduction band (having no holes because they were extra e^- to begin with).

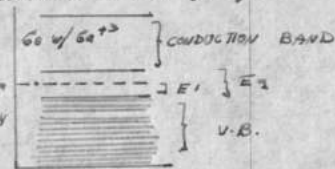


P^{+5} impurity \rightarrow extra $e^- \rightarrow$ n-type.

Let's add Al^{+3} or Ga^{+3} to a semiconductor (Ge)

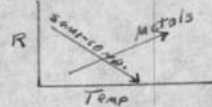
There will be a deficiency of $1e^-$ per Al^{+3} atom, this deficiency will "reside" on the impurity level.

v.b. e^- , energized by thermal agit., will jump to impurity level to fill holes, thus creating holes in v.b.



Al^{+3} impurity \rightarrow extra $p^+ \rightarrow$ p-type.

SEMICOND. CONDUCTION INCREASES w/ TEMP (increased thermal agit.)
METALLIC " DECREASES w/ "



METALLIC CONDUCTION:

$\sigma \propto$ CONDUCTIVITY

$\rho =$ RESISTIVITY

$$\sigma = 1/\rho$$

$$\sigma = ne\mu$$

$$\frac{1}{\rho} = ne\mu$$

$\mu =$ mobility of e^- , $e = e^-$ charge
 $n =$ no. of carriers

Mathiessen's Rule: $\rho_{TOTAL} = \rho_{RESIDUAL} + \rho_{THERMAL}$

$$\rho_{TOTAL} = \rho_{20} [1 + \alpha (t - 20)] \quad \alpha = \text{TEMP. COEFF. OF } \rho / \rho \text{ AT } t = \text{TEMP.}$$

ρ_T : TEMP. DEPENDENT

ρ_R : TEMP. INDEPENDENT.

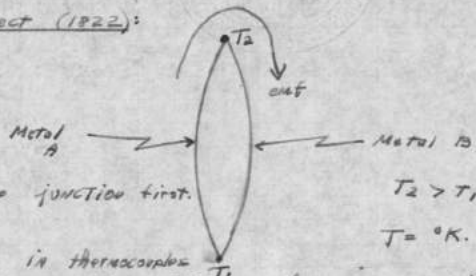
THEMEOLECTRIC EFFECTS

10/15/62

I. Seebeck effect (1822):

$\text{emf} = E_{AB}(T_2, T_1)$

The direction of positive current is from A to B along the high temp junction first.



$T_2 > T_1$

$T = ^\circ K.$

10/17/62

This effect is used in thermocouples. One junction kept constant at $0^\circ C.$, other junction in contact w/ object being measured (T_2). Measure emf & solve for T_2 .

Seebeck effect laws:

1. Law of Magnus: E_{AB} depends on T_1 & T_2 & NOT on the way in which the temp. is distributed along the wires
2. Law of Successive Temperatures: $E_{AB}(T_2, T_1) = E_{AB}(T_2, T_0) + E_{AB}(T_0, T_1)$
3. Law of Intermediate Metals: $E_{AC}(T_2, T_1) = E_{AB}(T_2, T_1) + E_{BC}(T_2, T_1)$
4. Law of Avenarius: If $T_1 = \text{constant}$, then $E_{AB}(T_2, T_1) = a(T_2 - t_1) + b(T_2 - T_1)^2$ where a, b constants.

II. Peltier effect:

A, B - 2 different metals.



Peltier heat is not assoc. w/ joule heat.

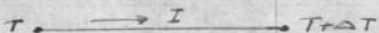
Peltier heat absorbed or given off at this junction (not joule heat)

Peltier heat = $\pi_{AB} I$ where

$\pi_{AB} = \text{Peltier coeff} = \frac{\text{cal/cond}}{\text{volt/amp}} = \text{volts}$

π_{AB} is + when heat absorbed. $I \rightarrow A$ to B
 π is a function of temp.

III. Thompson effect (one metal):



ONE METAL w/ ends at diff. temps will experience a slight current flow

Thompson heat = $\sigma_R I \Delta T$ where

$\sigma_R = \text{Thompson coeff. (function of temp)} \rightarrow \sigma_R(t)$

$\sigma = +$ when I flows up a temp gradient, i.e.

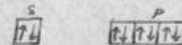
$\downarrow \rightarrow$ from T to $T + \Delta T$.

MAGNETIC PROPERTIES

10/19/62

2 types of mag. prop.: dia, para & ferro-

Diamagnetic materials have all e^- paired



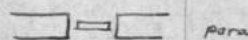
Paramagnetic, ex. Mn Cr } have unpaired e^-
ferromagnetic, ex. Fe, Co, Ni, Dy, Gd } \therefore spin.

$B \equiv \text{Magnetization} = \frac{M (\text{Total mag. moment})}{V (\text{Volume})}$

$H \equiv \text{Magnetic value}$



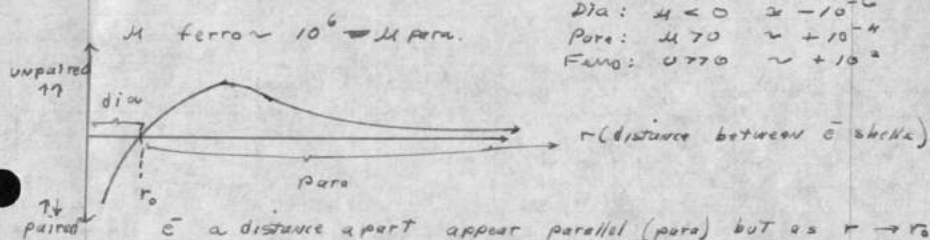
dia



para

$\mu = B/H = \text{permeability or susceptibility}$

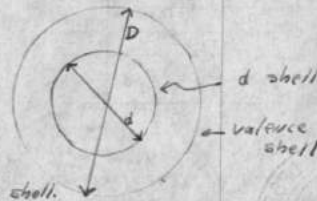
- Dia: $\mu < 0 \approx -10^{-6}$
- Para: $\mu > 0 \approx +10^{-4}$
- Ferro: $\mu > 770 \approx +10^2$



e^- a distance apart appear parallel (para) but as $r \rightarrow r_0$ and beyond, e^- appear paired and \rightarrow dia.

CONDITIONS FAVORING FERRO-:

1. A partially filled inner shell d shell only partially filled (+ shell for rare earths)



$d = \text{dia. of unfilled shell}$
 $D = \text{dia. of atom} = \text{dia. of valence shell.}$

2. $D/d > 1.5$

Fe, Co, Ni, Dy, Gd are only elements which satisfy these conditions

Domain \equiv portion of solid where all the mag moments point in same direction



Ferro:



Para.

Mag. Prop. (cont.)


Equilib. No. of domains: when exchange force = magnetostatic force.

Magneto static energy: energy due to discontinuities in material (surface mag. poles)


Domain wall = Bloch wall

Directions of Mag.

	easy	middle	hard
Fe	BCC 100	110	111
Ni	FCC 111	110	100
Co	hex 001		all other

Fe:  edge directions.

Ni: body diagonal

Co:  along center hex. axis

LAB Movie STRIP

10/19/02

$B = \mu_0 H + I$

$m =$ mag. dipole moment = Ia where $I =$ current, $a =$ area

$\vec{M} =$ magnetization = $\frac{\sum \vec{m}}{V} =$ sum dipole moments / volume

$\vec{B} = \mu_0(\vec{H} + \vec{M})$

Paramag. = free & independent moments.

$T_c =$ Curie temp: temp at which alignment of molecular field is eliminated.

The molecular field equiv. to $\sim 4 \times 10^5$ ampere/meter

Molecular field due to exchange forces.

Exchange Energy min. when all dipole moments are ||.

Domains form \Rightarrow they minimize the sum of a number of diff. energies.

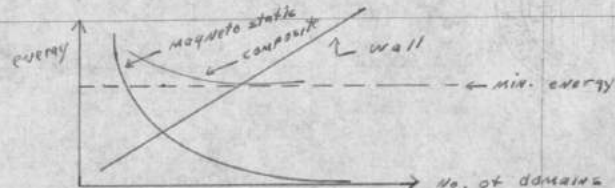
Magneto static energy $E \propto \int H^2 dv$
H lines NOT continuous

Magneto static energy is driving energy behind domain formation.

Domain walls add exchange energy.

MUNIR Mag. Prop (cont.)

LAB Movie:



Magneto static energy appears whenever \vec{M} is not continuous

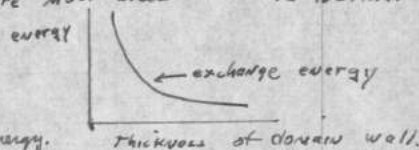
A bdry at rt. \perp to magnetization, $M_w = M$, a max. discontinuity, \therefore a max field. $M_w < M$ if bdry not \perp to M

The less discontinuities, the less H field H fields arise whenever norm. comp. of M isn't continuous across a bdry.

Magneto crystalline anisotropy (mag. prop. not same in all direct.)

Magnetostriction = change in dimension due to magnetization. A specimen will elongate in direction of magnetization.

Walls of domains of closure must bisect \vec{M} is normal at bdrys.



as wall width increases, anisotropy energy increases (compensate curve) gives min. energy.

10^{-5} cm. is min. wall width

exchange
magneto static
anisotropy
magnetostrictive } MIN. energy \Rightarrow stable domain structure

Wall energy = exchange + anisotropy energies
End of film strip

Lecture: Magnetic Properties

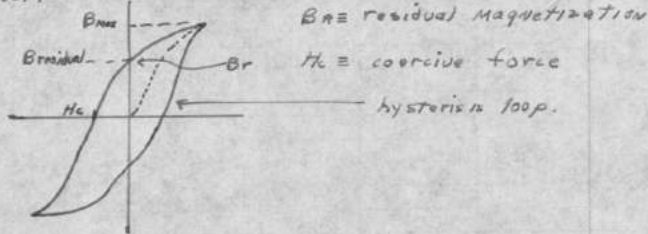
10/29

crystalline anisotropy:

easy	Med	hard
Fe, Co, Ni	Fe (BCC) 100	110 111
	Ni (FCC) 111	110 100
	Co (hex) 001	all other

MUNIT Magnetic Prop. Cont.:

Hysteresis effect:



Perm. Magnet

considerations

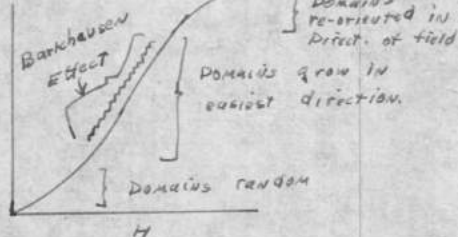
Electro Magnet

1. High B_R
2. High H_C

1. High B_{max}
2. Low B_p
3. Low H_c
4. High permeability μ .

Barkhausen Effect: magnetization is not smooth as field increases but is a series of discrete steps.

The Barkhausen effect is due to impurities or other imperfections. Domain wall "stores" energy, then "jumps" impurity barrier.



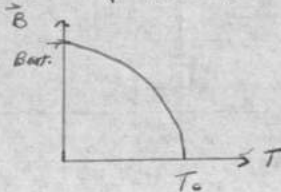
Magnetostriction is the phenomenon of change of length w.r.t. magnetic field direction. \approx (few parts/million).

$H \rightarrow$ $[Fe]$ $[Ni]$
 81% Ni, 19% Fe alloy has no magnetostriction.

Curie Temperature (T_c):

T_c is temp. at which the ferromag. material becomes paramag.

	Pd	Fe	Co	Ni	Gd
T_c °C	-168	770	1120	352	16



MUNIT

MECHANICAL PROPERTIES

Definitions:

σ = stress = load / area of cross-section.

ϵ = strain = change in length / original length = $\Delta l / l_0$

$\sigma \propto \epsilon$

$\sigma = E \epsilon$ Hooke's Law

E = constant : Young's Modulus
 Hooke's Law only obeyed in elastic region

$E = \sigma / \epsilon = m$ (slope of σ vs ϵ line)

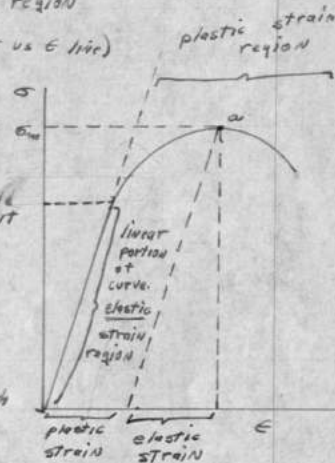
Yield strength: stress at which plastic deformation starts (usually at 0.2% plastic deformation).

Eng. Yield strength: 0.2% plastic deform. stress at.

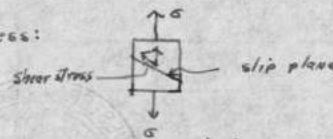
Strength implies stress.

σ_m : tensile stress = Max. stress of σ vs ϵ curve.

$\% \text{ elongation} = \frac{\text{total change in length}}{\text{original length}}$



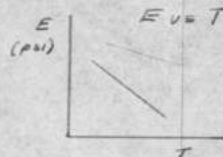
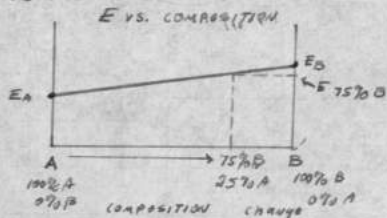
SHEAR STRESS:



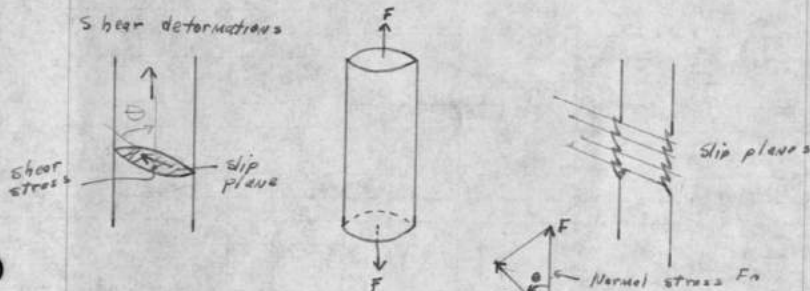
Factors influencing slip direction:

1. slip occurs along crystal planes only.
2. Resistance to slip is less along widely separated planes (planes of high atomic density).
2. shear stresses causing slip are higher in certain direction, depending on direction of normal stress. largest component at 45° .

Young's Modulus:



Shear deformations



$\tau = \text{shear stress} = F_s/A_s$
 $= F_N \cos \theta \cdot \sin \theta / A_N$

$\gamma = \sigma \sin \theta \cos \theta$

Planes of easy slip:

1. FCC: 111
2. BCC: 110, 112, 123
3. hex: 0001

Directions of easy slip: [planes of highest at. density]

1. FCC: 101
2. BCC: 111
3. Hex: 1120

Hardness \equiv the resistance to penetration

Basis for hardness Tests:

1. measure depth of penetration (Rockwell) ✓
2. measure area of indentation (Brinell) ✓

MS 25

MUNIT

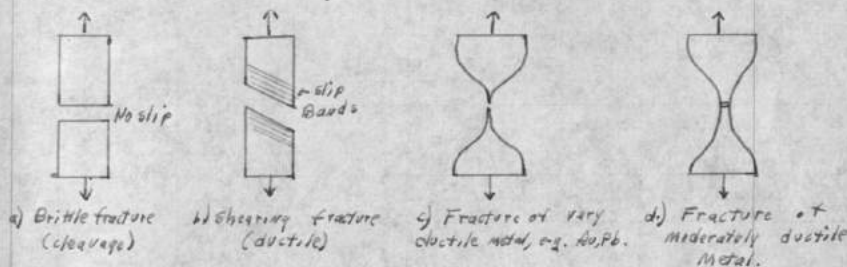
Impact Behavior, Impact Tests (Sudbon Blow):

1. Tension Impact.
2. Keyhole-Charpy impact.
3. Notched-Ized Impact.
4. Unnotched Ized "
5. Torsion "

FRACTURE

Type 1: brittle
 " 2: ductile

Types (by observation)



Types (classification):

1. Cleavage (a): Planes "peel" apart w/out a movement of planes — a brittle fracture.
2. Fracture by shear (b):
3. Fatigue fracture.

Cleavage:

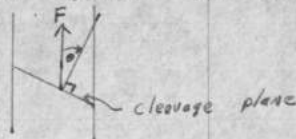
min. value at which cleavage occurs \equiv critical stress.

Substance	Cleavage plane	T°C.
Fe (BCC)	100	-109
Mg (hcp)	(0001) (1011)	-185
Te (hex)	1010	20
Sb rhombohedral	111	20

Sohmcke Law:

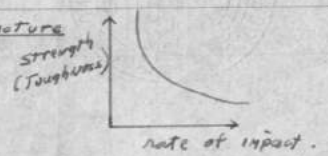
Fracture occurs when the resolved normal stress reaches a critical value

$\sigma_c = F/A \cos^2 \theta$

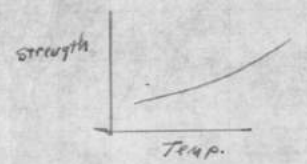


Factors Affecting Type of Fracture

1. Rate of impact



2. Temperature

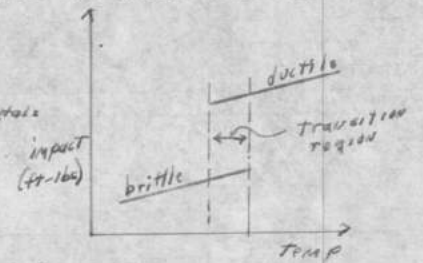


3. Geometry

Irregular surfaces have hi & low pts. ∴ areas have areas of hi & low stress distribution. Areas of hi stress will develop cracks which will spread.

