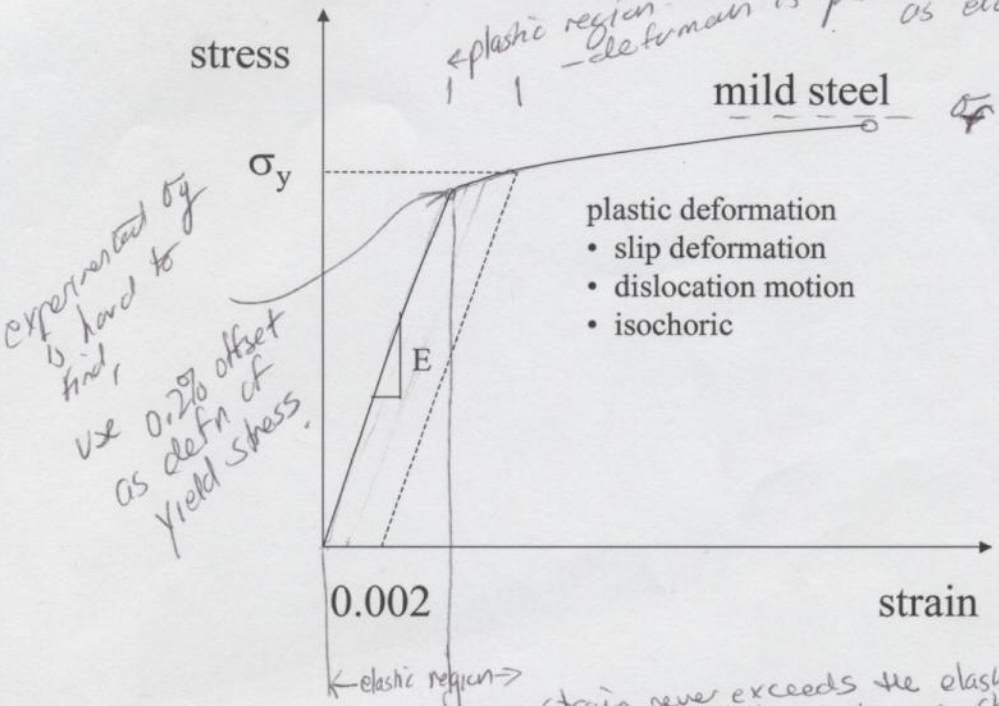
Move to Solids

stress-strain diagram



← plastic region - deformation is permanent, but material behaves as elastic if stress is reduced

σ_f - failure tensile stress (stress to failure - single load)

experimental fig is hard to find, use 0.2% offset as defn of yield stress.

← elastic region →
- as long as strain never exceeds the elastic strain, material will return to original position as stress is released.
- if not, then permanent deformation

32. What does the non-linear portion of a stress-strain diagram represent?

Plastic region -
Permanent deformation.
Strain is not linear with stress.

i.e. $\varepsilon = f(\sigma)$ | linear model $\quad f(\sigma) = k\sigma + \varepsilon_0$

↑ constant of proportionality

In plastic region

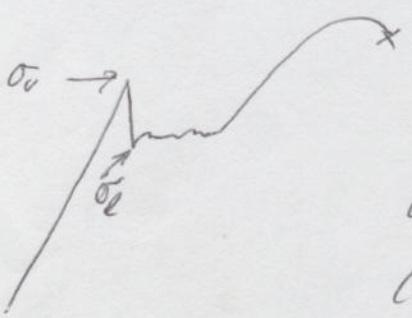
$\varepsilon = f(\sigma)$, $f(\sigma)$ is not linear in σ

33. What is the 0.2% offset yield stress?

This is a "convention" (agreement) where yield stress is defined because experimental determination of plastic onset is difficult to do.

