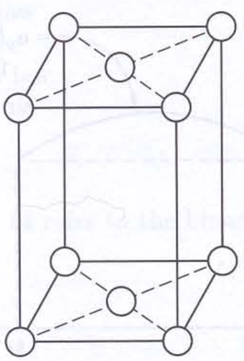
Diagnostic Examination

TOPIC XIII: MATERIALS SCIENCE/STRUCTURE OF MATTER

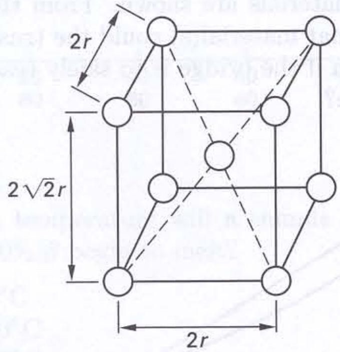
TIME LIMIT: 45 MINUTES

1. How many atoms per cell are in the base-centered orthorhombic crystal shown?



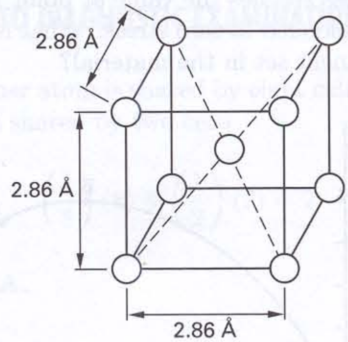
(A) 2
(B) 4
(C) 6
(D) 8

2. What is the packing factor for the body-centered tetragonal crystal with the dimensions shown? (Assume atoms are hard spheres and have a radius of r.)



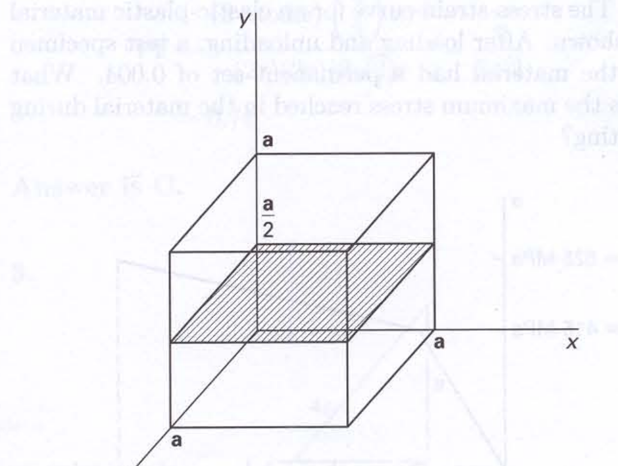
(A) 0.52
(B) 0.68
(C) 0.74
(D) 0.82

3. At a particular temperature, iron exhibits a body-centered cubic crystal structure with a cell dimension of 2.86 Å. What is the theoretical atomic radius of iron? (Assume atoms are hard spheres and have a radius of r.)



(A) 0.88 Å
(B) 0.95 Å
(C) 1.24 Å
(D) 1.43 Å

4. What are the Miller indices of the plane shown in its cubic crystallographic cell?

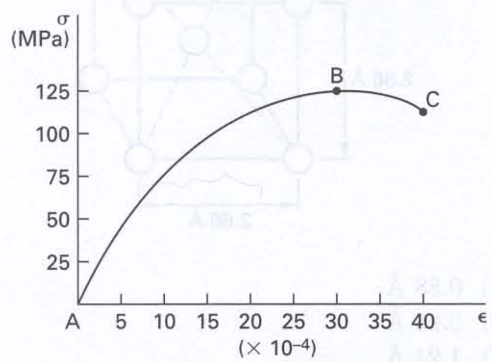


(A) $(0\ \frac{1}{2}\ 0)$
(B) (0 2 0)
(C) (1 2 1)
(D) $(\infty\ \frac{1}{2}\ \infty)$