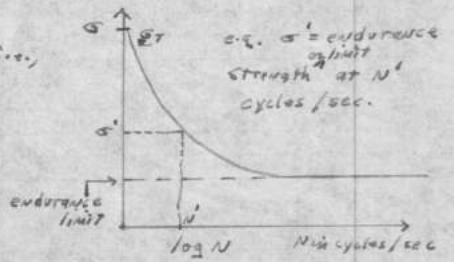
Transition Temp.

ductile to brittle transformation occurs only in bcc metals



Fatigue: Fracture due to cyclic stresses

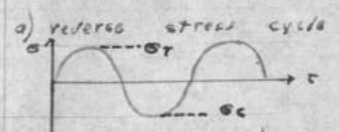
σ_T = Tensile strength, i.e., value of σ at $N=1$



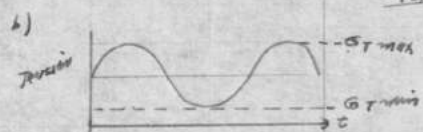
Fatigue is due to the fact

that material is NOT homogeneous.

Fatigue stress cycle:



$\sigma_T = \sigma_c$
 $\sigma_T = \sigma_{TENSION}$
 $\sigma_c = \sigma_{COMPRESSION}$



Stress Ratio $R = \frac{\sigma_{min}}{\sigma_{max}}$
 $R \leq 1$

Cyclic but in tension area at all times (or compression area, etc)

Hi Temp Prop (cont)

Hi Temp Strength

At low temp., rate of strain has little or no effect on yield strength.

Hi. Temp: deformation = f(time)

low temp. hi temp

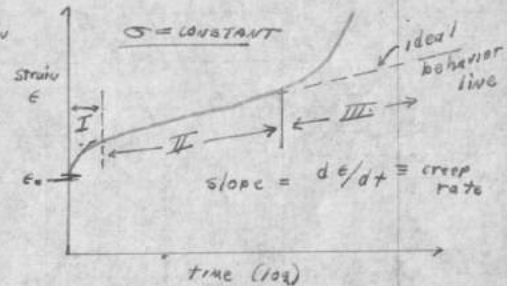
Tensile strength → rupture strength
 Yield " → creep "
 strain → creep

creep = f(time)

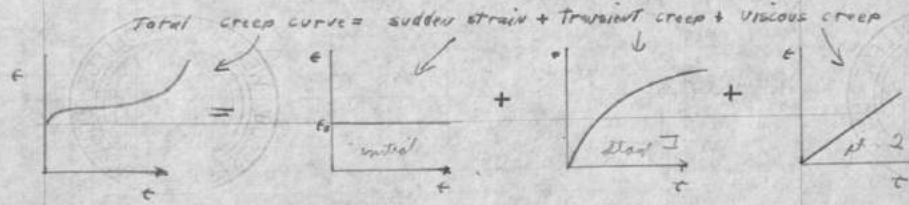
CREEP (Hi temp strain):

Creep = "the progressive deformation of a material at constant stress."

Ex: instantaneous strain
 Load (σ) and temp. held constant in graph



ANDRADE'S ANALYSIS OF CREEP CURVE:



Stage I: Primary Creep:

A region of decreasing slope rate ($\frac{d\epsilon}{dt}$). Creep is predominantly transient. Creep resistance increases by virtue of material's deformation. $\frac{d\epsilon}{dt I} > \frac{d\epsilon}{dt II}$

Muir Creep (cont)

Stage II: Secondary Creep: or steady state creep:

$\frac{d\epsilon}{dt}$ (creep rate) is essentially constant. This results from a balance between strain hardening & recovery (deformation to relieve the strains).

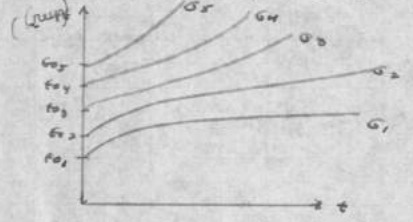
Creep rate of st. II = min. creep rate $\frac{d\epsilon}{dt II} = \frac{d\epsilon}{dt min}$.

Stage III: Tertiary Creep:

This behavior due to structural changes in metal.

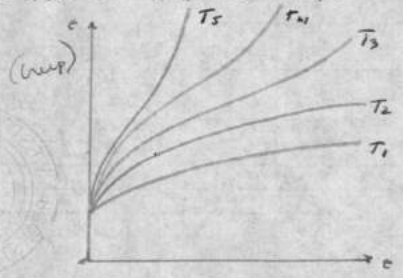
$\frac{d\epsilon}{dt III} > \frac{d\epsilon}{dt II}$

Effect of stress on creep. Temp = constant



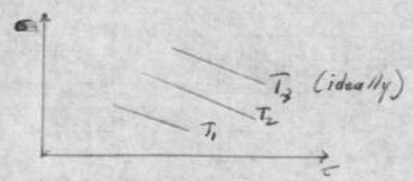
Temp = constant
 $\sigma_5 > \sigma_4 > \sigma_3 > \sigma_2 > \sigma_1$

Effect of temp. on creep: Hold sigma constant, vary Temp.



Hold sigma constant, vary Temp.
 $T_5 > \dots > T_1$

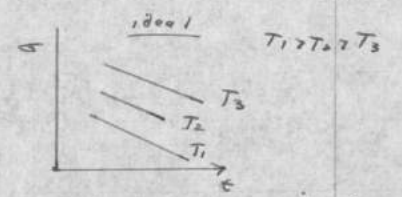
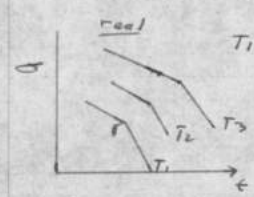
Effect of temp. on stress (rupture) $T_1 > T_2 > T_3$



Muir Hi Temp Prop (cont)

Stress Rupture Test:

Effect of temp. on rupture stress



Change in slope due to structural changes occurring in the material, e.g., oxidation, recrystallization, phase transformations, etc.

Rupture strength = stress of a given temp. to produce rupture.

Creep strength = stress of a given temp. which produces min. creep rate ($d\epsilon/dt$) of a certain value (usually 0.0001 %/hr or 0.0002 %/hr)

end of hi temp. prop.

WEAR = the deterioration of a surface thru frictional processes.

Factors influencing wear:

1. Hardness: hardness $\propto 1/\text{wear}$
2. ability to deform plastically.
3. Surface finish: this determines the no. of contact pts.

Types of wear:

Types of wear	example
metal-to-metal lubricated	shaft in bearing
" " " " "	wheel on track
" " non-" , dry friction	belt on pulley
" " non-metal, particle impact	sand blast nozzle
" " fluid - liquid particle	steam in turbine.

hard-surfaced Metals:

1. carburizing
2. nitriding

nitride actually imbedded, not coated on.



CORROSION OF METALS:

corrosion: the destructive chemical action on the metal by the environment.

Imp't. Metal Prop. Affected by Corrosion:

1. Mechanical, e.g. support
2. Transmission of heat & electricity
3. Impermeability as a container
4. Purity as a container.
5. Appearance
6. Reflectivity
- 7.

Corrosion is a function of:

1. metal
2. chemical environment
3. physical and mechanical conditions prevailing, e.g., Temp., stress, etc.

Corrosion Systems: (corrosion cell)

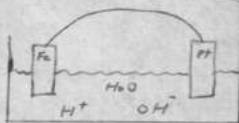
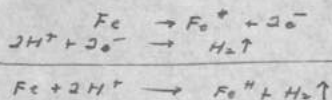
1. anode
2. cathode
3. electrolyte
4. electronic conducting element

Corrosion of iron:



metal (free state) \rightarrow metal (combined state)
free metal \rightarrow compound

Corrosion Process



11/5/62

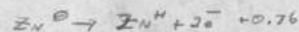
anode is where metal is corroding

Reaction	E°
Li Li ⁺	3.02
Ca Ca ²⁺	2.76
Al Al ³⁺	1.67
Pb Pb ²⁺	0.129
H H ⁺	0.000
Au Au ⁺	-0.220

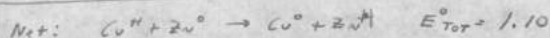
anode: $M^0 \rightarrow M^+ + e^-$
cathode: $M^+ + e^- \rightarrow M^0$

Reaction w/ highest potential is anode

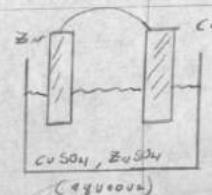
Anode reaction:



Cathode reaction:



$Cu, Cu^{2+}: -0.34$
 $Zn, Zn^{2+}: 0.76$



Effect of concentration on E°:

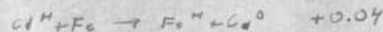
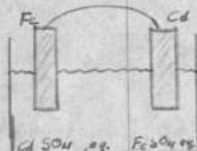
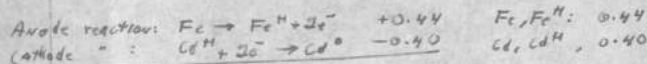
in general: $E = E^{\circ} - \frac{RT}{nF} \ln C$ where

2.303 base 10 = base e
& change nat log to base 10 log.

E° = emp. at concentration C
E° = " " " of unity
F = Faraday constant = 96,500 $\frac{coulombs}{mole}$
R = gas constant
n = valence of ion
T = temp, °K.

AT 18°C: $E = E^{\circ} - \frac{0.059}{n} \log C$ AT 18°C only

Use of conc. equation:



AT 18°C

$$E_{Fe} = 0.44 - \frac{0.059}{2} \log [Fe^{2+}]$$

$$E_{Cd} = 0.40 - \frac{0.059}{2} \log [Cd^{2+}]$$

At equilib: $E_{Fe} = E_{Cd}$

$$\therefore 0.44 - \frac{0.059}{2} \log [Fe^{2+}] = 0.40 - \frac{0.059}{2} \log [Cd^{2+}]$$

$$0.04 = 0.029 \log \left[\frac{Fe^{2+}}{Cd^{2+}} \right]$$

$$\log \left[\frac{Fe^{2+}}{Cd^{2+}} \right] = 1.35$$

$$\left[\frac{Fe^{2+}}{Cd^{2+}} \right] = 22.4 = 10^{1.35}$$

At this concentration ratio, there is equilibrium and \therefore no reaction occurs for a ratio < 22.4 , reaction goes as above.
" " " > 22.4 , iron is positive, i.e., iron doesn't corrode and NO reaction occurs.

AT 18°C

Rate of Corrosion Eq:

From Faraday law:

$$W = i t m / q$$

where

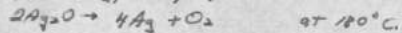
W = wt. of metal destroyed (grams)
 i = current (amps)
 t = time (sec)
 m = gram-equiv = at.wt./valence
 q = es above

OXIDATION: H₂ Temp. Corrosion

11/7/02

I. Types of oxidesA. Oxides of Low Dissociation Temp.

e.g. Ag, Au, Pb, Pt



No scale formed; No wt. loss

B. Volatile oxides

e.g. Mo, Os, Ru

No scale formed; wt. loss

C. Porous oxides

Oxide occupies less space than the metal (per atom of metal)

e.g. Na, K, Ca, Mg

D. Non-porous oxides

Oxide occupies more space than the metal.

e.g. Al, Be, Cu, Ni, Pb.

II. Rates of OxidationA. Linear:

$$\Delta W = k_p \Delta T$$

 ΔW = change of wt. of oxide ΔT = change in time k_p = constant.B. Parabolic:

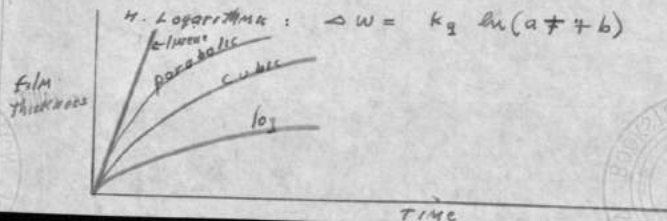
$$\Delta W^2 = k_p \Delta T$$

3. Cubic:

$$\Delta W^3 = k_c \Delta T$$

4. Logarithmic:

$$\Delta W = k_g \ln(a + b) \quad a, b \text{ constants}$$

III. Mechanism of Oxidation

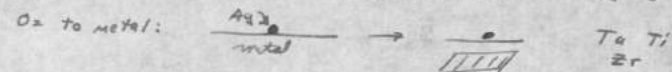
Thin films form first. Scale growth continues by diffusion processes

1. Diffusion thru oxide lattice

a. Oxygen diffuses thru oxide to metal

Ta, Ti, Zr

b. Metal diffuses thru oxide to oxygen. Cu, Ni, Zn, Fe

2. Diffusion along grain bdr's. V, Ni3. Diffusion thru cracks & fissures. e.g. Co

Cu, Fe,

IV. Corrosion ControlDesign Precautions

- Selection of metal
- Avoid 2 dissimilar metals in contact
- " localized stresses during fabrication
- " stray currents from other sources
- bacteria (depolarizers).

missed this lecture (diffusion)

More methods of controlling corrosion:

- 1.) Design Precautions
 - a) selection of metal
 - b) Avoid 2 dissimilar metals in contact.
 - c) Avoid localized stresses during fabrication.
 - d) Avoid stray currents from other sources.
- 2.) Physical Control
 - a) Temperature
 - b) Pressure
 - c) Velocity, etc.
3. Chemical control - controlling chemical environment.
 - a) Control of concentration of reactive elements in environments - either raise or lower from critical point
 - b) Neutralization, make sol. pH \Rightarrow corrosion is minimized
 - c) Removal of corrosive elements or agents
4. Castings Coatings
 - a) non-metallic - paints
 - b) chemical
 - c) metallic

Diffusion

Mechanism

1. Volume diffusion - diffusion w/in the crystal lattice
2. Grain bdy diffusion - at & along grain bdy's.
3. Surface diffusion.

Fick's 1st law: $\frac{dw}{dt} = -D \frac{\partial c}{\partial x} A$

dw = no. of grams of metal that cross a plane \perp to the direction of diffusion.

D = "diffusability"

c = concentration

A = area of plane

x = direction

D_1 D_2 D_3
 $J = \frac{dw/dt}{A}$
Flux
rate of flow of grams
time & area

On general:

$F \propto \frac{1}{x}$
Diffusion \propto concentration gradient

$J = -D \frac{\partial c}{\partial x}$

Diffusion high conc \rightarrow low conc, \therefore it is neg.

$J = \frac{\text{grams}}{\text{unit } t \times \text{unit area}}$

2nd Midterm: range 22-97, average: 67, 85-100 A
78-84 B

Diffusion: Know Fick's 1st law (don't worry much ab. 2nd)

ANNEALING: The process of relieving strains and retaining prop. lost by cold-working.

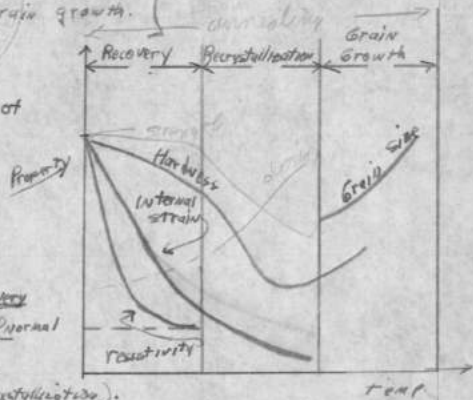
- 3 stages: { 1. Recovery
2. Recrystallization
3. Grain growth }

Recrystallization

1. RECOVERY = restoration of

the physical properties of the cold-worked metal w/out any observable change in micro-structure

Driving force for recovery is the excess energy in the metal due to cold-working (this is also the driving force for recrystallization).



2. Recrystallization = replacement of the cold-worked structure by a new set of strain-free grains.

Recrystallization is the process of breaking up the large grains. This "uses up" or rid the excess energy remaining after recovery.

Driving force is excess energy in metal due to cold working that was not eliminated by recovery.

3. Grain Growth:

Driving force is the decrease in free energy resulting from a decrease in grain body area.

Surface area increases energy. Many sm. grains have more surface area than large grains, thus have an energy excess. In order to reach normal equilib., grains "grow" to reduce energy.

You can go thru for more stages:

To "recover" but avoid recrystallization, run recovery below recrystallization temp.

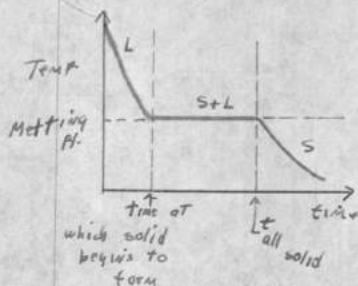
PHASE DIAGRAMS [Discussion assumes EQUILIBRIUM]

PHASE = A portion of matter whose properties and chemical components are homogeneous.

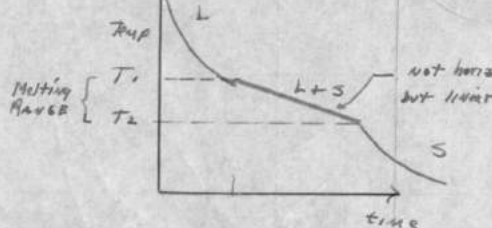
Component = Any element or chemical compound whose concentration must be given in order to describe the composition of the phase.

Cooling Curves:

ONE COMPONENT (pure metal)



BINARY alloy



An alloy has no melting pt., but a melting range.

All substances have a vapor pressure but it's small; we ignore it in practical situations

Phase Diagrams:

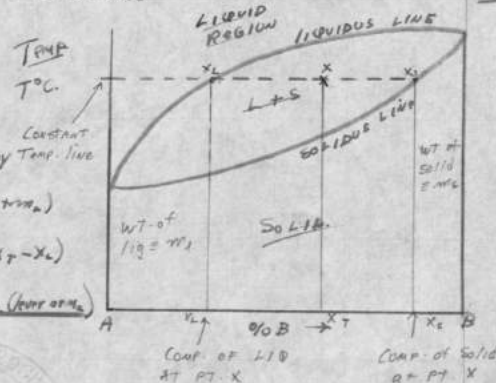
Lever Rule:

wt of B in solid + wt of B in liq = wt of B in alloy

$$x_s m_s + x_L m_L = x_T (m_s + m_L)$$

$$m_s (x_s - x_T) = m_L (x_T - x_L)$$

$$wt_s (\text{lever arm}) = wt_L (\text{lever arm})$$



Phase Rule: [Gibbs - 1870's]

System \equiv a portion of the universe containing all the matter considered to be taking place in the equilibrium. All the rest of the universe is called the surroundings.