∴ A line parallel to elastic region at 0.2% strain is used to identify a "working" value of yield stress

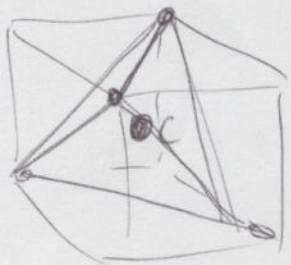
34. What metal exhibits upper and lower yield points?



steel and iron alloys ~~occurs~~ exhibit upper & lower yield

Cause is attributed to interaction of carbon atoms (coordination Number 4) and dislocations (defects)

Iron (Fe) has coordination nubers of 3 and 5.



Hence in an alloy random atoms of the carbons and Fe are not necessarily aligned. Hihor stress can be applied until alignment, then slip

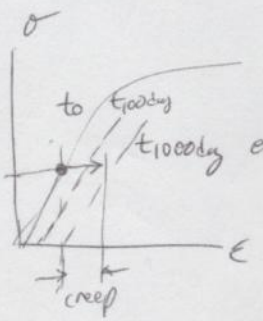
creep and fatigue

creep
- deformation at constant stress and high temperature
- grain boundary sliding, formation of voids (failure)

fatigue
- failure in cyclic loading due to surface defects
- sensitive to surface properties (corrosion, finish)
- endurance limit for steels (unlimited life)

35. What is the cause of creep failure?

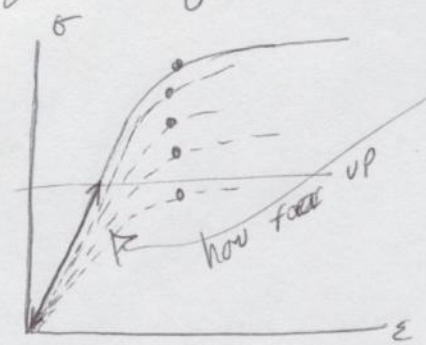
Creep is deformation of material under constant stress.
- Negligible until 40%+ of absolute melting point for most materials (glass ~~is a not and ice are~~ is notable exception)



- Internal thermal energy allows dislocations (i.e. C, Fe atoms to rearrange in such a way as to lose ability to resist strain and thus slowly move)
  - depends on rate of load.
- Pushing water
- → Grain boundary sliding for more internal voids