5. Which of the following planes is a member of the family of equivalent planes containing (1 0 1)?

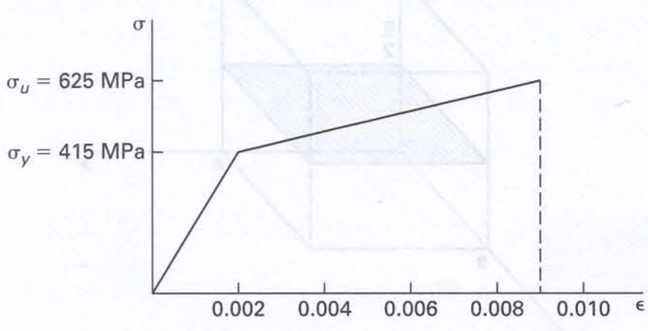
(A) $(0\,1\,0)$
(B) $(0\,\bar{1}\,0)$
(C) $(\bar{1}\,1\,\bar{1})$
(D) $(0\,\bar{1}\,\bar{1})$

6. The stress-strain curve for a nonlinear, perfectly elastic material is shown. A sample of the material is loaded until the stress reaches the value at point B. Then, the material is unloaded to zero stress. What is the approximate permanent set in the material?



(A) 0
(B) 0.001
(C) 0.002
(D) 0.003

7. The stress-strain curve for an elastic-plastic material is shown. After loading and unloading, a test specimen of the material had a permanent set of 0.004. What was the maximum stress reached in the material during testing?

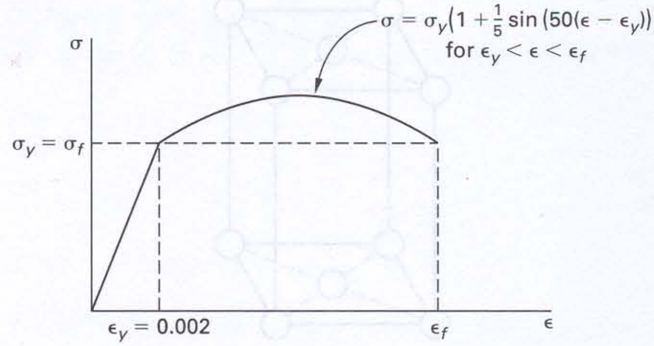


(A) 475 MPa
(B) 485 MPa
(C) 525 MPa
(D) 555 MPa

8. A cylindrical test specimen with a 15 mm diameter is tested axially in tension. A 0.20 mm elongation is recorded in a length of 200 mm when the load on the specimen is 36 kN. The material behaves elastically during testing. What material could the specimen be made of?

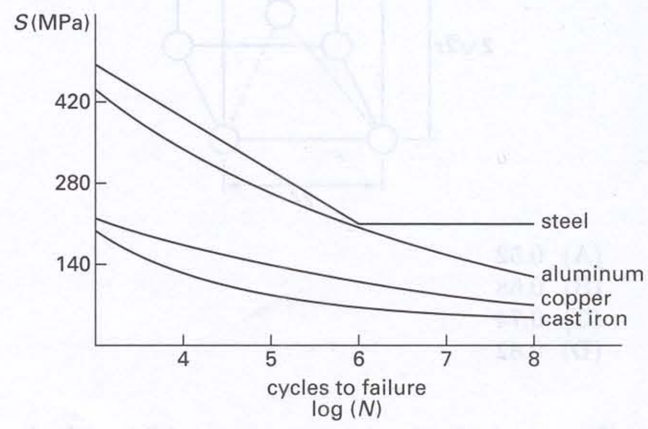
(A) aluminum
(B) magnesium
(C) polystyrene
(D) steel

9. The stress-strain curve for an elastic-plastic material is as shown. What is the percent elongation of this material just before failure?



(A) 3.2%
(B) 6.5%
(C) 9.5%
(D) 16%

10. A 5 cm diameter bridge tension member experiences a loading of 275 kN every time a car crosses the bridge. The average traffic on the bridge is 50 car/h, and the bridge has a design life of 5 yr. The *S-N* curves for several materials are shown. From the standpoint of fatigue, what material(s) could the truss bar be constructed from if the bridge is to safely reach the end of its design life?