Degree of Freedom \equiv A variable that may change its value independently of the other variables, and w/out destroying or creating a phase.

Equilibrium \equiv a condition in which the fugacity of each component is the same w/ all phases.

fugacity: effective pressure
fugacity \propto "escaping tendency".

At any temp. there is an "escape tendency"
 $A_1 \rightarrow A_2$
 $A_2 \rightarrow A_1$

at equilib: $A_1 \rightarrow A_2 = A_2 \rightarrow A_1$, thus no net change

Total No. degrees of freedom = Total No. of Variables - No. of restrictions
= " " " " - No. of indep. eqs connecting them.

in phase equilibria the variables are:

- 1. Composition
- 2. Temperature
- 3. Pressure

Consider a system with C components
P phases.
The composition of each phase is described by C nos.
For P phases, we have PxC variables.

$\therefore P \times C =$ total No. of composition variables
Total No. of variables = PxC + 2 (Temp. + Pressure)

Restricting Eqs:

- 1. fractions of all components in a phase add to 1
 $x_1' + x_2' + \dots + x_c' = 1$ (subscript: comp. No.)
(superscript: phase No.)
- There are P such eqs.

Phase Rule (cont):

2. Condition of Equilibrium:

$f_{x_1'} = f_{x_2'}$ $f =$ fugacity

$f_{x_1'} = f_{x_2'} = \dots$

There are P-1 such eqs for each component.

\therefore There are C(P-1) such eqs

Total No. Restricting Eqs = C(P-1) + P

F (degree of freedom) = [PC + 2] - [C(P-1) + P]
expanding & canceling:

$P + F = C + 2$ Gibbs' Phase Rule (general)

CONDENSED PHASE RULES

$P + F = C + 1$ (eliminating Pressure variable as it is negligible)

At Melting pt:

↑ liq, solid

pure metal: $P = 2$ $2 + F = 1 + 1$
 $C = 1$ $F = 0$

bivary alloy: $P = 2$ $\therefore F = 1$
 $C = 2$

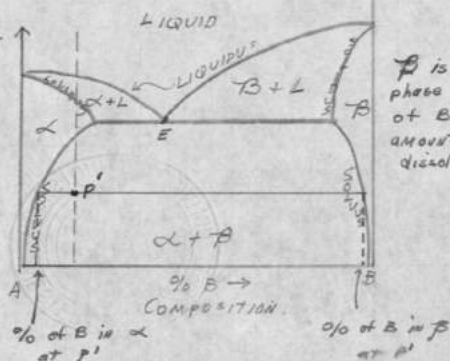
Temp. can be varied w/in certain bounds and still have two phases.

Eutectic Diagrams

α is one solid phase composed of A w/ small % B dissolved in A

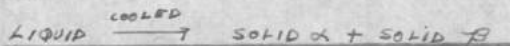
E = eutectic point.

Solvus = line between 2 solid phases

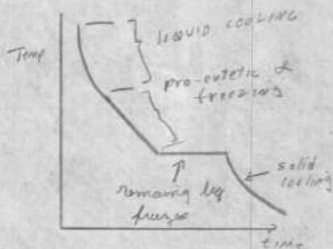
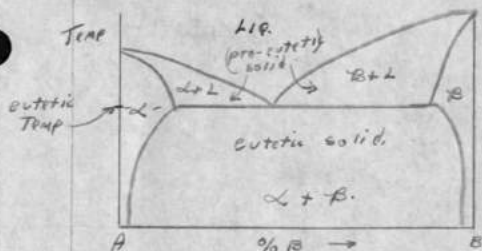


β is one solid phase composed of B with a small amount of A dissolved in it.

Eutectic reaction:



isotherm = a line of constant temp.



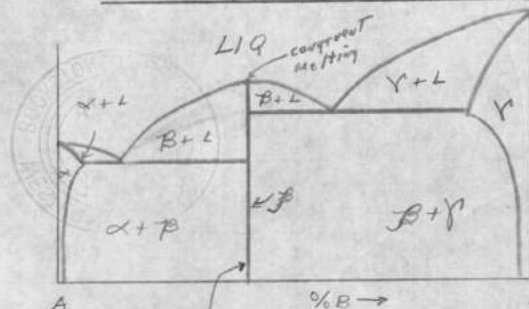
α is ($\alpha + L$) and β is ($\beta + L$) is pro-eutectic

Congruent melting = melting at constant temp.
incongruent " = " over a range of temps.

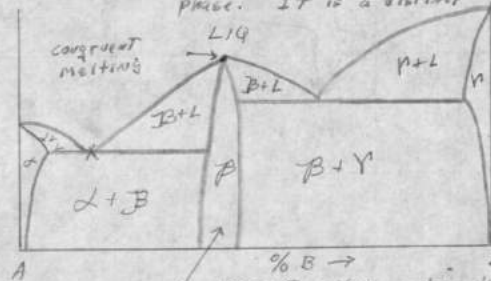
A congruent melting intermediate phase = a phase which melts at a constant temp.

Intermediate Phases (interstitial compounds)

Definition: a phase which is stable only where interstitial phase both components are present. It can only exist when there are (2 components) present.

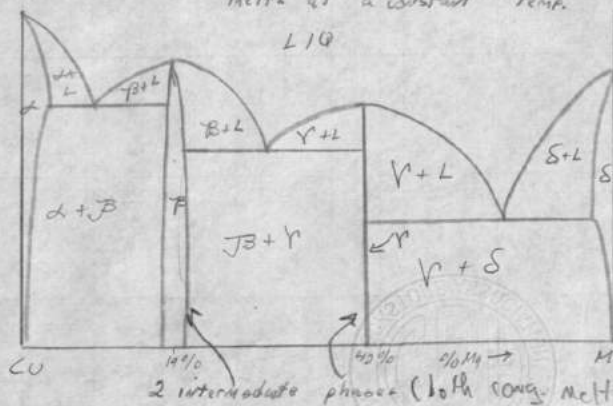


this line is a congruent melting intermediate phase. IT is a distinct phase composed of β .



congruent melting intermediate phase.

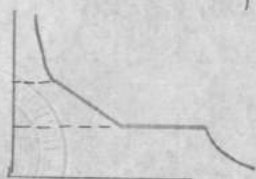
A congruent melting phase is a phase which has a composition such that it melts at a constant temp.



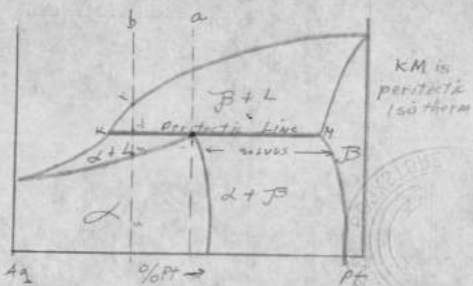
2 intermediate phases (both congruent melting)

(A₀-pt)Peritectic Diagrams

Cooling curve for pt. A:



Cooling curve for pt. B:

Eutectic reaction: $Liq \xrightarrow{cool} \alpha + \beta$ Peritectic Reaction: $Liq + \alpha \xrightarrow{cool} \beta$ Non-Equilibrium Cooling:Binary - isomorphous alloy

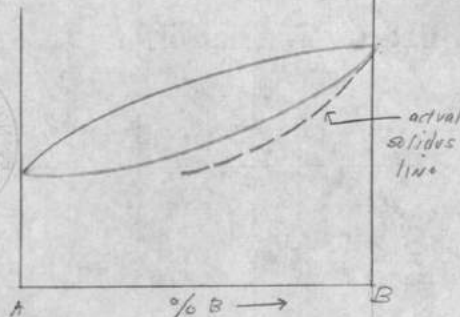
Coring:



Coring is the progressive change in concentration of the deposited phase due to non-equilibrium cooling.

The % B is greater in center of solid formed.

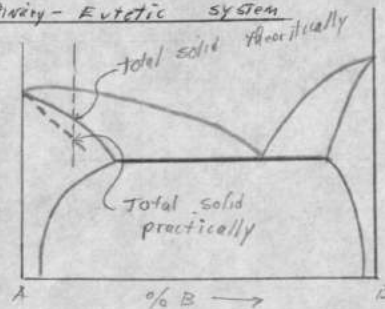
Diffusion is a slow process whose driving force is the concentration difference.



To bring a non-equilib alloy to melt on equilibrium solidus line, raise T to a point just below that which the alloy begins to melt (the experimental or actual solidus). Wait until diffusion lessens the difference in concentrations slightly, then again raise T until just before melting, etc. In this way we can approach the theoretical solidus to any degree of accuracy we desire.

Binary - Eutectic system

Treatment is identical as above - in fact the treatment is the same in any solid-liquid system.



AGE HARDENING:

In general - if an element is added to an alloy, the hardness increases. The new element's atoms act as obstacles to dislocation movement w/in the alloy's crystal lattice.

Degree of hardness \propto concentration of impurities (obstacles)

amt of hardening \propto concentration (at low concentrations)

it is also dependent on size & atomic structure of impurity atoms.

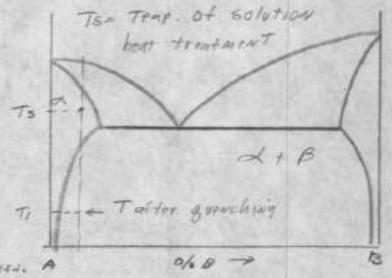
12/5/62

If we add so much impurity (call it B) that it forms grains in A - thus we have a new, B, phase. the movement of dislocations is slowed down even more as now they have to go around much larger areas, & not simply single atoms. The more grains, the more difficult is dislocation movement.

let d = average distance between grains,

I. Precipitation Hardening

Solution heat treatment is dissolving B in A at hi temperatures such that a single phase results.



The α phase has been retained at T_1 after quenching. As time increases the α at T_1 begins to deposit some β as grains in the α structure, thus increasing the hardness.

At T_1 , equilibrium says we should have $\alpha + \beta$, but due to the rapid quenching, we have retained α at T_1 from T_0 . Diffusion is very slow at the low T_1 . Thus as $t \rightarrow$, some β is deposited w/in α , increasing the hardness.

Natural Aging: hardening w/ time at room temp.

To speed up β precipitation rate, raise Temp (but keep temp. w/in $\alpha + \beta$ region) - this is artificial aging. (it must not cross solvus).

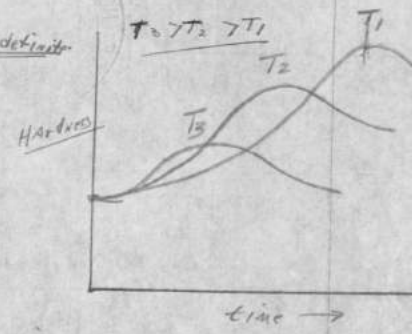
As time increases the hardness reaches a maximum & then decreases again.

hardness \propto distance between grains. As the no. of grains becomes very large, the grains will tend to grow to minimize the excess energy due to surface area. Thus d between grains increase again, and hardness decreases.

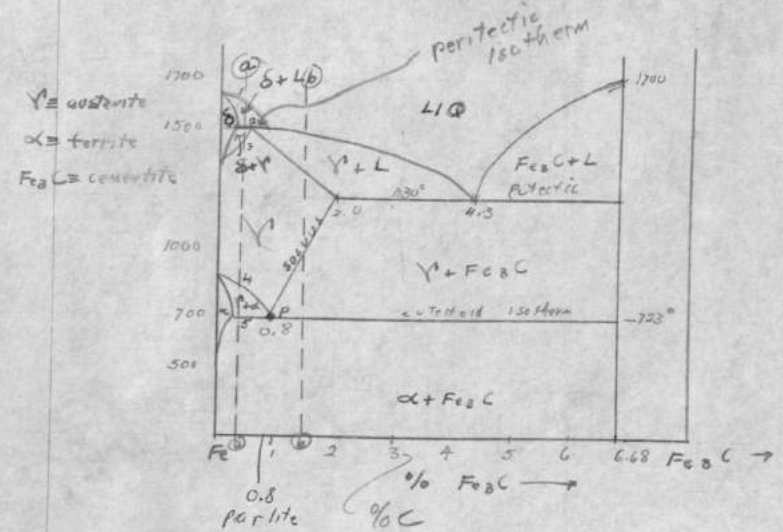
After the hardness peak is reached, we say the sample is over-aged.

The hardness max is definite.

Rate of hardness decrease is usually less than the rate of hardness increase.



IRON-CARBON PHASE DIAGRAM:
(Iron-Iron Carbide)



12/7/62

The Iron - Iron Carbide System has 3 reactions.

Peritectic: $L + \text{SOLID}_1 \rightarrow \text{SOLID}_2$

Eutectic: $L \rightarrow \text{SOLID}_1 + \text{SOLID}_2$

Eutectoid: $\text{SOLID}_1 \rightarrow \text{SOLID}_2 + \text{SOLID}_3$

at point P $\gamma \rightarrow \alpha + \text{Fe}_3\text{C}$, a eutectoid reaction
 \therefore P is a eutectoid point.

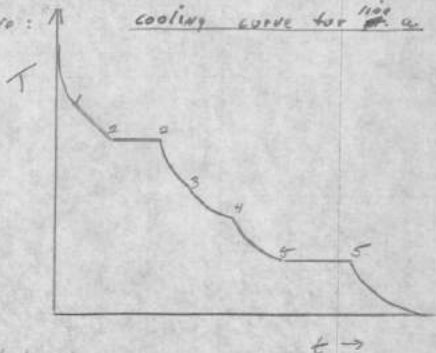
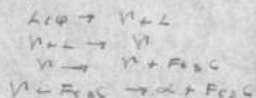
Whenever you cross a particular isotherm, you have its characteristic reaction, be it perit, eutectic, or eutectoid.

Pearlite is that particular ^{eutectic} composition that results from ferrite & cementite.

Cooling along composition a line: T cooling curve for $\frac{110}{100} \text{ a}$



along comp. b:



Eutectic Comp (at 4.3% C) \equiv Ledeburite

Eutectoid comp (at 0.8% C) \equiv Pearlite.

Steel: C-Fe alloy (may have other elements)

Iron: essentially pure iron, usually $< \frac{1}{10}$ of 1% C; α , γ , δ irons.
 α ferrite is common type (BCC); δ (BCC) γ (FCC)
 Very ductile & soft.

Steels: Steels are C-Fe alloys up to 2% C

Cast Iron: 2% and up C (usually max at 4.5% C) very brittle.

Eutectoid steel = 0.8% C.

steels $< 0.8\% \text{ C} \equiv$ hypo-eutectoid steels
 $> 0.8\% \text{ C} \equiv$ hyper- " steels.

Heat Treatment of Al - Movie

pl. FCC

Basic Heat Treating Processes:

I. Tempering

Heat uniformly to a pt. below the lower critical Temp
 Uniformly cool in air

Increases Toughness; decreases hardness.

II. Normalizing

Heat 100 to 200° above upper critical temp.
 Uniformly cool in air

Reduces size of grains.

III. Annealing

Heat to 75° above upper crit. temp.
 Cool in furnace

Relieves stresses and increases ductility.

Case Hardening

Place parts in container w/ carbon (charcoal) etc.,
 ground. Bring up to 1700°F and hold for 8 hrs. - then
 the carbon partially penetrates the steel resulting
 in a hi-carbon steel.

If the parts are placed in hot molten cyanide,
 this is cyaniding and the skin is very thin & hard.

If parts placed at low temp in presence of ammonia
 gas, this is nitriding. Very hi hardness
 (for certain alloys only).

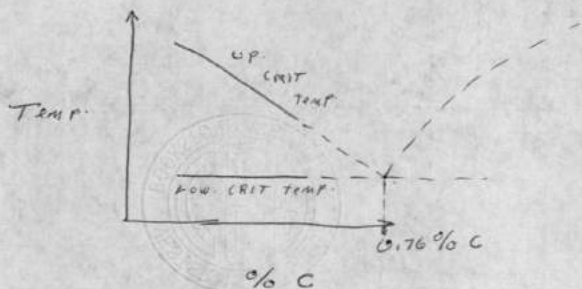
Flame Hardening

Heating area w/ torch & quenching.

Induction Hardening

Heating part by setting up eddy currents
 prod. by a hi-freq current in inductor, then
 quenching.

Lower Crit Temp: Temp. at which specimen begins to harden (1st appearance of martensite) ←
 Upper Crit Temp: Temp. of max hardness (Spec. all martensite) ←
 for hi-carbon steels



TYPE	LOW C.T.	UP C.T.	INIT HARD	MAX HARD
1013	1320	1575	9	45
1031	1320	1490	10	56
1042	1320	1450	10	60

low carbon steels generally have lower MAX HARD

OK MAX HARD = K % C.

Heat Treatment of Steel:

A process of which certain design properties are attained by heating or cooling the metal.

Normalizing:

Purpose: To obtain a uniform microstructure

properties & to grain size. ∴ we want a uniform microstructure so we can predict prop.

Heat to γ region, then cool in air.

Annealing:

Purpose: To relieve stresses

heat to γ (austenite) region, cool in furnace. grains will grow more than in normalizing

Spheroidizing:

Larger the area of contact, the larger the surface tension. but as equilibrium wants min. surface area.

heat to just below eutectoid iso-therm. air cool. metastable surface tension is at min ^{implying} min surface area.

Purpose: To increase toughness for purposes of machining.

Martensite: Hardest of all steels. Formed by Quenching

Structure changed from FCC to almost BCC, but no time for C to leave. IT is "trapped" inside distorting the BCC cube and forming a tetragonal structure.

austenite $\xrightarrow{\text{rapid quench}}$ martensite
 FCC $\xrightarrow{\text{rapid quench}}$ BCC Tetragonal

martensite very brittle. so now heat it to just below eutectoid isotherm and hold it, some particles will precipitate out and quench it when it is ductile enough.

Tempering: heat below eutectoid isotherm

HARDENABILITY

Martensite - BCC tetragonal structure (Carbon trapped inside).

Rapid cooling produces Martensite w/ pearlite in center of specimen.
Equilib cooling results in pearlite.