37. Define metal fatigue?

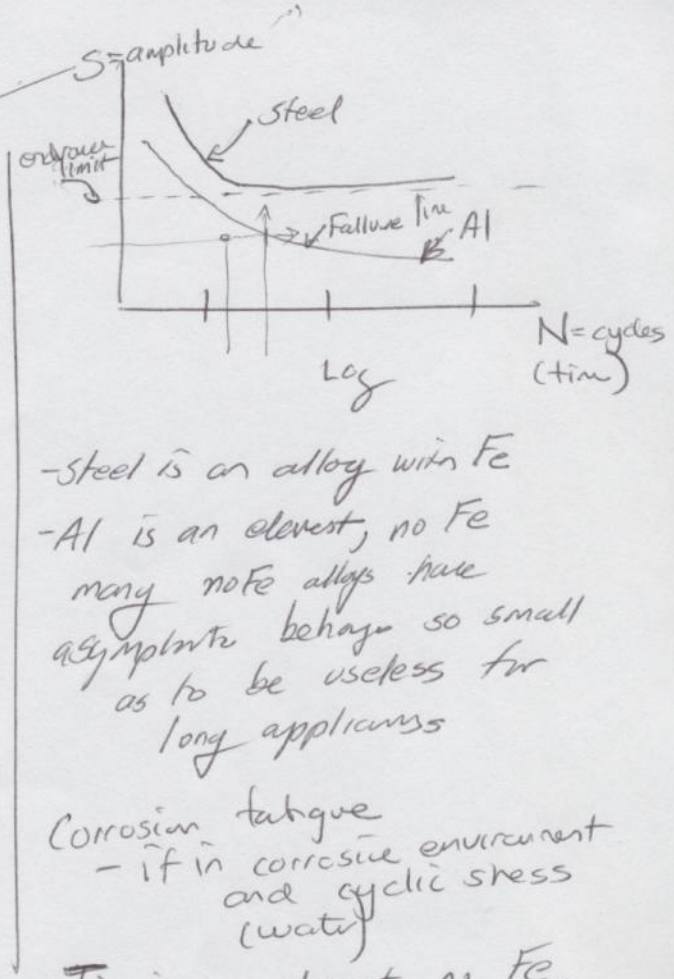
Cyclic loading



generates heat ⇒ ~~creep~~ "creep-like" behavior

material changes
(crystal structure rearranges
becomes more Brittle)

starts at surface and propagates inward
- surface treatments help.
  - cold roll
  - shot peen
  - bead blast
  - polish
  - case hardening



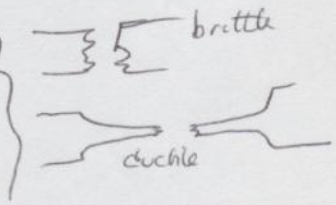
- steel is an alloy with Fe
- Al is an element, no Fe
  many no Fe alloys have asymptote behavior so small as to be useless for long applications

Corrosion fatigue
- if in corrosive environment and cyclic stress (water)

- Ti is an element, no Fe, but Ti alloys have a touch of Fe (not much) and Va to give them many cycles resist.

ductility, hardness, toughness

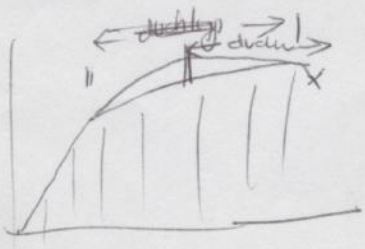
ductility
- deformation without fracture (% elongation)
- increases with temperature, lower carbon content

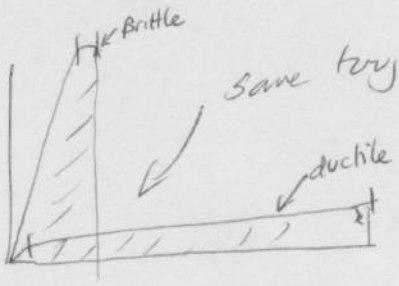


hardness
- resistance to penetration (Brinell, Rockwell tests)
- increases with carbon content, smaller grain size

601 C3 steel (cutting tools)
Refers to Hardness Brinell and carbon content.

toughness
- energy absorbed before fracture (Charpy test)
- area under the stress-strain curve



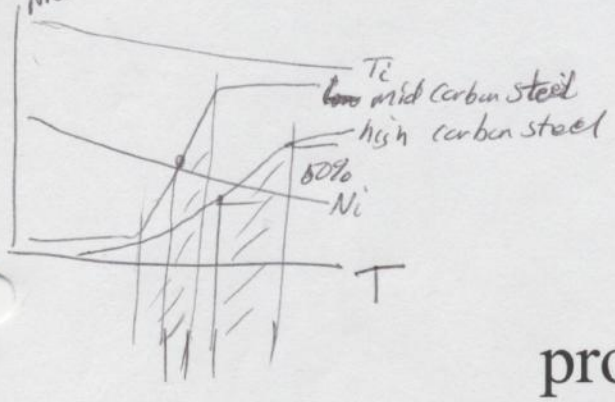


36. Which statement regarding ductile-brittle transition is false?

- sudden loss of ductility below a critical temperature (true)
- loss of toughness at lower temperatures true
- carbon steels less susceptible to this transition (sudden, very susceptible)
  - occurs at teneshral temp
- some pure metals (aluminum, copper, nickel) do not exhibit this transition (true

(Surrogate toughness/ ductility)

Impact NRG



i.e. chemistry & microstructure

processing

annealing
- heat and slowly cool (relieves internal stresses)
- increases ductility, lowers yield, softens the material

} changes material properties

→ used to work material.