(A) steel only
(B) steel and aluminum
(C) steel, aluminum, and copper
(D) steel, aluminum, copper, and cast iron

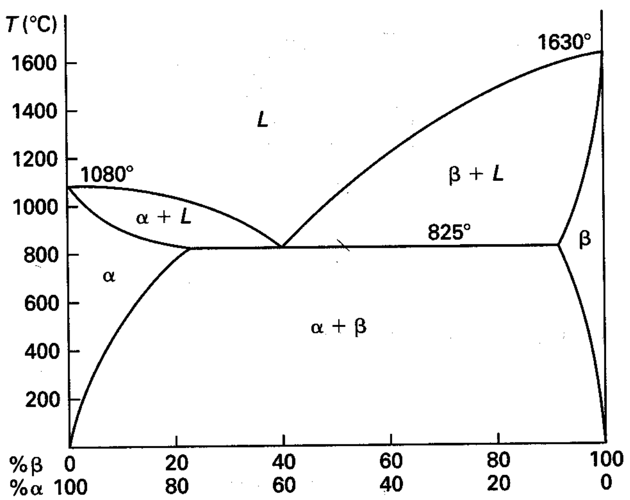
11. All of the following metals will corrode if immersed in fresh water except

(A) copper.
(B) nickel.
(C) chromium.
(D) aluminum.

12. The movement of defects through a crystal by diffusion is described by which of the following?

(A) Boyle's law
(B) Fick's law
(C) Dalton's law
(D) Gibbs' rule

Problems 13 and 14 refer to the binary phase diagram shown.



13. At what temperature will a sample composed of 20% α and 80% β begin to melt?

(A) 825°C
(B) 1050°C
(C) 1500°C
(D) 1630°C

14. A sample composed of 80% α and 20% β is heated to 900°C. What is the percentage of solid in the sample at this temperature?

(A) 25%
(B) 40%
(C) 60%
(D) 75%

15. The process of annealing can be used to achieve all of the following actions except

(A) stress relief.
(B) recrystallization.
(C) grain growth.
(D) toughness.

SOLUTIONS TO DIAGNOSTIC EXAMINATION TOPIC XII

1. Each corner atom is shared by eight cells, while each base atom is shared by two cells.

$$\left(\frac{1}{8}\right)(8) + \left(\frac{1}{2}\right)(2) = 2$$

Answer is A.

2. The packing factor is the volume of the atoms divided by the cell volume.

The number of atoms per cell is

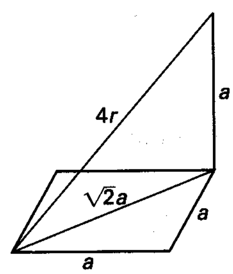
$$\left(\frac{1}{8}\right)(8) + 1 = 2$$

The packing factor is

$$\text{PF} = \frac{(2\text{ atoms})\left(\frac{4}{3}\right)\pi r^3}{(2r)(2r)(2\sqrt{2})r} = \frac{\pi}{3\sqrt{2}}$$
$$= 0.74$$

Answer is C.

3.



The atoms are touching along the cell diagonal. The length of the cell diagonal is four atomic radii.

$$(\sqrt{2}a)^2 + a^2 = (4r)^2$$
$$r^2 = \left(\frac{3}{16}\right)a^2$$

$$r = \left(\frac{\sqrt{3}}{4}\right) a$$
$$= \left(\frac{\sqrt{3}}{4}\right) (2.86 \text{ Å})$$
$$= 1.24 \text{ Å}$$

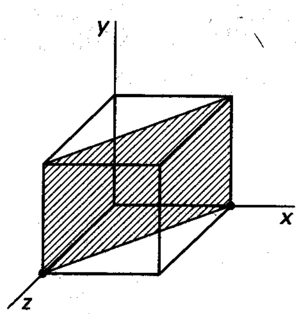
Answer is C.

4. The intercepts of the x-, y-, and z-axes are ∞, 1/2, and ∞, respectively. The Miller indices are the reciprocals of the intercepts, normalized to the lowest possible integer values. For this plane, the Miller indices are (0 2 0).

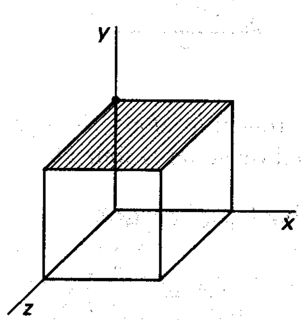
Answer is B.