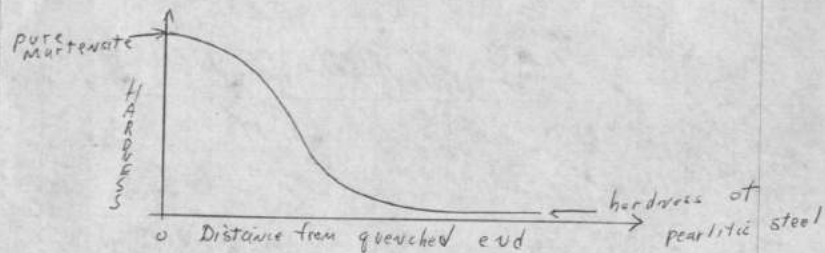
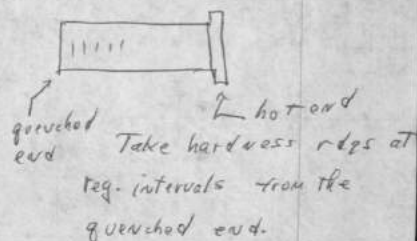
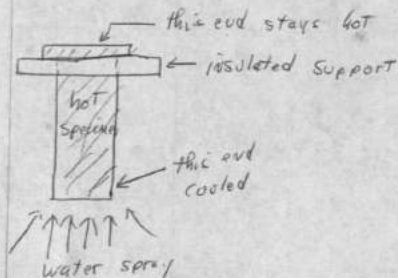
Must add other alloying elements in order to get pure martensite.

AT EQUILIB: $\gamma \rightarrow \alpha + Fe_3C$

QUICK QUENCH: $\gamma \rightarrow$ Martensite.

Def. A steel has high hardenability if cooled at a relatively slow rate & still goes to Martensite.

JOMINY TEST:

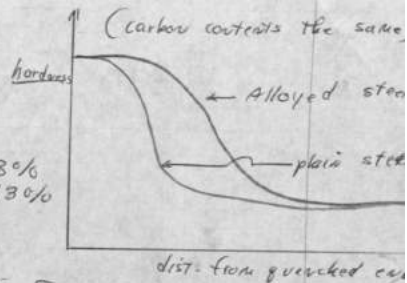


Effect of Chem. Composition on Hardenability:

Chem. comp. is the chief factor affecting hardenability

Critical Dia. = max. dia. at which we can get all martensite

V	0.01%	V. increase Cr Dia. by 13%
Mn	0.1% Mn	" " " 33%



ALLOYING ELEMENTS IN STEEL:

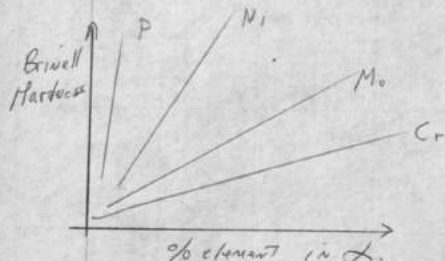
Reasons:

1. To improve Mech. props. (by changing Microstructure)
2. To improve oxid. & corrosion resistance.
3. To secure special prop. [magnetic, hi temp, etc.]

Distribution of Alloying elements & their effect on prop. of Ferrite:

Elements which dissolve in α : Si, Al, Cu, Ni, Co, P, Mn, Cr, Mo, W, Ta, V, Ti, Nb, Nb

Elements dissolved in α increase its hardness & strength.

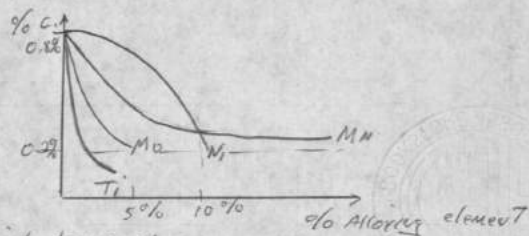


Elements dissolve in γ (Fe₃C) have essentially no effect on strength prop.

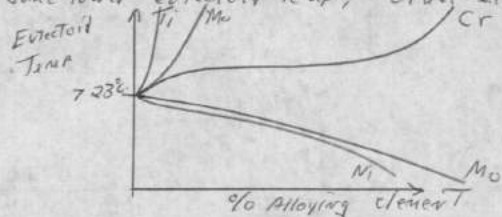
Effect of Alloying Elements on the Iron-Iron Carbide Diagram

Addition of alloying element changes eutectoid composition

1. Carbon content of eutectoid comp. All elements lower the carbon content of eutectoid comp.



2. Eutectoid temperature. Some lower eutectoid temp, other elements raise it.

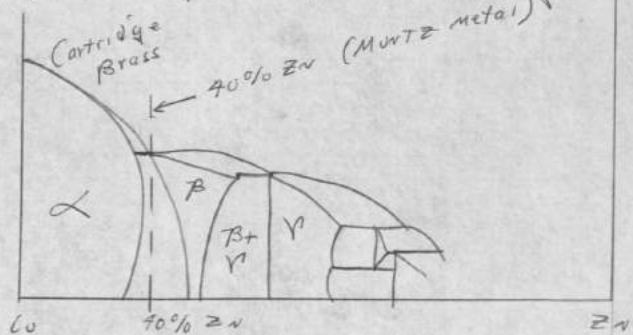


COPPER ALLOYS

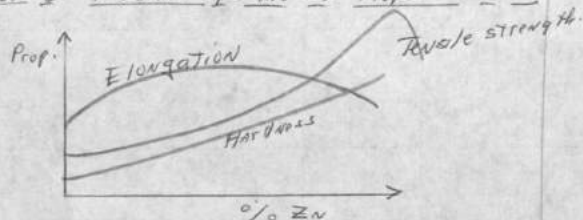
Brasses: Cu-Zn } historically, only.
Bronzes: Cu-Sn

Bronze is actually containing Cu + anything

α = FCC
 β = BCC



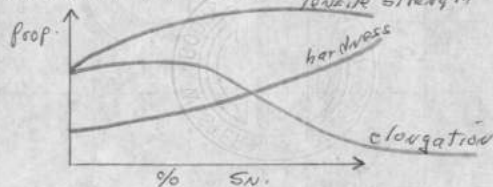
Effect of Addition of Zinc on Properties of Cu



BRONZES:

Cu-Sn example.

Effect of Zn addition on Cu Prop.

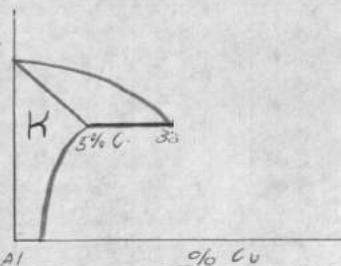


LIGHT METAL ALLOYS:

1. ALUMINIUM Alloys (Al most abundant metal in nature)

Principle alloying elements: Cu, Si, Mg

Al-Cu } hi strength
Al-Mg }
Al-Si } moderate strength.



Addition of Cu to Al increases Tensile strength at expense of ductility.

Addition of Cu also decreases corrosion resistance.

Corrosion considerations:

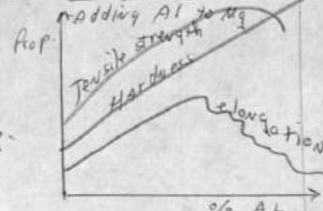
1. env
2. protective oxides
3. microstructure

Individual constituents tells about localized energies

2. Magnesium: Very ductile but not strong.

Principal alloying elements: Al, Zn, Mn.

Addition of Al increases strength of Mg.



3. Titanium: very abundant - ~0.6% of earth's crust

In natural state it has NAD gaseous impurities in it & is so very ductile.

Pure Ti wasn't obtained until 1940

Properties:

1. protective oxide [corrosion resistance]
2. hi tensile strength
3. hi strength to wt. ratio (i.e. low density)

REFRACTORY METALS (metals used at hi temp.)

Considerations for hi-temp use:

1. Hi melting pt.
2. Low vapor pressure
3. Reactivity
4. Mech properties
5. Cost-availability

1. Melting Pt: (W has highest of all metals)

Metal	M.Pt.
Tungsten, W	3410°C.
Re	3180
Ta	2996
Os	2700 ± 200
Mo	2625
Ru	2500
Ir	2454
Nb	2415
Zr	1830
Th	1827
V	1735
Ti	1725

2. Vapor Pressure:

Estimated max temp at which the wt. loss (due to vaporization) is less than 1% in 100 hrs.

Metal	°C
W	2560
Ta	2400
Mo	1910
Zr	1500
V	1440
Ti	1140
Cr	895

$$\ln P = \frac{W}{A} \sqrt{\frac{2997}{M}}$$

W = wt loss
M = Mo. WT

P vs T is
a logarithmic relationship.

3. Reactivity:

excepting the Pt. metals, all metals have poor resistance to attack by atmosphere.

4. Mech. Props:

a. Tungsten: Variation of tensile strength w/ temp.

T° C	T.S. (psi)
1500	10,700
1750	8250
2000	5800
2250	3400

b. Mo has excellent mech props. between 875-1000°C.

NUCLEAR MATERIALS

Uses of metals:

1. Fissionable materials (the fuel)
Uranium, Plutonium, etc.

2. Cladding metals (protective) - [metal between coolant & Al, Zr reactor center].

Desired Prop:

- A. Corrosion resistant
- B. Low cross-section [an indication of the probability of capturing a neutron]
- C. Good thermal cond.
- D. Hi melting pt.

3. Structural members: e.g. Zr & alloys
Prop: low cross-section & hi melting pt.

4. Control rods - Boron alloys
- hi cross section

Effect of radiation on materials:

1. Contamination w/ radio-active prop.
2. Induction of undesirable reactions (creep)
3. Radiation damage -
effect on physical & mech properties.

e.g. decrease in ductility

" " impact strength.

Non-metallic inorganic materials

Uses:

1. structural members for containers.
2. hi Temp. properties.
3. Semiconductors
4. Electrical insulators
5. Thermal " "
6. Corrosion resistant coatings.

1. OXIDES:

	M.P.T
Al_2O_3	$\rightarrow 2015^\circ C$
B_2O_3	$\rightarrow 2575$
ThO_2	$\rightarrow 3300$
ZrO_2	$\rightarrow 2677$
MgO	$\rightarrow 2800$

Characterized by: resistance to oxidizing atmospheres.

2. CARBIDES:

of simple compounds, carbides are highest melting in nature.

	M.P.T
HfC	$\rightarrow 3887^\circ C$
MoC	$\rightarrow 2692$
TaC	$\rightarrow 3877$
ThC	$\rightarrow 2625$
ZrC	$\rightarrow 2530$

Characterized by: 1. hi melting pt.
2. lack of oxid. resistance at hi Temp.

3. BORIDES:

AlB_2	$\rightarrow 1100$
TiB_2	$\rightarrow 2600$
ZrB_2	$\rightarrow 3000$
HfB_2	$\rightarrow 3062$

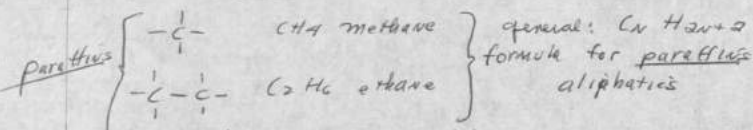
1. hi hardness
2. good corrosion resistance
3. hi electrical conductivity.

4. NITRIDES:

BN	\rightarrow sublimed at $3000^\circ C$.
AlN	$\rightarrow 2230$ (M.P.T)
TiN	$\rightarrow 2950$
TaN	$\rightarrow 2980$

1. hi melting pt
2. low oxid. resistance
3. hi hardness
4. hi volatility.

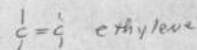
5. SULFIDES: (didn't cover them)



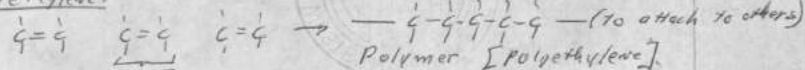
Aliphatics = straight chain compounds

$$M.P.T. \text{ (Paraffins only)} : \frac{1}{T.M.P.T.^\circ K} = 2.395 \times 10^{-3} + \frac{17.1 \times 10^{-3}}{n(\text{no. of Carbons})}$$

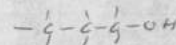
Saturated compounds: those w/ all single bonds.
Unsaturated " " w/ at least 1 double or triple bond.



Polyethylene:

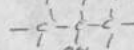


Polymer vs Isomer:



isopropanol.

Isomer = compound of like composition but different arrangement.

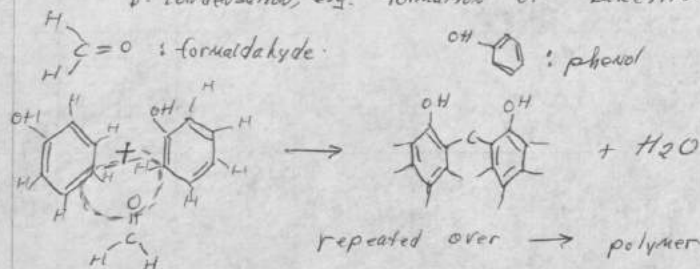


isopropanol.

Polymerization Mechanism:

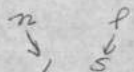
a. addition - e.g. formation of polyethylene

b. condensation, e.g. formation of "Bakelite".



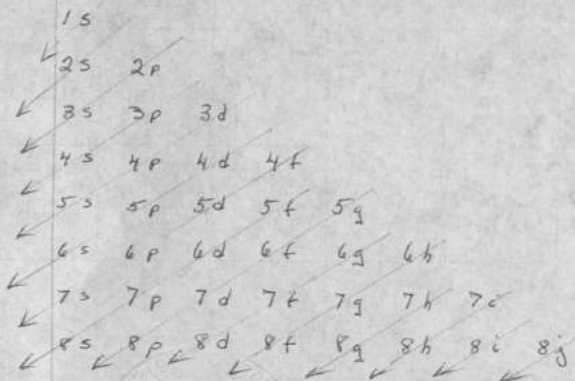
the phenol-formaldehyde resin, or "Bakelite".

ORDER OF ENERGY LEVELS:



MAX. NOS.:

- s = 2
- p = 6
- d = 10
- f = 14



KEEP N+L TO A MINIMUM
IN CASE OF TIE, LOWEST N WINS

Engg Metallurgy b, Committee on Metallurgy

Chapt. 2: "Fund. Structure of Metals and Alloys"

De Broglie (wave mechanics) $\lambda = h/mV$

- h = Planck's constant
- m = mass
- V = Velocity } of particles

Heisenberg: Position & momentum (mV) cannot be exactly determined simultaneously

Pauli: No 2 e⁻ have same 4 Q.N.

Miller indices of planes ()
family of planes []
indices of direction []
family of equis " < >

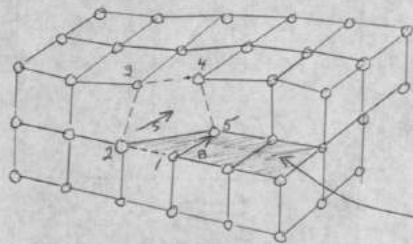
Crystal Defects:

1. Surface
 2. Line
 3. Point or atomic
1. includes surface grain boundaries which give rise to a zone of disregistry
2. edge & screw (no explanation)
3. atom vacancy, etc.

Barrett Structure of Metals
Chapter 16: "Dislocation Theory"

Edge: Resulting displacement is same whether a + dislocation moves to the right or a - to the left.

Screw:



Dotted Lines show
Burger's circuit.

Fig 2, P. 396

A Right Handed Screw Dislocation in a Simple Cubic Structure

The Dislocation moves \perp to itself.

Burger's circuit is a spiral path.

BURTON - APPLIED METALLURGY for ENGINEERS (NOTES)

Chapt. 3 - Mechanical Testing:

I. Tensile Properties:

1. Tensile strength
2. Yield strength (or point)
3. elongation
4. Area reduction
5. Modulus of elasticity.

All 5 above can be determined from a tensile test.

Tensile strength = Max. load / original Area
(has no fundamental significance)

Ductility is indicated by: % elongation & % area reduction.

$$\% \text{ elong} = \frac{L_f - L_0}{L_0} \times 100$$

$$\% \text{ Area red} = \frac{A_0 - A_f}{A_0} \times 100$$

Stress-Strain Curve:

Plot stress as ordinate, strain (ϵ) as abscissa.

Yield Pt. = the stress at which a marked increase in elongation occurs w/out a corresp. increase in stress.
Most metals do not show a yield pt., and we determine a yield strength for them.

Yield strength = stress required to permanently change a metal 0.2%.

E = Young's Modulus of elasticity is slope of initial linear portion of stress-strain curve.

$$\text{True strain } \epsilon = \int \frac{dL}{L} = \ln A_0/A$$

II. HARDNESS:

A. Brinell: A relatively large ball is driven into spec. producing slight indentation.

$$BHN = \frac{P}{\pi D} \left(D - \sqrt{D^2 - d^2} \right)$$

P = load, kg
 D = dia of ball, mm
 d = dia. of impression, mm

This test leaves large impression, \therefore good for inhomog materials to determine average hardness.

II

B. ROCKWELL:

Uses small penetrator w/ minor load to calibrate then adds major load & measures penetration depth, d_H which is inversely \propto to hardness, which is read on dial.

III FATIGUE & ENDURANCE:

fatigue loading = repeated loading of metal to stresses lower than the ultimate strength.
(generally results in a fatigue fracture)

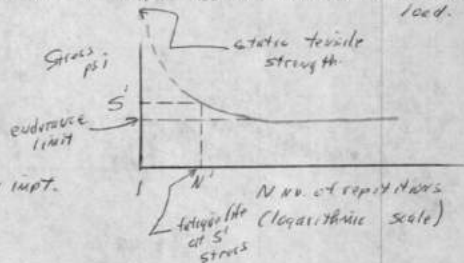
endurance limit = limiting stress below which fatigue fracture will NOT occur.

endurance ratio = $\frac{\text{endurance limit}}{\text{ultimate strength}}$

fatigue life = No. of repetitions a sample can withstand at certain load.

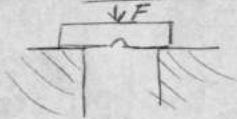
fatigue failure starts as a surface crack which grows & spreads until sudden fracture

is surface of metal is very imp.