cold working
- stressing past the yield point (reduces grain size)
- increases toughness, hardness, yield strength

quenching
- rapid cooling that promotes hardening
- strong but brittle material (low toughness)

- martensite (crystal structure)
- hardening
- very hard, approaches carbide (nearly diamond hardness)
- cutting tools

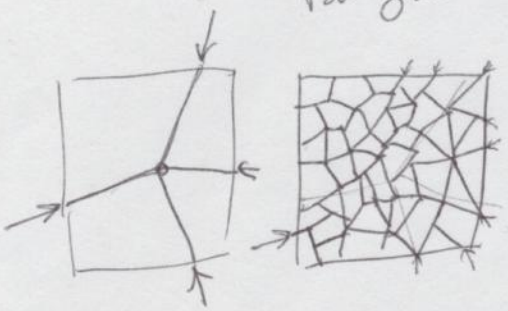
Case hardening

37. Which statement regarding carbon steel is false?

- a steel can be hardened without carburizing – true
- yield strength can be increased by cold rolling – true
- ductility decreases for steels with more carbon – true
- steels with larger grain size are stronger – false

– Grain boundaries strengthen steel.

For given volume/area smaller grains = more boundaries ∴ stronger



boundaries act like a truss, distributes forces

W% = weight fraction of an alloy

A% = molar fraction of an alloy

$$W\%\,A = \frac{WA}{WA + WB} \times 100\%$$

80 − C = 20 + C

80 − C = C

60 = 2C

C = 30

20 + 30 = 50

80 − 30 = 5

reactions

- eutectic: liquid → two solid phases (coo; distinct)
- eutectoid: solid → two solid phases $S_1 \rightarrow S_2 + S_3$
- peritectic: liquid + solid → solid (second solid)
- peritectoid: two solid phases → solid $S_1 + S_2 \Rightarrow S_3$

$$at\% = \frac{\text{mols } A}{\text{mols } A + \text{mols } B} \times 100\%$$

~~$WA \times MW$~~

$$\text{mols } A = \frac{W\text{-}A}{MW_A}$$

Phase Rule

$P + F = C + 2$

P = # phases

F = # of DF (determines composition boundaries)

C = # elements

$2 = \underset{\sim}{\Delta p} + \underset{\sim}{\Delta T}$ if $\Delta p = 0$ (constant pressure)

= # Thermodynamic variables adjusted

Less need need dense solid & liquid

Some alloys are completely miscible H_2O & alcohol, Co, Ni

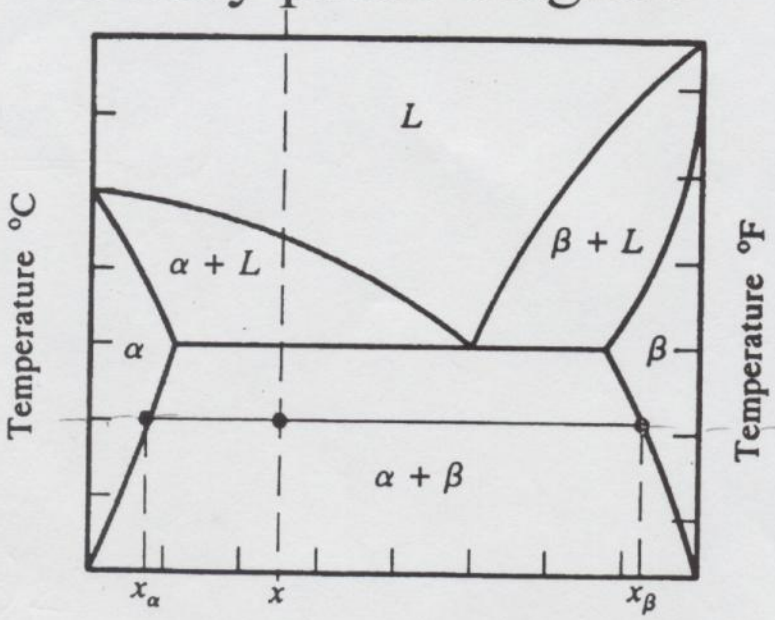
Some only mix at exact compositions, reject extra some blend into alloy & pure