5. Due to the symmetry of the cubic structure, the choice of origin of a unit cell is arbitrary. Planes that belong to the same family of equivalent directions pass through the same sequence of atoms in the unit cell.

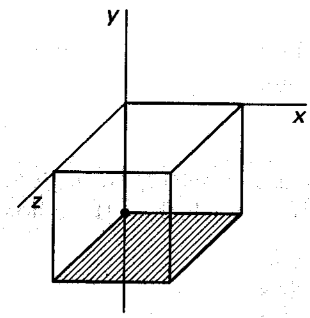
The (1 0 1) plane is



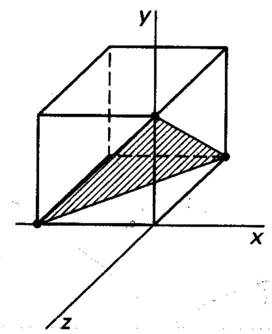
Choice (A): The (0 1 0) plane is



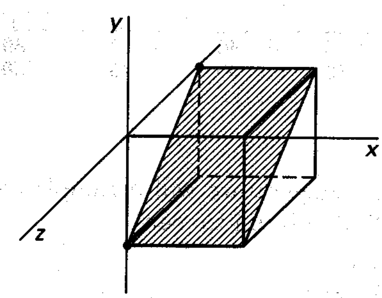
Choice (B): The $(0\ \bar{1}\ 0)$ plane is



Choice (C): The $(\bar{1}\ 1\ \bar{1})$ plane is



Choice (D): The $(0\ \bar{1}\ \bar{1})$ plane is



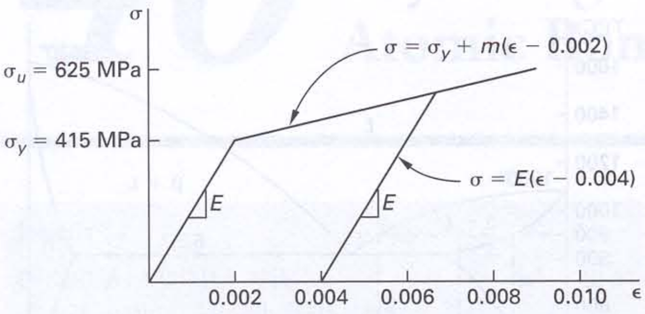
The plane that is crystallographically equivalent to (1 0 1) is $(0\ \bar{1}\ \bar{1})$.

Answer is D.

6. A purely elastic material exhibits no permanent deformation upon unloading.

Answer is A.

7.



The modulus of elasticity is

$$E = \frac{\sigma_y}{\epsilon_y} = \frac{415 \text{ MPa}}{0.002}$$
$$= 207\,500 \text{ MPa}$$

The slope of the plastic portion of the curve is

$$m = \frac{\sigma_u - \sigma_y}{\epsilon_u \ \epsilon_y} = \frac{625 \text{ MPa} - 415 \text{ MPa}}{0.009 - 0.002}$$
$$= 30\,000 \text{ MPa}$$

The equation of the plastic portion of the line is

$$\sigma = \sigma_y + m(\epsilon - 0.002)$$
$$= 415 \text{ MPa} + (30\,000 \text{ MPa})(\epsilon - 0.002)$$

The slope of the unloading curve is the same as the modulus of elasticity.

$$\sigma = E(\epsilon - 0.004)$$
$$= (207\,500 \text{ MPa})(\epsilon - 0.004)$$

These two equations can be solved simultaneously for σ. Solve for ϵ from the second equation and substitute into the first.

$$\epsilon = \left(\frac{1}{207\,500 \text{ MPa}}\right)\sigma + 0.004$$

$$\sigma = 415 \text{ MPa} + (30\,000 \text{ MPa}) \times \left(\left(\frac{1}{207\,500 \text{ MPa}}\right)\sigma + 0.004 - 0.002\right)$$
$$= 415 \text{ MPa} + 0.145\sigma + 60 \text{ MPa}$$
$$(0.855)\sigma = 475 \text{ MPa}$$
$$\sigma = 555 \text{ MPa}$$

Answer is D.