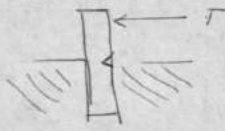


IV

IMPACT:

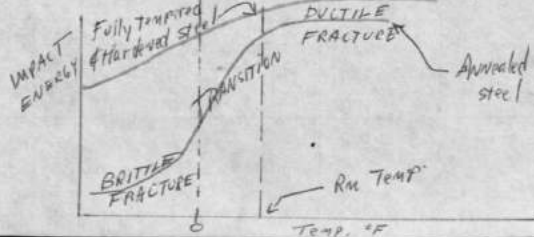


CHARPY TEST



IZOD TEST

A plot of impact test data often shows a transition temp range, above which the metal is ductile and below which brittle fracture occurs. A low transition temp is desirable.



Chapter 6: Principles of Heat Treatment:

" Response to heat ~~heat~~ treatment results from the instability of a hi-temp phase when cooled to lower Temp & the possibility of forming a new low-temp phase during cooling. If the low temp phase is in equilb

- 1) it has negligible effect on prop. of metal.
- 2) A new low temp phase may precipitate w/in a matrix of super saturated hi-temp phase & have a definite effect on the prop. of the alloy.
- or
- 3) A metastable phase may form which also has an effect on the prop. of the material.

Austenite:

Soft, ductile phase - Carbon dissolved in γ -iron, [FCC]

Max C solubility in austenite is 2.0%

Austenite usually exists only at hi-temp.

Austenite is a single phase

Ferrite:

Solid solution of Carbon in α iron (BCC)

Carbon soluble only up to 0.025%
ferrite commonly called "pure iron".

Ferrite is softest constituent of steel & very ductile.

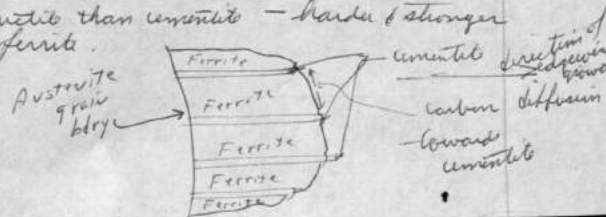
Cementite: (Fe₃C):

Hardest constituent of steel - but very brittle.
Carbon content \rightarrow 6.67%

Pearlite:

Pearlite is a lamellar structure of alt. plates of cementite & ferrite w/ prop. intermediate between cementite & ferrite

Softer, more ductile than cementite - harder & stronger than ferrite.

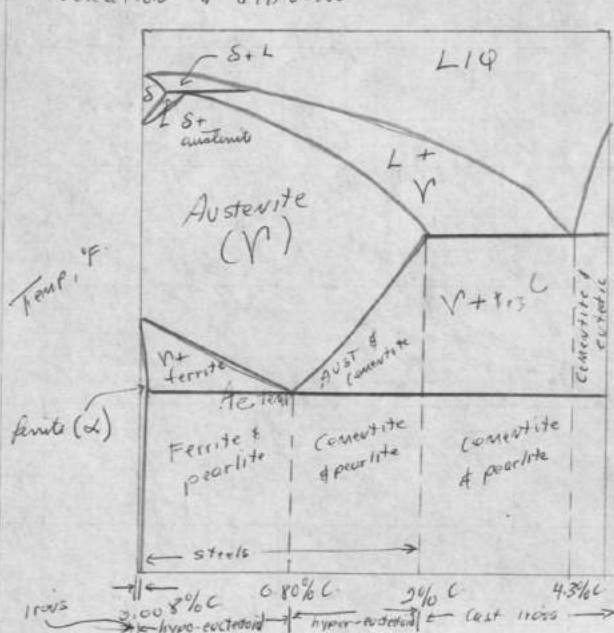


During slow cooling of austenite, nuclei of cementite form at the austenite grain bdr's & grow into platelets by edgewise growth in the aust. matrix. The C. content of cementite is much higher than C. content of aust., & C. must diffuse thru aust. toward the growing cementite plates. Aust. adj. to growing cementite plates is depleted of C. & transforms to ferrite.

Pearlite is nucleated at aust. grain bdr's & grows by consuming aust. When aust. C. content depleted so cementite can no longer form, remaining aust. → ferrite.

NON-EQUILIB COOLING:

Temp. affects rate of transformation by means of nucleation & diffusion



Pearlite forms slowly at its highest & lowest temps. and more rapidly in between.

Rapid cooling doesn't allow sufficient time for atom movement, ∴ aust. does NOT → to pearlite + ferrite or cementite excess, but → bainite or martensite.

Fine Pearlite: Pearlite formed by more rapid cooling, much stronger & harder than coarse (slowly cooled) pearlite.

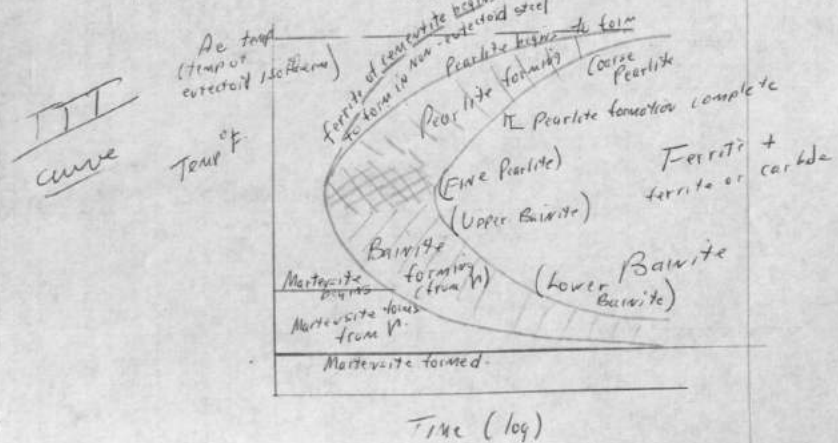
Martensite: Hard, strong, brittle. A super sat. solution of C. in ferrite. The excess C. distorts cubic & to tetragonal strained struct. which is ∴ hard & strong.

Martensite plates form by a shearing action along crystallographic planes rather than by atom movements.

Bainite: Temp. range between 1st pearlite & 1st martensite. Bainite formed by a nucleation & growth process. Bainite can be ignored if we cool fast enough.

TTT (Time, Temp, transformation) Curves:

- ∇ slow cooling → α + Fe₃C
- ∇ rapid cooling → fine pearlite + bainite + martensite.



HARDENING OPERATIONS

3 heat treating groups:

hardening, annealing (softening), stress relieving.

Hardening: heat steel to Temp \rightarrow all aust., then cool \rightarrow pearlite is avoided & all martensite formed.

- Annealing:
1. full annealing (slowly cooled from γ region, cooled in furnace.
 2. Normalizing (as above but air cooled)
 3. Process annealing - softening operation

4. spheroidizing, et al.
(for hi-carbon steels only) - a softening process, heat to very near A_c temp.

Spheroidized steels softest & most ductile one possible in hi-C steels.

Stress Relieving: metal not appreciably softened but is heated to remove internal stresses (microstructure not noticeably altered).

TEMPERING:

Chapters 4 4-1 - 4-10

Chapt. 11, 1-12

" 12, 1-8

" 14, 1-11, 15-19

Strain hardening: the increase in strength due to cold work the mat. remains mechanically distorted but will now strain less readily, thus \rightarrow increased strength.

Recrystallization: the realignment of the atoms of cold-worked material into their more natural configurations.

annealing: At high temp's, greater thermal vib. of lattice realigns the distorted lattice.

recrystallization forms softer crystals.

Temp. of marked softening in a strain-hardened material is the recrystallization temp. The more strain hardened, greater the % cold work, the more unstable the material and -- lower recrystalliz. temp.

Recryst. temp. also affected by time of heating. ^{at 7, 10 min}

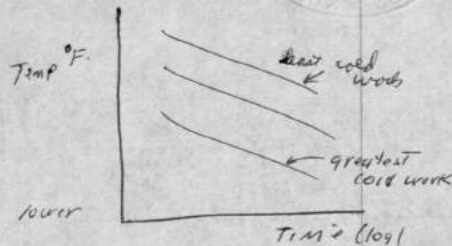
T_{Recr} decreases.

Hot working: work performed ^{at a temp} above T_{Recr} temp.

Cold working: work at temp. below T_{Recr} temp.

Recryst. Temp. $\equiv T_{Recr}$

$T > T_{Recr}$: metal soft & ductile
 $T < T_{Recr}$: metal harder & less "



Chapt 11

Deformation:

relaxation time = time required for the adjustment of stresses in strained materials.

Fatigue Failure Pattern:

1. repeated cyclic stressing causes incremental slip & cold-working.
2. gradual reduction of ductility ~~in~~ in the locally work-hardened areas results in the formation of sub-microscopic cracks.
3. Notch effect of the sub-micro cracks concentrates stresses until complete fracture occurs.

Fatigue failure related to synergetic effects.

The maximum strain not developed uniformly, but at grain bodies and surface irregularities, etc.

Factors of Fracture:

1. rate of impact
many materials which fracture brittle at sudden impact would show ductility w/ a slower application of an = force.
2. ~~at~~ Temp.
materials tougher at higher temps (more ductile), brittle at lower temps
3. Geometry
Irregular shapes lead to conc. stresses & localized fracture, and a crack, once started, seems to further concentrate stresses at its root.

Transition Temp's:

Property of BCC metals

at imp. low temps, transition occurs from ductile fracture (requiring hi energies) to brittle fracture (requiring lower energies)
change occurs over a range of temp.



WEAR: surface of material removed by mechanical abrasion.
wear resistance, in general, parallel to hardness.

Exceptions: rubber tires wear out faster than metal tires.

Railroad materials more satisfactory under conditions of particle impact, as energy is absorbed & returned to particles w/out ~~in~~ impairing the material. A ~~non~~ non-rigid material "give", rigid one does not.

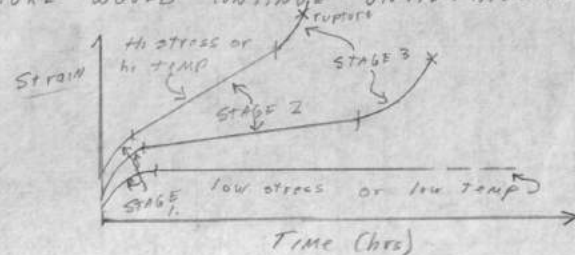
In a cutting or grinding situation, the material must:

- 1.) be harder than the abrading particles and/or
- 2.) be as tough that it cannot be torn apart by the abrading particles.

We want compromise between toughness & hardness.

HIGH TEMP. PROPERTIES:CREEP (P 351)

WHEN A METAL IS STRESSED, IT UNDERGOES IMMEDIATE PLASTIC ELONGATION, AND IN THE FIRST SHORT PERIOD OF TIME MAKES ADDITIONAL PLASTIC ADJUSTMENTS AT POINTS OF STRESS ALONG GRAIN BOUNDARIES AND AT FLAWS. AFTER THESE INITIAL ADJUSTMENTS, A SLOW, NEARLY STEADY RATE OF STRAIN, CALLED CREEP, SETS IN AND CONTINUES UNTIL SUFFICIENT STRAIN HAS OCCURRED SO THAT A NECKING DOWN AND REDUCTION OF CROSS-SECTIONAL AREA OCCURS. AFTER THIS AND UNTIL RUPTURE, THE RATE OF ELONGATION INCREASES BECAUSE THERE IS LESS AREA TO SUPPORT THE LOAD. IF THE LOAD WERE REDUCED SO THAT THE APPLIED STRESS REMAINED THE SAME, THE STRAIGHT LINE OF STAGE 2 IN THE FIGURE WOULD CONTINUE UNTIL FAILURE.



Creep rate = $\frac{\text{steady strain}}{\text{steady time}}$, i.e. slope of stage II line

1. steady creep rate increases w/ temp.
2. " " " " " stress
3. Total elongation at rupture increases w/ stress
4. Time before eventual failure by rupture is decreased as the temp (i.e. the creep rate) is increased.

Steady creep rate related movement of dislocations, ∴ Any feature which restricts slip also restricts creep.

Strain hardening does NOT ordinarily restrict the dislocation movements which produced creep because creep temps. are usually above the recrystallization temps for the time involved.

At low temps, grain bdr's are stronger than grain themselves.
At hi temps, grain bdr's serve as paths for creep & rupture.

Conductivity $\equiv \sigma = n e \mu =$ $n =$ no. of charge carriers $\mu =$ mobility of carriers

$$\sigma = \frac{1}{\text{ohm-cm}} = \left(\frac{\text{carriers}}{\text{cm}^3} \cdot \frac{\text{Coul}}{\text{carrier}} \cdot \frac{\text{cm}}{\text{Volt-sec}} \right)$$

$\mu =$ velocity per unit voltage gradient

Ionic Conductivity:

Due to charged ions:

σ_{ionic} increases w/ temp because μ is increased.

$\sigma_{\text{ionic}} \ll \sigma_{\text{electronic}}$.

Electronic σ :

valence e^- oscillate equally in all directions until an E field is applied. Then the e^- travel w/ a drift velocity towards the + pole of the field.

Current (by convention) is in direct opp. to e^- flow.

Atomic energies:

bands are the collective energy levels of many atoms close together; a group of related but diff. levels

level refers to the various valence e^- energies in a single atom.

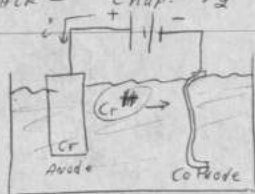
Insulators: Mat's w/ large energy gaps.

SEMI-CONDUCTORS

Semicond. are between cond. & insulators,

10^{-4} resistivity $\sim 10^2$ ohm-cm

Electroplating

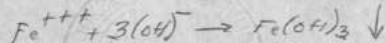


electroplating is the reverse of corrosion.

In electroplating, metal is deposited from solution. In corrosion, metal is dissolved into.

Corrosion occurs at anode; electroplating, at cathode.

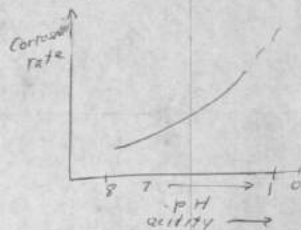
Rust:



Rust deposits at cathode & precipitates.

Types of Galvanic Cells:

1. composition cells
2. stress "
3. concentration "



Composition Cells established between 2 dissimilar materials. The one w/ higher ~~pot~~ and anode potential is anode.

e.g. Zn-plated iron: Zn serves as anode, Fe as cathode & Fe protected even when Zn is scratched

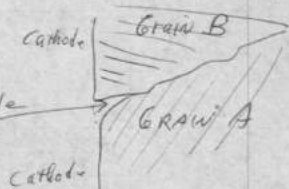
e.g. Sn-plated iron: Fe protected as long as Sn continuous. When Fe exposed, it acts as anode, Sn acts as very large cathode & severe local corrosion occurs.

EACH phase w/ its individual properties possesses its own electrode potential - so galvanic cells can be set up in most 2 phase alloys when they are exposed to an electrolyte.

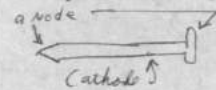
Stress Cells:

dry stress at higher potential

∴ fine grained metal will have higher corrosion rate than a coarse-grained because there is greater anode area.



Cold-worked areas serve as anodes w.r.t. non-cold worked areas



Concentration Cells: conc. cells accentuate corrosion, but accentuates it where the conc. of electrolyte is lower. w/in homog electrolyte, less concentrated area becomes anode.

Oxygen accelerates corrosion, but accelerates it where the oxygen is low or less.

Anodes undergo corrosion, cathodes are protected.

CORROSION PREVENTION

1. isolation of electrolytes from electrodes by means of protective surfaces
2. avoidance of galvanic couples
3. Use of galvanic protection.

1. Protective Surfaces:

can sometimes cause electrolyte-cathode reaction to place an insulating deposit on cathode, thus insulating the cathode from the electrolyte - this is called passivation



CrO_4^- acts as an inhibitor to isolate cathode from electrolyte.



2. Avoidance of galvanic couples:

limit design to one metal

Special procedures to inhibit intergranular corrosion (pp 370-391)

3. Galvanic Protection:

1. Sacrificial anodes e.g. Zn or Fe
2. Impressed Voltage. Supplies extra e^- so metal becomes cathode and corrosion reactions cannot proceed.

1. Sacrificial Anodes:

uses Mg plates connected to a pipe line

Zn plates on ship hulls
Mg bar in hot water tanks
these sacrificial anodes can all be easily replaced.

2. Impressed Voltage:

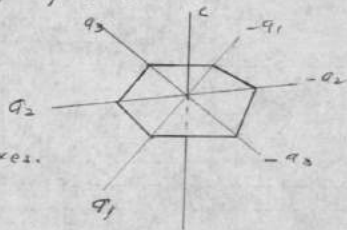


A small d-c voltage will provide sufficient e^- to make the pipe a cathode.

Chap. 13, p. 297
 Chap. 14, p. 316-317-318 only
 Chap. 15, part of allot γ , p. 336

P. 9. Hexagonal Indices

C is diagonal axis
 a_1, a_2, a_3 basal axes.



Zone theory of solids P 303

FACTORS AFFECTING ELECTRICAL RESISTANCE OF METALS:

1. Resist. increases w/ temp. (thermal vib. interferes w/ conductivity σ).
2. " " " w/ impurities & alloying. (disturbance prod. in lattice by the foreign atoms).
3. R increases w/ cold work. (due to locally distributed internal strains).

SLIP:

FCC: Slip plane Normally the plane in the lattice that's most densely packed w/ atoms. (111 plane)

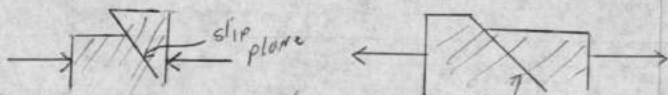
CPHct: Basal plane (most dense plane).

BCC: Several planes (among most densely packed ones)

slip system: a plane & direction of slip.

Slip recognized by slip lines formed by intersections of slip planes w/ crystal surface.

If movement is conc. on a single plane, should appear as below for compression & tension:



If slip occurs on several or a group of planes, the contour will be curved rather than abrupt & discontinuous.