18. What is a peritectoid reaction?

two solids in solution are in equilibrium with a third solid at a given temperature

toid – solid →
tic – liquid →

binary phase diagram



Tool to predict mixture components – Equilibrium diagram

2 components are α & β

~~3 Solids~~, 3 possible solids α, α+β alloy, β

x is composition of interest, depends on starting composition.

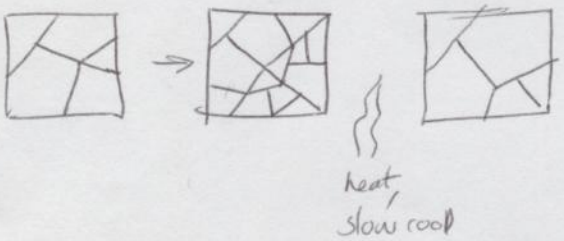
lever formula tells composition of α+β if it exists.

$$\alpha\,\text{wt\%} = \frac{x_\beta - x}{x_\beta - x_\alpha} \times 100 \; ; \; \beta\,\text{wt\%} = \frac{x - x_\alpha}{x_\beta - x_\alpha} \times 100$$

16. Which condition does not lead to stronger metals and alloys?

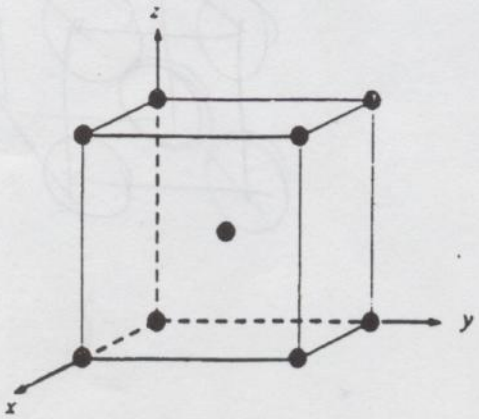
- presence of second phase precipitates s'
- presence of dispersed fibers or particles stronger
- presence of martensite phase in steel stronger
- annealing of cold worked metal above its recrystallization temperature ≠