BARRETT

CRITICAL RESOLVED SHEAR STRESS:

$$\tau = F/A \cos \phi \cos \lambda$$

below τ_c , the flow is called creep, around τ_c , flow is called slip.

τ_c decreases w/ increase temp. and drops to 0 at melting. shear stress increased by cold work.



CREEP:

STAGE I: load 1st applied. This is an instantaneous elongation then a transient stage in which $\frac{d\epsilon}{dt}$ becomes constant and goes to a min and increases that way (S.T.H.).

FRACTURE:

Cleavage: on crystallographic planes of low indices.

DCAN - Principles of Physical Metallurgy

[1,000] direction is direction || to principal axis.

(0001) plane is basal hexagonal plane

CREEP

Chapter 6: Physical Properties

Electrical Properties:

$$R = \rho \frac{l}{A} \quad \Omega$$

6-1

electric current density $j = N e v_D$ amps/cm²

6-2

$N =$ no. of free e⁻ / cm³

$v_D =$ drift velocity of e⁻.

distance (average) between collisions = mean free path

average time " " \equiv relaxation time τ .

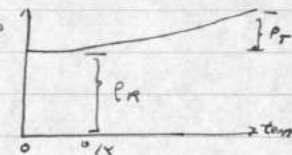
MONOVALENT metals are generally better conductors than DIVALENT metals because mono- have more vacant energy states in which conduction can occur.

Mathiessen's rule: $\rho = \rho_T + \rho_R$ (6-3)

$\rho_R =$ residual resistivity

$\rho_T =$ thermal " term

at 0K, $\rho_T \rightarrow 0$



ρ_T is generally linear w/ temp at room temp & above.

ρ_R results from lattice disturbances other than those caused by thermal vibration.

$$\rho_T = \rho_{T=0} [1 + \alpha (T - T_0)]$$

6-4

$\rho_T = \rho$ at T_0 , $\rho_{T=0} = \rho$ at $20^\circ C$, $\alpha =$ temp coeff of ρ per $^\circ C$.

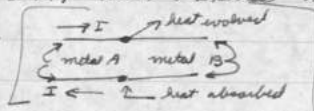
Thermoelectric Properties:

Peltier, Thomson, Joule heat, & CONTACT POTENTIALS

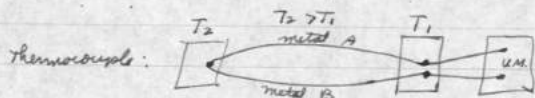
Joule heat: temp. of a cond. rises as current is passed thru it.

Peltier effect: a heat effect associated w/ current; heat may be absorbed or evolved (depending on direct. of i).

Occurs at junction between 2 diff metals & depends on the metals, temp., and current.



Thomson effect: Prod. of current in homog. metal as a result of a temp gradient: $T_2 \xrightarrow{I} T_1$



Thermocouple: uses Seebeck effect which is a combination of Peltier & Thomson.

Voltage developed as result of (1) heat flow at junctions (Peltier) and (2) temp gradients (Thomson).

Contact Potentials: developed at junction of 2 dissimilar metals but cancel in a metallic circuit.

Magnetic Properties:

see p. 178 for excellent explanation of net mag. moment of atoms.

Mag substances:

dia, para, ferro : see notes

ferro: the entire metal crystal cannot be 1 large domain as this would mean this would be many poles on the metal surface and the associated magnetostatic energy would be very high. \therefore metal assumes domain structure & few poles appear in int. or at surface of metal.

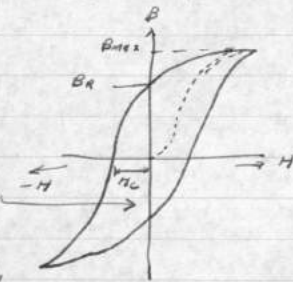
anisotropy energy: additional energy required to magnetize a substance in a direction other than the "easy" direction. Block wall is the domain bdy. ≈ 1000 atoms wide, in which mag. direct changes from 1 domain to other.

B_{max} \equiv saturation magnetism

B_r \equiv residual "

H_c \equiv coercive force

Hysteresis loss \propto to area inside loop

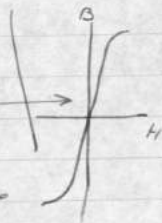


When H applied to mag material, domains w/ orientation closest to H have lower energy & are more stable. The more stable domains "grow" as a result of Bloch wall motion. Then when $H > H_c$, the domains rotate into alignment w/ H .

Mag Prop. (cont.)

"Soft" Materials:

graph of ideal soft material



Prop. of "Soft" Materials

1. B_{max} should be high
2. $\mu = B/H$, H large ($\therefore H$ doesn't have to be as large to produce same B)
3. H_c small
4. core loss or total power loss = hysteresis loss + eddy current loss. should be as low as possible.

HARD MAGNETS:

H_c , B_r should be large.

$(BH)_{max} \equiv$ max. st. energy.

Magnetostriction:

Δ is degree of magnetization results in a Δ length, this \equiv magnetostriction, converse also. open principle of Sonar.

Chapter 7: Elastic & Plastic Deformation

Elastic Prop

$E \equiv$ Young's Modulus

Hooke's Law: $\epsilon = \frac{1}{E} \sigma$

7-1

where

$\epsilon \equiv$ strain = $\frac{\Delta L}{L}$

$\sigma \equiv$ tensile stress = load/Area

increasing temp tends to decrease E

Design Principle: Working stress must lie within elastic range.

Stress raiser: a shape effect in which stress may be higher in certain portions of a material due to shape. nominal stress is over all stress (total load / total cross-sectional area)

Two classes of stress:

1. Body stress (macroscopic)
2. Textural stress (microscopic inhomogeneities)

Body stresses:

1. ext. loads
2. residual stress — prod. by cold-working nonuniform change in vol. due to thermal effects.

Plastic Deform.

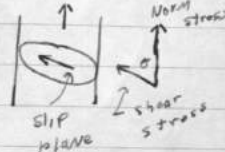
Normal temp: deform. generally by slip.

1. slip process occurs only on slip planes & in slip dir.
2. min. stress, critical resolved shear stress, must act.

$F_s = F_v \cos \theta$

$\gamma = \text{shear stress} = \frac{F_s}{A_s} = \frac{F_v \cos \theta}{A_v} \cdot \frac{a \sin \theta}{a}$

$\therefore \gamma = \sigma \sin \theta \cos \theta$



Slip occurs when $\tau = \tau_0$

τ_0 = critical resolved shear stress.

single slip (easy glide) is uniaxial slip behavior
 crystal lattice is undisturbed, most near slip plane,
 the τ_0 remains constant through the process

Cold-work/Hardening:

strengthens a metal

slight decrease in el. work.

more corrosion resistant

Preferred orientation

Hi Temp Deform.

1. vacancies & interstitial atoms ^{created by deform. process} move thru lattice

this is an ex. of diffusion in metals.

vacancies & interstitials move to lower ~~free~~ energy areas.

2. "climb" of dislocations

creep: caused by low stresses at hi temps.

Stress - Strain Definitions:

$$d\epsilon = dl/l$$

$$\epsilon = \int_{l_0}^{l_0 + \Delta l} \frac{dl}{l_0}$$

7-4

$\epsilon \equiv$ true strain

$$\epsilon = \int_{l_0}^l \frac{dl}{l} = \ln l \Big|_{l_0}^l = \ln \frac{l}{l_0} \quad 7-5$$

$\epsilon \equiv$ elastic strain 7-5 valid only for uniform deform.

$\delta \equiv$ plastic strain nonuniform deform., e.g. necking,
 plastic strain has diff values at diff parts.

max. strain or strain at necked section:

$$\delta = 2 \ln \frac{d_0}{d} \quad , \quad d_0 = \text{init dia.} \quad 7-8$$

$$d = \text{neck dia}$$

Stress $\sigma = F/A_0$ 7-7

Flow stress

Below a certain stress σ_0 , ^{plastic} no strain is produced.

elastic: $\epsilon = \frac{1}{E} \sigma$

plastic: $\delta = 0$ for $\sigma < \sigma_0$

$\delta = f(\sigma)$ for $\sigma > \sigma_0$ } 7-11

begin. of plastic deform. = 0.2% offset yield strength.

flow stress is yield strength: practical limit for design stresses

yield strength decreases as T increases, i.e. $\sigma_0 = A_0 e^{B/T}$ 7-10

A, B constants

microstructure of alloy influences flow stress:

$$\sigma_0 = \sigma + k \ln \frac{1}{d}$$

7-13

k, h constants; d = mean free path in matrix of alloy.

Effective stress-strain curve:

$$\sigma = K \delta^n \quad \text{for region}$$

7-14

between elastic & linear plastic part of curves

Fracture

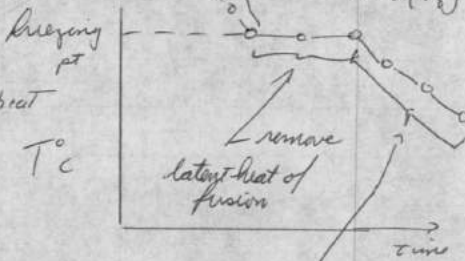
cleavage: along a crystal plane

shear:

Phase Diagrams:

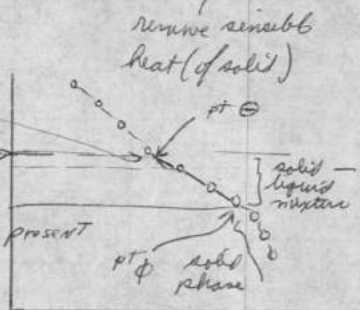
METAL:

constant rate of heat removal.



ALLOY:

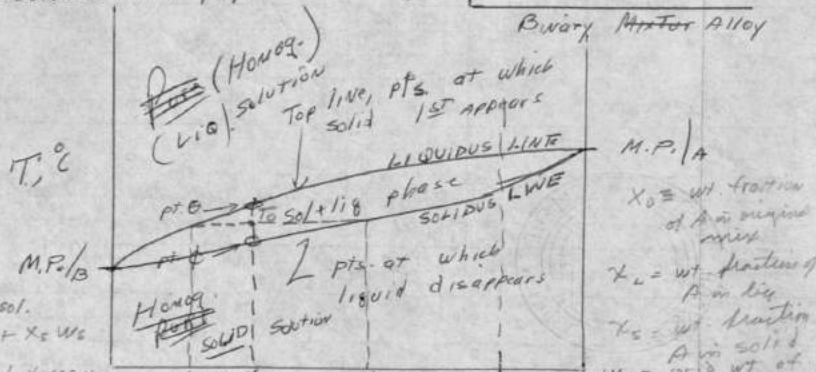
abrupt change in slope



Binary Alloy, $x_A + x_B = 1$

Phase or Equilib. Diagram: (IDEAL) which solid is present

A, B soluble in all prop.



Binary Alloy

(HOMOGENEOUS) (LIQ) solution

Top line, pts at which solid 1st appears

pts at which liquid disappears

(wt fraction component A, B wt. %, et. al)

line intersects solid lines, drop I's to X line, and you have X2, X3, X0 pure B

50% A 50% B

X_0 = wt fraction of A in original mix

X_L = wt fraction of A in liq

X_S = wt fraction of A in solid

W_0 = 0.5 wt of comp A system (constant)

W_L = wt liquid

W_S = " solid

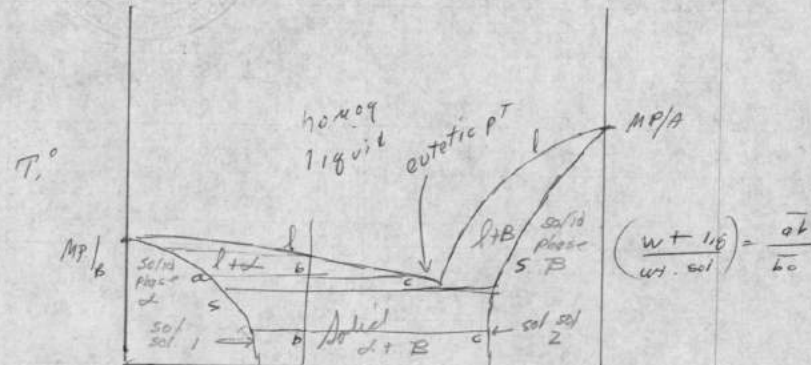
$$X_0(W_L + W_S) = X_L W_L + X_S W_S$$

$$W_L(X_0 - X_L) = W_S(X_S - X_0)$$

LEVER RULE

pure A

Ideal Binary System



pure comp 0%

% A

pure comp 100%

eutectic pt: saturated w/ T both solids

$$\left(\frac{\text{wt solid soln 1}}{\text{total wt}} \right) = \left(\frac{bc}{ac} \right)$$



PROBLEM #1: Determine the number of electrons in the "d" and "f" states:

d state: $N=3$
 $l = N-1 = 2$
 $m_l = \pm l = -2, -1, 0, +1, +2$
 $m_s = \pm 1/2$

∴ The total number of possible combinations is 10.

(5 different m_l possibilities and 2 different m_s possibilities for each m_l possibility).

f state: $N=4$
 $l = N-1 = 3$
 $m_l = \pm l = -3, -2, -1, 0, +1, +2, +3$
 $m_s = \pm 1/2$

∴ The total number of possible combinations is 14.

∴ There is a max. of 10 electrons in the d state and a max. of 14 electrons in the f state.

PROBLEM #2: Write the electron configurations for elements 1-19 (inclusive):

- 1: $1s^1$
- 2: $1s^2$
- 3: $1s^2 2s^1$
- 4: $1s^2 2s^2$
- 5: $1s^2 2s^2 2p^1$
- 6: $1s^2 2s^2 2p^2$
- 7: $1s^2 2s^2 2p^3$
- 8: $1s^2 2s^2 2p^4$
- 9: $1s^2 2s^2 2p^5$
- 10: $1s^2 2s^2 2p^6$
- 11: $1s^2 2s^2 2p^6 3s^1$
- 12: $1s^2 2s^2 2p^6 3s^2$
- 13: $1s^2 2s^2 2p^6 3s^2 3p^1$
- 14: $1s^2 2s^2 2p^6 3s^2 3p^2$
- 15: $1s^2 2s^2 2p^6 3s^2 3p^3$
- 16: $1s^2 2s^2 2p^6 3s^2 3p^4$
- 17: $1s^2 2s^2 2p^6 3s^2 3p^5$
- 18: $1s^2 2s^2 2p^6 3s^2 3p^6$
- 19: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^1$
- 20: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2$
- 21: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^1$
- 22: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^2$

PROBLEM No. 2:

Sb - Antimony - Atomic No. 51 is in Group 5A of the Periodic Table, therefore it has 5 electrons in its outer orbit.

Show $(8-N) = \text{MAX NO. OF NEAREST NEIGHBORS}$

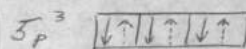
$8-N (8-5) = 3$

Sb has 3 nearest neighbors with which it shares 3 electrons.

If we did not have a periodic table, we could solve the problem by the energy level scheme

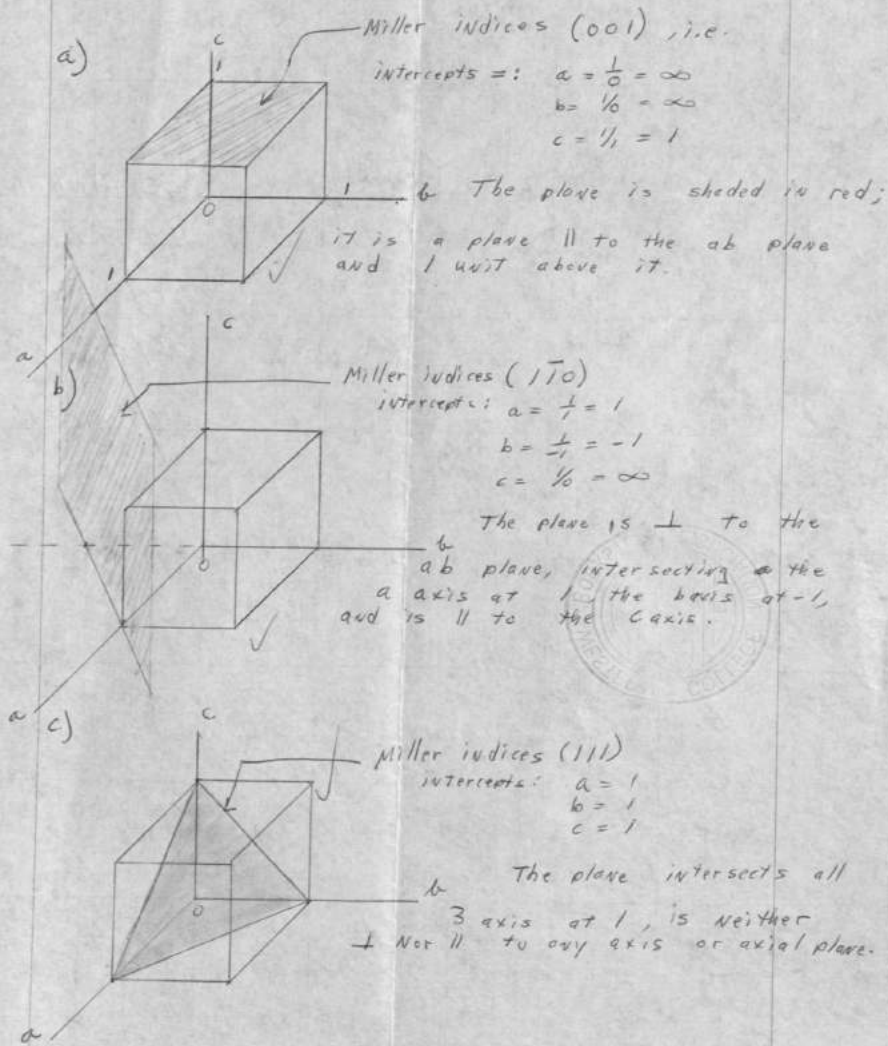
$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2$
 $\rightarrow 4d^{10} 5p^3$

This gives us the 51 electrons necessary for Sb and shows us that there are 3 electrons in the 5p level



Using the "box" configuration we see that we need 3 more electrons to pair with the others. Thus we can conclude that Sb shares electrons with 3 nearest neighbors.

PROBLEM No. 4:



MATERIALS SCIENCE PROBLEM No. 3:

SPECIMEN CROSS-SECTION: 0.5 in. x 0.05 in.
GAUGE LENGTH: 2.5 in.
AREA: 0.025 sq. in.

LOAD (lbs)	EXTENSION (inches)	STRESS σ (lb/in ²)	STRAIN ϵ (unitless)
100	0.001	4000	0.004
150	0.0015	6000	0.006
200	0.002	8000	0.008
250	0.0025	10000	0.010
300	0.005	12000	0.020
320	0.010	13000	0.040
500	0.050	20000	0.200
600	0.100	24000	0.400
620	0.125	24800	0.500
660	0.250	26400	1.000
670	0.375	26800	1.500
690	0.450	25000	1.800
FAILURE	—	—	—

- YIELD STRENGTH $\approx 10,500 \text{ lbs/in}^2$ (SEE GRAPH NO. 2).
- TENSILE STRESS $\approx 26,900 \text{ lbs/in}^2$ (SEE GRAPH NO. 1).
- PLASTIC STRAIN AT FAILURE (AT LAST POINT BEFORE FRACTURE) ≈ 0.170 (SEE GRAPH NO. 1).
- ELASTIC STRAIN AT FAILURE (SEE GRAPH NO. 1) ≈ 0.002 .

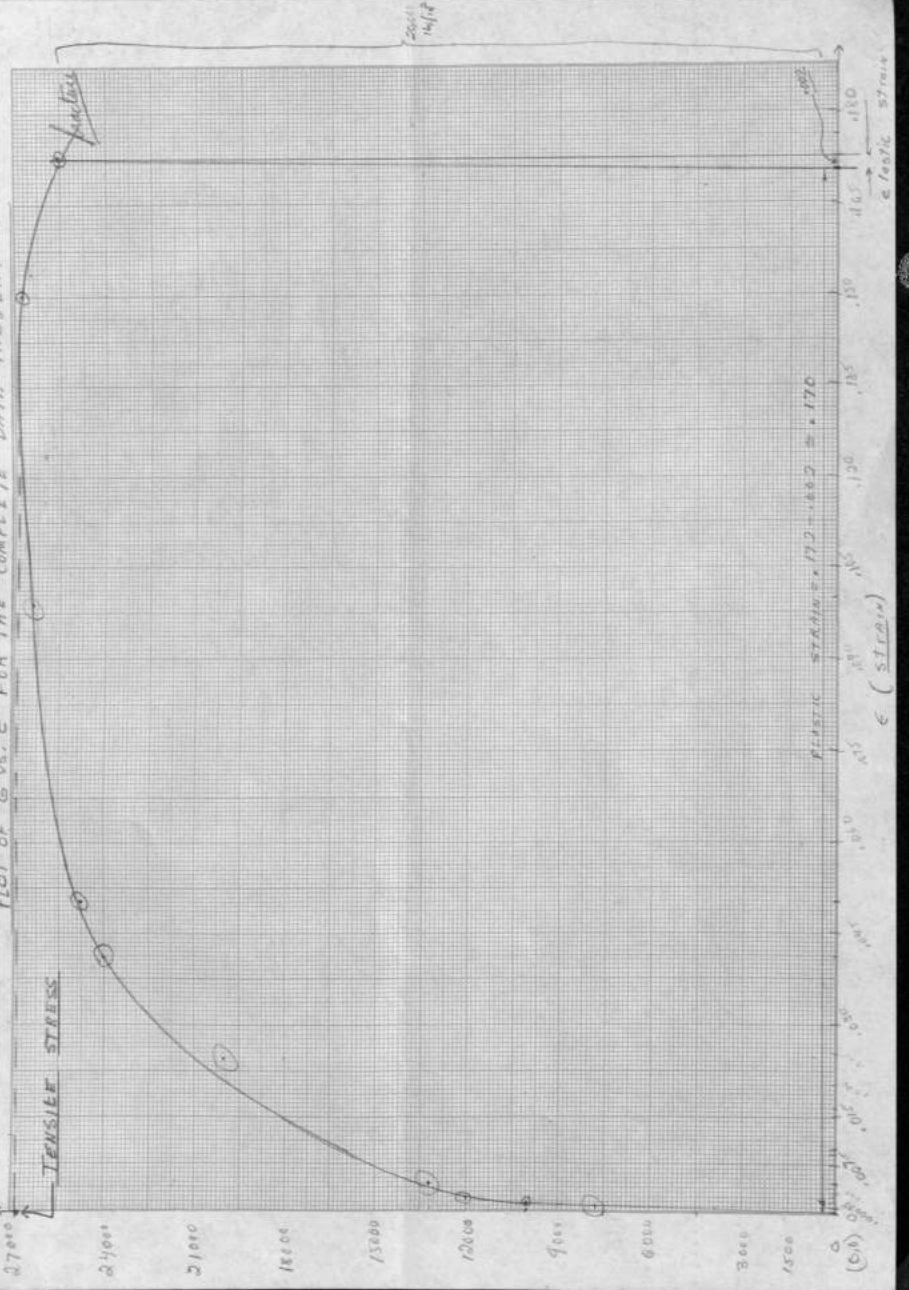
1) PLOT OF σ VS. ϵ ON NEXT PAGE (GRAPH NO. 1)
2) $E = 10 \times 10^6 \text{ lbs/in}^2$ (CALCULATIONS ON GRAPH NO. 2)
3) 7% ELONGATION = $\frac{\Delta L}{L_0} \times 100$
ORIG. LENGTH = 2.5 in.
 $= \frac{0.175}{2.5} \times 100 = 7\%$
% ELONGATION = 7%

ANDRADE
MAT SCI 25
MUNIR MAFRA

From No. 810, 10 Millimeters to Centimeters
GRAYS HANDBOOK & PAPER CO., HOUSTON, TEXAS

GRAPH # 1:

PLOT OF σ vs. ϵ FOR THE COMPLETE DATA TABULATION



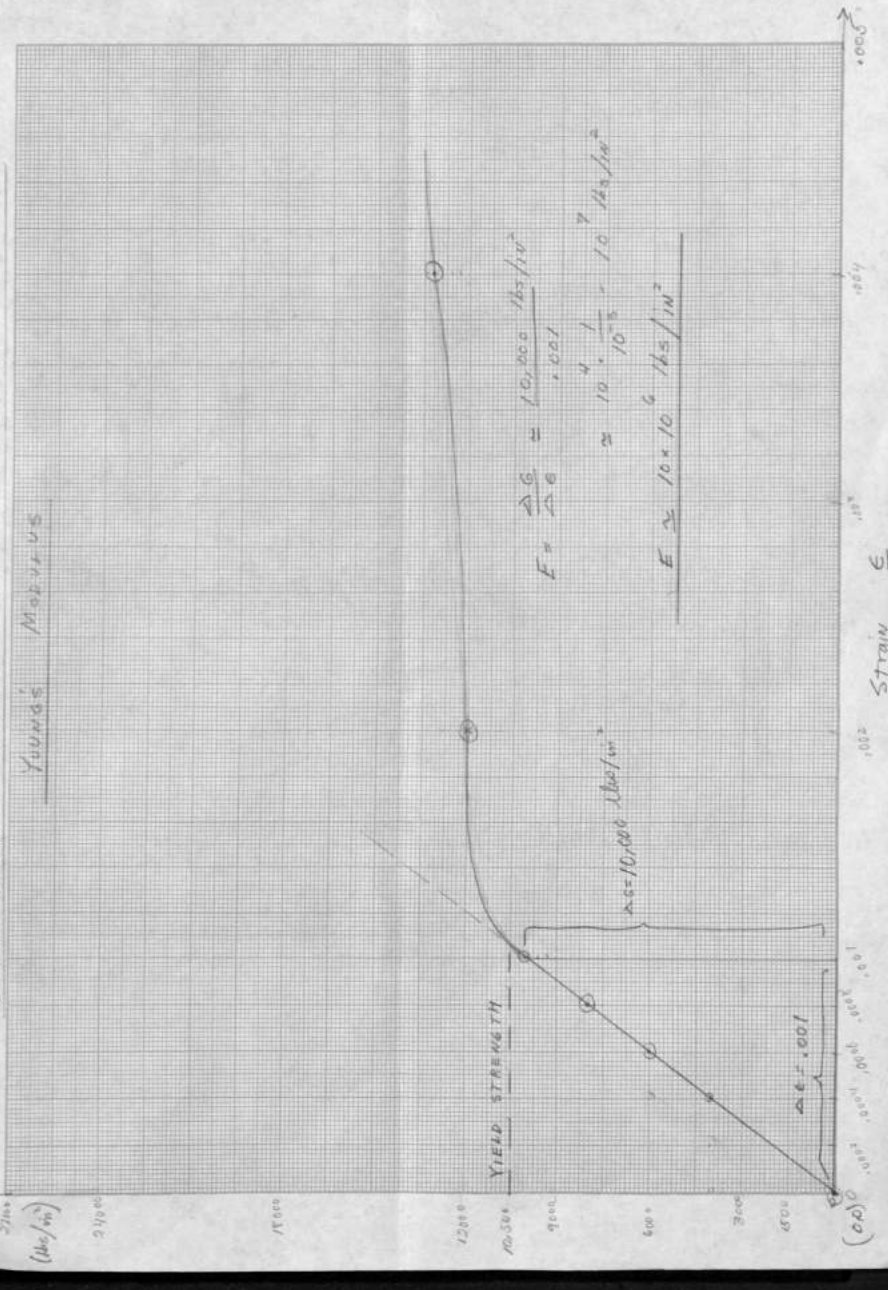
ANDRADE
MAT SCI 25
MUNIR MAFRA

GRAPH # 2:

From No. 810, 10 Millimeters to Centimeters
GRAYS HANDBOOK & PAPER CO., HOUSTON, TEXAS

EXPANDED LINEAR PORTION OF THE σ vs. ϵ CURVE, USED TO FIND

YOUNG'S MODULUS

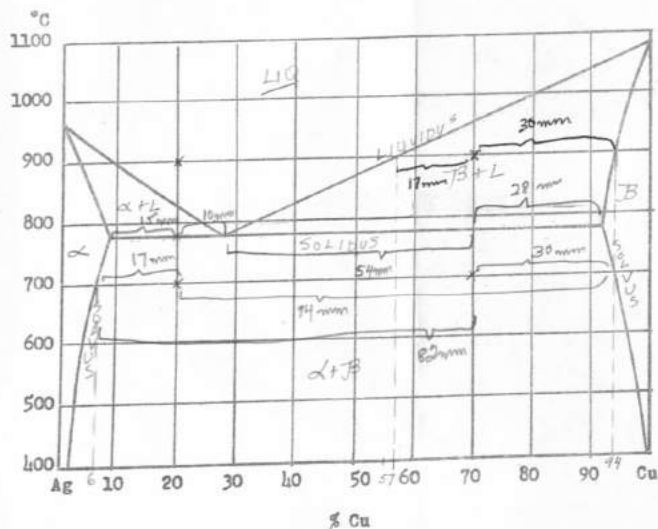


10
try good

Problem:

In the Silver-Copper phase diagram shown below, name the phases present, give their compositions, and their relative amounts at the following points:

- | | %Cu | T °C | |
|---|-----|------|--|
| a. | 20 | 900 | LIG PHASE, 20% Cu, 80% Ag, 100% of total wt |
| b. | 70 | 900 | LIG & B PHASES. LIG: 57% Cu, 63.8% of wt
B: 94% Cu, 26.2% of wt |
| c. | 20 | 700 | - give % proeutectic α |
| d. | 70 | 700 | - give % proeutectic β |
| c. α & β phases: α = 6% Cu, 24.7% total wt.
β = 94% Cu, 15.3% total wt.
proeutectic α = 10/11 (100%) = 90.9% of α | | | |
| d. α & β phases: α = 6% Cu, 26.9% total wt.
β = 94% Cu, 73.1% total wt.
Proeutectic β = 66% of total = 90.3% of β | | | |



- a.) Phase Present: LIQUID: 20% Cu
100% total wt. ✓
- b.) Phases Present: LIQUID & B: LIQ = 57% Cu
B = 94% Cu
wt. LIQ \times lever arm = wt B \times lever arm
wt LIQ + wt B = wt total = 100%
17mm wt LIQ = 20mm wt B.
wt LIQ = 20/17 wt B.
20/17 wt B + 1 wt B = 100%
wt B = 17/17 (100%) = 26.2% of total
 \therefore wt LIQ = 63.8% of total ✓

- c.) Phases Present: α & β α = 6% Cu
 β = 94% Cu
wt. α \times 17mm = wt β \times 44mm
wt α = 44/17 wt β
wt β = 17/44 (100%) = 15.3%
wt α = 15.3%
 \therefore wt α = 24.7% ✓

- Proeutectic α :
wt p.e. α \times 15mm = wt LIQ \times 10mm
wt LIQ = 15/10 wt PE α
PE α = 10/15 (100%) = 40%
PE α = 40% of total
PE α = $\frac{40\%}{84.7\%}$ = 47.3% of α ✓
PE α = 47.3% α
or 47.3% of α was PE α .

Prof Munir

d) Phases Present: α & β $\alpha = 6\% Cu$
 $\beta = 94\% Cu$

$82\text{ mm wt } \alpha = 30\text{ mm wt } \beta$ } $wt \alpha + wt \beta = 100\%$
 $wt \alpha = \frac{30}{82} wt \beta$

$wt \beta + \frac{30}{82} wt \beta = 100\% = \frac{112}{82} wt \beta$

$wt \beta = \frac{82}{112} (100) = 73.1\%$ total wt

$\therefore wt \alpha = 26.9\%$ total wt

Proeutectic β :

$wt P.E. \beta \times 28\text{ mm} = wt P.E. \alpha \times 4\text{ mm}$

$P.E. \beta + \frac{28}{4} P.E. \alpha = 100 = \frac{82}{4} P.E. \alpha$

$P.E. \beta = \frac{54}{82} \times 100 = 66\%$ of total

$\% P.E. \beta \text{ in } \beta = \frac{60}{73.1} = 90.3\%$

$\approx 90.3\%$ of β was P.E. β

Munir

12/10/62

HW Solutions

Phases	Comp (Cu)	Relative %
a } L	20% Cu	100%
b } L	87%	65%
b } β	94%	35%
c } α	7%	85%
c } β	94%	15%

$\% \text{ proeutectic } \alpha = \frac{42}{85} \times 100 = 50\%$

d } α	7%	28%
d } β	44%	72%

$\% \text{ proeutectic } \beta$:

$\text{proeutectic } \beta = \frac{70-28}{92-28} = \frac{42}{64} = 66\%$ of Total

$\% \text{ proeutic } \beta \text{ in } \beta_{\text{total}} = 66\% \text{ of } 72\% = \frac{66}{72} \times 100 = 92\%$

Exam

Corrosion also oxidation

Corrosion control

Diffusion

Annealing

Phase Diagrams

non-equilib cooling

Age hardening

iron-carbon system

Normalizing

100/100
very good

1. (30 pts.) Given the following:

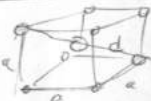
Silver

Structure = fcc
Atomic radius = 1.44 Å
Atomic weight = 107.9
N = 6 x 10²³

Iron

Structure = bcc
Atomic radius = 1.24 Å
Atomic weight = 55.9

To find a for Fe:



$$d = \sqrt{a^2 + a^2 + a^2}$$

$$d = \sqrt{3}a$$

but d = 4r for bcc cell

$$3a^2 = 16r^2$$

$$a^2 = \frac{16}{3}r^2$$

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

Calculate $a = \frac{4r}{\sqrt{3}}$

- the density of silver.
- the density of iron.

$$\text{Density} = \frac{\text{Weight}}{\text{Volume}}$$

Ag: fcc structure:

$$a^2 + a^2 = d^2$$

$$2a^2 = d^2 \quad a = \frac{d}{\sqrt{2}}$$

$$\frac{55.9 \text{ g/mol}}{6 \times 10^{23} \text{ atoms}} \times \frac{1}{\text{unit cell}}$$

but d = 4r (for fcc cell)

$$a = \frac{\sqrt{16}r}{\sqrt{2}} = 2\sqrt{2}r$$

$$\text{Density} = \frac{wT}{Vol} = \frac{wT \text{ of unit cell}}{\text{Volume of unit cell}} = \frac{\text{atoms in unit cell} \times wT \text{ per atom}}{\text{Volume unit cell}}$$

$$\text{Density Ag} = \frac{4 \frac{107.9 \text{ g/mol}}{6 \cdot 10^{23} \text{ atoms}}}{\left[\frac{2\sqrt{2}}{\sqrt{3}} (1.44 \text{ \AA}) \right]^3} \text{ / unit cell}$$

$$\approx 10.64 \times 10^{-23} \text{ g/cm}^3 \approx \boxed{10.64 \text{ g/cc}} \text{ OK}$$

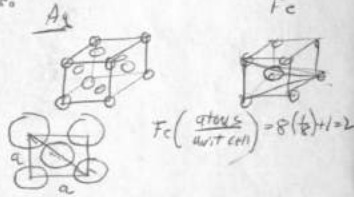
$$\text{Density Fe} = \frac{2 \frac{55.9 \text{ g/mol}}{3 \cdot 10^{23} \text{ atoms}}}{\left[\frac{4}{\sqrt{3}} (1.24 \text{ \AA}) \right]^3} \text{ / unit cell}$$

$$\approx 7.94 \times 10^{-23} \frac{\text{g}}{\text{\AA}^3} = \boxed{7.94 \text{ g/cc}} \text{ OK}$$

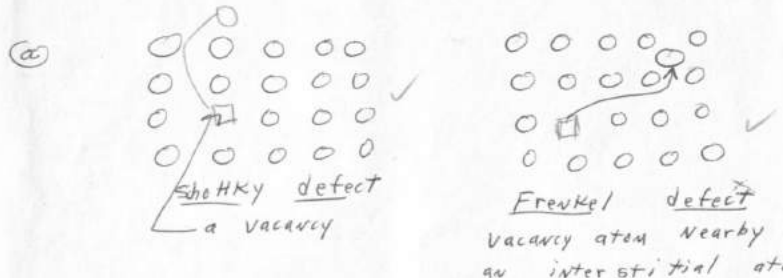
Handwritten calculations for density of silver:

$$2\sqrt{2} \frac{1.44}{\sqrt{3}} = 2.88 \frac{\sqrt{2}}{\sqrt{3}}$$

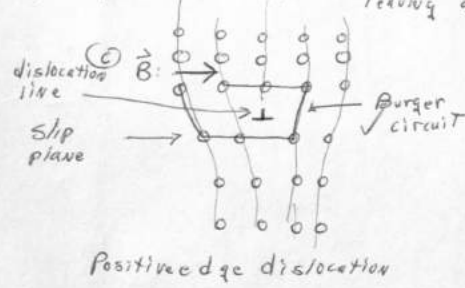
$$\frac{107.9}{2.88 \frac{\sqrt{2}}{\sqrt{3}} \cdot 10^{-23}} = 10.64 \times 10^{-23}$$



- (20 pts.)
 - Show in a sketch the difference between a Shottky and a Frenkel defect.
 - What condition(s) favor the formation of each?
 - Draw an edge dislocation with its Burgers circuit and Burgers vector.
 - Given a dislocation line and a Burgers vector, how can you determine whether the dislocation is an edge or a screw dislocation?