→ cold work to crush grains

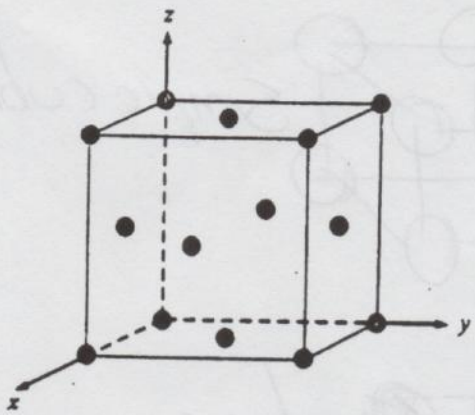


defeats purpose

crystal structures



BCC body-centered cubic

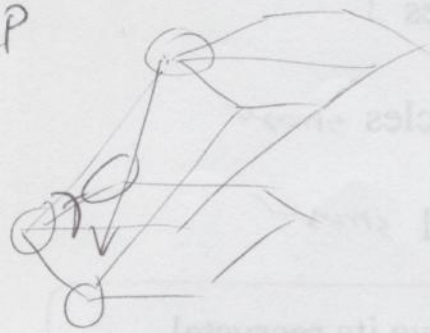


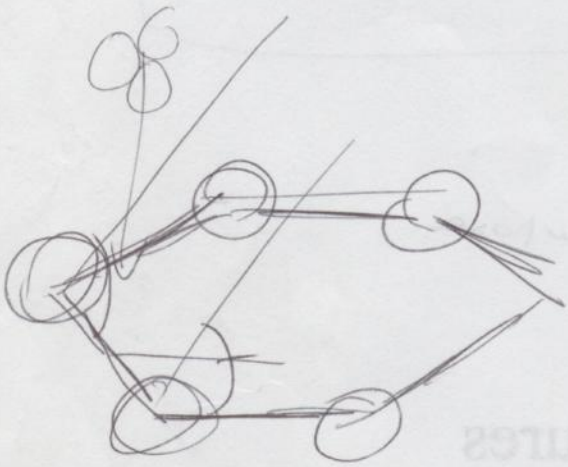
FCC face-centered cubic

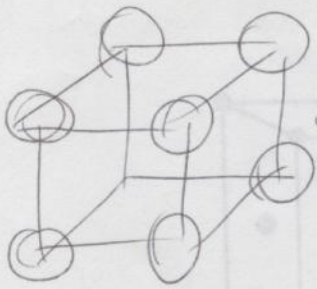
Important in calculating values & densities at atomic level

BCC
FCC are only "easy" to compute

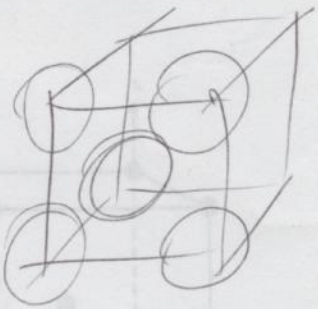
HCP



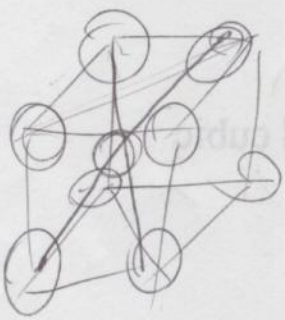




simple cubic



FCC



bcc

SAMPLE PROBLEMS

Problem 1

Why is aluminum more rust-resistant than steel?

(A) The reaction rate with atmospheric oxygen is higher for steel.
(B) The reaction rate with atmospheric oxygen is higher for aluminum.
(C) Iron atoms are larger than aluminum atoms, and thus, the interstitial spaces are larger.
(D) Iron has greater magnetic properties than aluminum.

Solution

Oxygen reacts faster with aluminum. In fact, it reacts so fast that it creates a film of aluminum oxide that acts as a protective coating.

Answer is B.

Problem 2

Which of the following metals do not have a face-centered cubic crystalline structure?

I. aluminum
II. gamma-iron
III. delta-iron
IV. lead

(A) III only
(B) II and III
(C) III and IV
(D) I, II, and IV

Solution

Aluminum, lead, and gamma-iron all have face-centered cubic structures. Delta-iron has a body-centered cubic structure.

Answer is A.

Problem 3

Which of the following will affect the hardenability of steel?

I. composition of austenite
II. composition of cementite
III. austenite grain size
IV. quenching medium
V. carbon content

(A) II only
(B) I and V
(C) III and V
(D) I, II, III, and V

Solution

Carbon content and grain size are the primary factors affecting hardenability.

Answer is C.