(b) A Frenkel defect is favored when the atoms in the crystal are very different in size. The much smaller atom could very easily "slide" or "slip" out of place and lodge itself in some other little space nearby. Shottky defects are favored in crystals where the atoms are approx. equal in size. Thus there is little room in which a "vacancy" atom may lodge interstitially and, therefore, the atom migrates to the surface, leaving a Shottky defect behind.



(d) If the Burger's vector is perpendicular to the dislocation line (as in c), the dislocation is an edge type. If the Burger's vector is parallel to the dislocation line, then it is a screw dislocation.

Positive edge dislocation

3. (20 pts.) Derive the expression for the total energy of the electron of the hydrogen atom according to the Bohr method. State all assumptions and approximations necessary.

e-s attraction force (in units such that $k=1$)

$$F_{e-s} = \frac{q^2}{r^2} = \frac{e^2}{r^2}$$

Centrifugal force $\Rightarrow F_c = \frac{mv^2}{r}$

$$KE = \frac{1}{2} mv^2$$

equating forces: $F_{e-s} = F_{cent}$

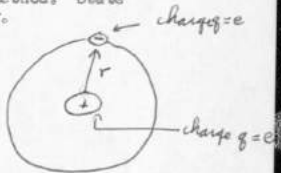
$$\frac{e^2}{r^2} = \frac{mv^2}{r} \quad \text{multiplying by } \frac{r}{2}$$

$$\frac{e^2}{2r} = \frac{1}{2} mv^2; \therefore KE = \frac{e^2}{2r}$$

Potential energy = Force exerted thru a distance

$$PE = \int_{\infty}^r F \cdot dr = \int_{\infty}^r \frac{e^2}{r^2} dr = +\frac{e^2}{-1r} = -\frac{e^2}{r}$$

$$E_{Total} = KE + PE = \frac{e^2}{2r} + \frac{-e^2}{r} = -\frac{e^2}{2r} = E_{Total}$$



4. (15 pts.) What are the four quantum numbers? State their physical significance and their limitations.

n, l, m_l, m_s limitations:

n : principal Q.N. 1, 2, 3, 4, ... n

l : orbital Q.N. 0, 1, 2, 3, ... $n-1$

m_l : magnetic Q.N. $-l, -(l-1), \dots, 0, \dots, (l-1), l$

m_s : spin Q.N. $\pm 1/2$

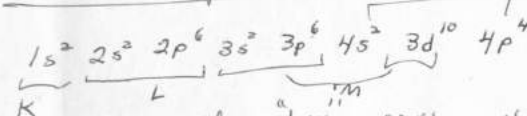
n gives the principal energy of the atom

$n+l$, gives total energy of the atom

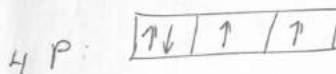
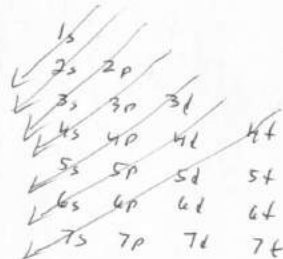
m_s , tells direction of electron spin

5. (15 pts.) The atomic number of Se is 34. Determine the number of covalent bonds it would form in the solid state.

electron configuration:



Using the "box" configuration:



We see that Se has 2 unpaired e⁻ in its final energy state, \therefore it will share these 2 or form 2 covalent bonds.

also we see $k=2$, $L=8$, $M=18$, $N=6$ in terms of shell structure.

\therefore Se has 6 e⁻ in outer orbit by 8-N rule: $8-6=2$

\therefore Se forms 2 covalent bonds with its 2 nearest neighbors

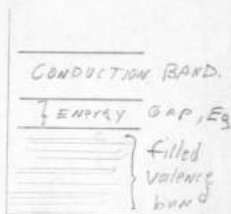
97
100
very good

Mat. Sci. 25 - 11:30 A.M.
Manir

Exam #2
November 14, 1962

1. a. What is meant by an intrinsic semiconductor? Cite an example of such a solid.
b. Draw the electronic energy distribution for it and label the following: valence band, conduction band and energy gap.

AN INTRINSIC SEMICONDUCTOR IS A NATURAL SEMI-CONDUCTOR, I.E., NO IMPURITIES HAVE BEEN ADDED. SILICON IS AN EXAMPLE.



2. a. How does the resistivity of a metal change with temperature? How does the conductivity of a semiconductor change with temperature?
b. Explain why they are different in terms of the equation $\sigma = ne\mu$.

a) The resistivity of a metal increases with temp. The increased thermal energy agitates the electrons. As the electrons are already "free" in the electron cloud, increased thermal agitation tends to hinder rather than aid conduction. Thus, the resistivity increases with temp.

Conductivity of a semiconductor increases with temp. as the increased thermal energy "pushes" ^{more} electrons through E_g and into the conduction band.

b) $\sigma = ne\mu$ In a metal, n is quite large, (the entire "electron cloud" is available for conduction).

In a semi-conductor n is quite small (the electrons pushed into the c.b. by thermal energy, the holes they left behind, and electrons or holes created by impurities).

you have answered (b) in (a)

ANDRADE

-2-

3. a. A metal has a resistivity of 11.4×10^{-6} ohm-cm at 20°C , calculate the resistivity of this metal at 550°C . ($\alpha = 0.0040 \text{ deg.}^{-1}$)
b. In a real metal, the resistivity is not zero at absolute zero temperature. To what can you attribute this residual resistivity?

$$\rho_T = \rho_{20} [1 + \alpha (T - 20)]$$

$$a) \rho_T = 11.4 \times 10^{-6} \text{ ohm cm} [1 + 0.0040 (530)]$$

$$= 11.4 \times 10^{-6} \text{ ohm cm} [1 + 2.12] = 3.12$$

$$\rho_{550} = 356 \times 10^{-6} \text{ ohm-cm. } \checkmark$$

530
0.04
2.000

The ρ_{residual} is due to inhomogeneities^A in the crystal structure & lattice. ^{imperfections}

inner shell
outer shell

4. a. What are the criteria for ferromagnetism?
b. Based on the above, list the elements that exhibit ferromagnetism.

a.) That the element have an unfilled inner shell (this is not the valence shell).

$$2. \frac{D}{d} > 1.5 \text{ where } D = \text{atomic diameter} = \text{diameter of valence shell}$$

$$d = \text{diameter of unfilled inner shell.}$$

b) Fe, Ni, Co, Dy, Gd. \checkmark
Iron, Nickel, Cobalt, Dy, Gadolinium^(?)

Other criteria are the same as for para-magnetism.

5. a. Weiss stated that the molecular orbital forces are responsible for aligning electrons in one domain. On this basis we would expect a ferrimagnetic material to behave as a magnet, yet we know from experience that this is not so. Explain briefly why.

b. What crystalline directions give no anisotropy energy in Fe and Ni?

a) The magnetostatic energy which would result by the formation of surface magnetic poles would be too great. The domain structure is the most stable structure as it is the arrangement with minimum energy.

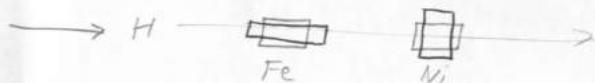
b) The edge (diagonal) directions in Fe and the body diagonal directions in Nickel

6. a. What two factors control the thickness of the Bloch wall in ferromagnetic materials?

b. How does Fe differ from Ni with regard to its magnetostriction behavior?

a) Exchange energy and anisotropy energy. The Bloch wall thickness is the result of the minimum energy of the summation of the exchange & anisotropy energies. very good

b) Fe elongates in the direction of applied H,
Ni " ⊥ to " " " " " "



7. a. What are the magnetic properties which control the choice of a metal for a permanent magnet?

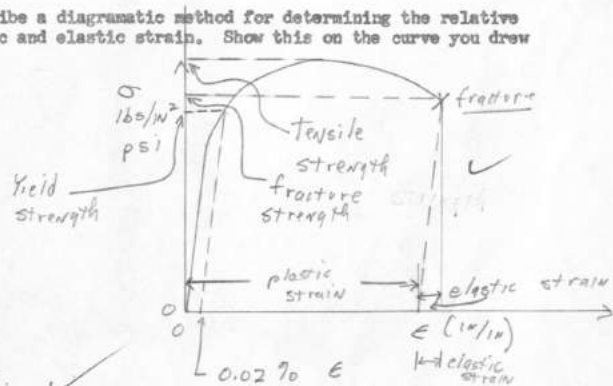
b. What are the properties desired for an electromagnet?

- | | |
|--|--|
| a) Hard Mag. Materials
(perm. magnet) | b) Soft Mag. Materials
(electro-magnet) |
| 1. B _{max} large ✓ | 1. B _{max} large ✓ |
| 2. B _{residual} large ✓ | 2. B _{residual} small ✓ |
| 3. H _{coercive} large ✓ | 3. H _{coercive} small ✓ |
| 4. Curie Temp. High ✓ | |

8. a. Draw a stress-strain curve for a typical metal labeling the following: yield strength, tensile strength, fracture strength.

b. At fracture describe a diagrammatic method for determining the relative amounts of plastic and elastic strain. Show this on the curve you drew in section (a).

ENG. CURVE

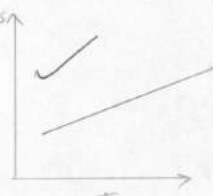


b) At fracture, drop a perpendicular to the ϵ axis. Then draw a line from fracture to the ϵ axis parallel to the elastic strain region of the curve.

The distance between the \perp & the line from fracture parallel to the elastic line represents the elastic strain at fracture. The distance between the σ axis & the drawn parallel line represents the plastic strain at fracture.

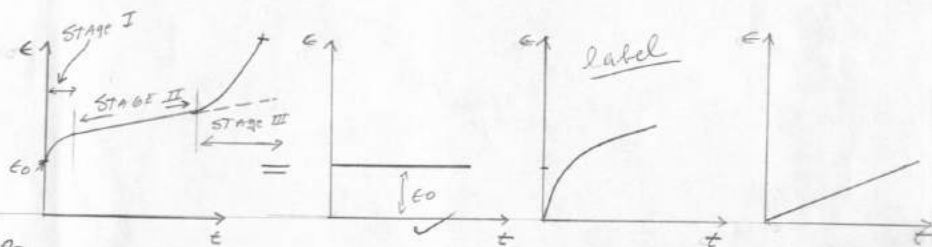
9. How does the toughness (with regard to fracture) change with increasing temperature? Briefly explain why.

As the temperature increases, the metal becomes more ductile. A ductile material has a greater resistance to fracture than a more brittle material. The brittle material will simply break when the critical stress is reached, but the ductile material will "resist" fracture. It will neck until it finally fractures. Thus as the ductile material temp increases, a material's ductility increases, and \therefore its toughness increases. ✓ OK



10. Schematically show Andrade's analysis of the creep curve. Label each component.

Total Creep = initial creep + transient creep + viscous creep



σ (stress) and T (temp) are constant

Upon the application of σ , the material deforms to ϵ_0 initial deformation. Then it goes through a transient state of decreasing slope rate ($d\epsilon/dt$). The next stage (II), $d\epsilon/dt$ becomes constant and a long stage of steady creep persists. If the material were ideal, stage II would continue indefinitely. Finally, at stage III, $d\epsilon/dt$ increases again until fracture.

(10) 1. a. Define corrosion and list the metallic properties which are affected by it.

b. List the components of a corrosion system.

a) Corrosion is the decomposition of a metal or alloy by its environment.
reflectivity, hardness, conductivity
others?

b) Anode
cathode
electrolyte
electronic conducting element

(15) 2. To protect a submerged metallic structure in an off-shore oil derrick, Mg metal was used as a sacrificial anode. If the current produced by the emf was 0.55 amp, how long would this protection last, if the Mg weighed 600 Kg? (emf for Mg, Mg^{2+} is 2.34 volts and its at. wt. = 24.3).

$W = 24m/af$
 $t = \frac{W}{i \cdot m} = \frac{600 \times 10^3 \text{ gm} \times 96,500}{0.55 \text{ amp} \cdot m}$
 $m = \frac{at \cdot W}{valence}$
 $t = \frac{105 \times 10^9 \text{ sec} \cdot 24.3}{600}$
 $t = 8.7 \times 10^8 \text{ sec}$
 $t = 425 \times 10^7 \text{ sec} \times \frac{1 \text{ hr}}{3600 \text{ sec}} = 118 \times 10^4 \text{ hr}$

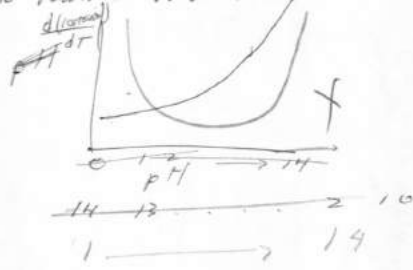
- (15) 3. a. List the important areas of corrosion control.
 b. How does corrosion rate change with pH? Show your answer in a graph.
 c. Two identical plates of iron metal were coated with a metallic layer. The first (A) with tin; and the second (B) with zinc.

1. Which coating will give longer protection? Why?
 2. If a scratch is made on the surface of these plates to expose the base metal, which of these two plates will suffer most from corrosion?

Explain why. Fe, Fe²⁺ 0.44 volts
 Zn, Zn²⁺ 0.76 volts
 Sn, Sn²⁺ 0.14 volts

a) -5

b.) pH is a measure of the concentration of H⁺ ions. The higher the pH (greater H⁺ concentration) the greater the corrosion rate.



c.) The Fe, Zn combination results in Zn as the anode because Zn has the higher potential. Thus the Zn would corrode, but not the iron.

The Fe, Sn couple results in Fe as an anode. So?

1) TIN gives longer protection as it will not corrode as fast as Zn and tin < end Zn.

2) Fe anode w.r.t Sn but cathode w.r.t Zn

∴ Zn does corrode w.r.t Sn cathode

(60) 4. Refer to the phase diagram shown on the next page.

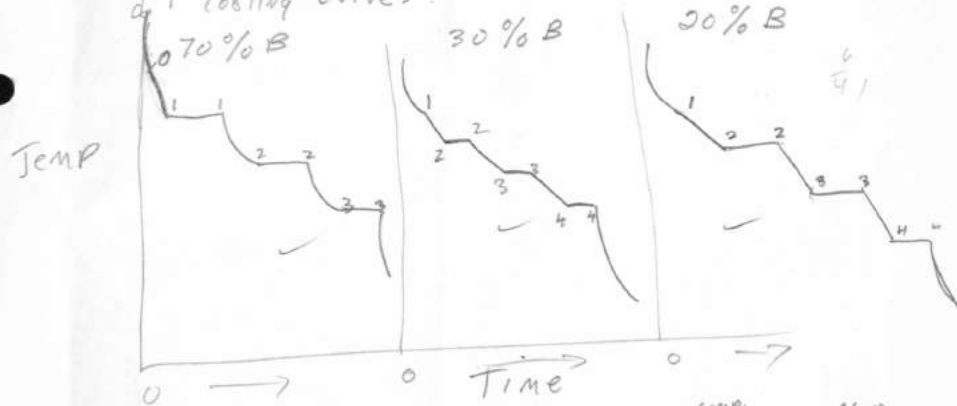
- 15 -3 a. Label all regions clearly.
 b. Identify each isotherm.
 -2 c. Give an example of a congruent melting phase; give two examples of incongruent melting phases.
 ✓ d. Draw cooling curves for the following compositions, starting with the liquid phase - 70% B, 30% and 20% B.
 ✓ e. Name the phases, give their compositions and relative amounts at the following points:

Q 70% B & 950°C
 R 45% B & 900°C
 S 90% B & 1000°C

-10 f. Upon crossing the 1000°C isotherm a certain reaction takes place calculate the % "pro-reaction" of the phase which exists before and after the reaction for point Q above. (low back)

c.) There is no congr. melting phase
 ✓ e.g. (f) are 2 incongruent melting phases

d.) cooling curves:



e.) Pt. Q: 2 solid phases, $\frac{g}{i} \neq \frac{comp. c}{comp. i} = \frac{84\% B}{17\% B} \neq \frac{67\% B}{17\% B}$
 $c = 83\% \text{ by wt} / g = 17\% \text{ by wt}$

Pt. R: 2 solid phases, $c \neq f$: $\frac{comp. e}{comp. f} = \frac{40\% B}{45\% B} \neq \frac{50\% \text{ by wt}}{45\% \text{ by wt}}$

Pt. S: one solid phase, \hat{c} , $comp = 90\% B$
 $c = 100\% \text{ total by wt.}$

H)
f)

$$\frac{7}{26} = \% K \text{ pro eutectoid} \\ = 27\% \text{ of total}$$

$$\% g = 73\% \text{ of total}$$

$$\frac{\% \text{ pro eutectoid}}{\% \text{ in } g} = 73\% \text{ of } \frac{17}{27} = .$$