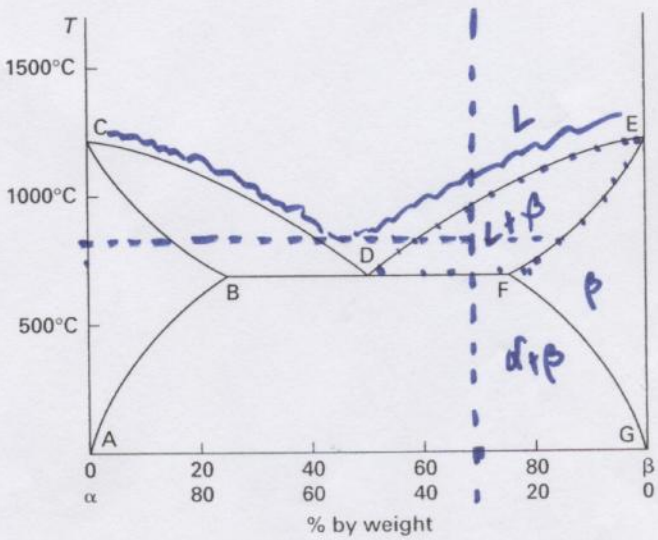
FE-STYLE EXAM PROBLEMS

1. Which of the following characterize a hot-worked steel part in comparison with a cold-worked part?

I. higher yield strength
II. better surface finish
III. greater hardness
IV. greater toughness
V. less ductility

(A) I and V
(B) II only
(C) III and IV
(D) none of the above

Problems 2–4 refer to the following phase diagram.



2. The region enclosed by points DEF can be described as which of the following?

(A) a mixture of solid β component and liquid α component
(B) a mixture of solid and liquid β component
(C) a peritectic composition
(D) a mixture of solid β component and the eutectic material

3. Which line(s) is (are) the liquidus?

(A) CBDFG
(B) CDE
(C) ABC and EFG
(D) CBFE

4. How much solid (as a percentage by weight) exists when the mixture is 30% α and 70% β and the temperature is 800°C?

(A) 0%
(B) 19%
(C) 30%
(D) 50%

Use formula - usually a good guess

5. Which of the following characteristics describes martensite?

I. high ductility
II. formed by quenching austenite
III. high hardness

(A) I only
(B) I and II
(C) II and III
(D) I and III

For the following problems use the NCEES Handbook as your only reference.

6. The activation energy, Q, for aluminum in a copper solvent at 575°C is 1.6×10^8 J/kmol. What is the diffusion coefficient, D, if the constant of proportionality, D_0, is 7×10^{-6} m^2/s?

(A) 4.04×10^{-47} m^2/s
(B) 2.04×10^{-20} m^2/s
(C) 9.75×10^{-16} m^2/s
(D) 2.31×10^{-5} m^2/s

7. An iron alloy contains 2.5% carbon by weight. In what phase is the alloy at 900°C?

(A) liquid
(B) γ + liquid
(C) δ + carbide
(D) γ austenite and carbide

8. A mixture of ice and water is held at a constant temperature of 0°C. How many degrees of freedom does the mixture have?

(A) −1
(B) 0
(C) 1
(D) 2

P+F = C+2 (P, T)

P=2, C=1

1+1 = 2+0

9. A brass alloy is 40% zinc and 60% copper by weight. What is the approximate mole fraction of zinc?

(A) 5%
(B) 26%
(C) 39%
(D) 50%

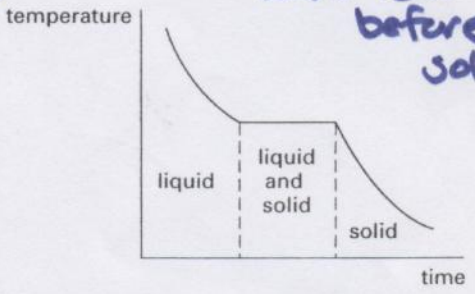
10. The crystalline structure of metals can be modified by several processes. Plastic deformation of the crystalline structure resulting in misalignment of atoms, dislocations, and large stresses and strains in small regions are characteristic of which process?

(A) tempering
(B) cold forming
(C) twinning
(D) isostatic pressing

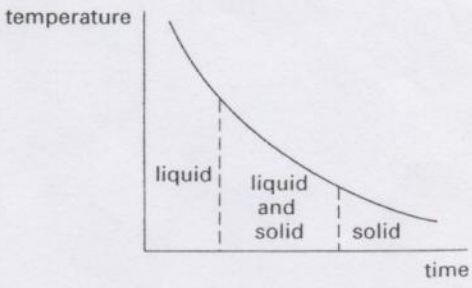
11. Which of the following figures is a cooling curve of a pure metal?

pure material latent heat fusion before solid if

(A)



(B)



(C)