8. The stress in the specimen is

$$\sigma = \frac{P}{A} = \frac{36 \text{ kN}}{\left(\frac{1}{4}\right)\pi(0.015 \text{ m})^2}$$
$$= 203\,718 \text{ kPa} \quad (203.7 \text{ MPa})$$

The strain in the specimen is

$$\epsilon = \frac{\delta}{L} = \frac{0.2 \text{ mm}}{200 \text{ mm}}$$
$$= 0.001$$

The modulus of elasticity of the material is

$$E = \frac{\sigma}{\epsilon} = \frac{203.7 \text{ MPa}}{0.001}$$
$$= 203\,700 \text{ MPa} \quad (203.7 \text{ GPa})$$

The moduli of elasticity of aluminum, magnesium, polystyrene, and steel are approximately 70 GPa, 45 GPa, 2 GPa, and 205 GPa, respectively. This material is probably steel.

Answer is D.

9. From the diagram, at failure, $\sigma = \sigma_y$, and $\epsilon = \epsilon_f$.

$$\sigma_y = \sigma_y\left(1 + \frac{1}{5}\sin\left(50(\epsilon_f - \epsilon_y)\right)\right)$$

$$\sin\left(50(\epsilon_f - \epsilon_y)\right) = 0$$
$$(50)(\epsilon_f - \epsilon_y) = \pi$$
$$\epsilon_f = \frac{\pi}{50} + \epsilon_y$$
$$= \frac{\pi}{50} + 0.002$$
$$= 0.0648 \text{ rad}$$
$$\% \text{ elongation} = \epsilon_f \times 100\%$$
$$= 0.0648 \times 100\%$$
$$= 6.48\% \quad (6.5\%) \quad \text{[before failure]}$$

Answer is B.

10. The number of loading cycles during the life of the bridge is

$$N = \left(50 \ \frac{\text{cycle}}{\text{h}}\right)\left(24 \ \frac{\text{h}}{\text{d}}\right)\left(365 \ \frac{\text{d}}{\text{yr}}\right)(5 \text{ yr})$$
$$= 2.19 \times 10^6 \text{ cycles}$$
$$\log(N) = \log(2.19 \times 10^6 \text{ cycles})$$
$$= 6.34$$

MATERIALS

The stress per cycle is

$$\sigma = \frac{P}{A} = \frac{275\,000\ \text{N}}{\frac{1}{4}\pi d^2}$$

$$= \frac{275\,000\ \text{N}}{\frac{1}{4}\pi(0.05\ \text{m})^2}$$

$$= 1.4\times10^8\ \text{Pa}\quad(140\ \text{MPa})$$

From the *S-N* curves, only steel and aluminum can be depended upon to resist the loading for the expected number of cycles without failing.

Answer is B.

11. From the table of oxidation potentials for corrosion reactions, copper has a positive voltage with respect to hydrogen, while the other metals have negative voltages. There is no driving potential for copper to go into solution, and it will not corrode in fresh water.

Answer is A.

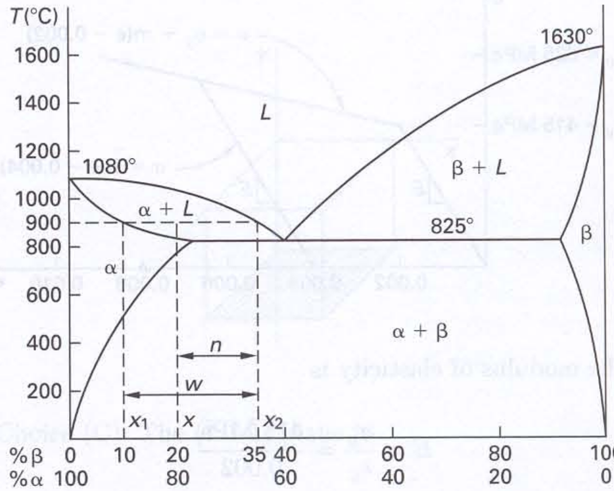
12. The movement of defects through a crystal is described by Fick's law.

Answer is B.

13. The sample begins to melt once the solidus line is crossed. For this alloy, the solidus line is the horizontal line.

Answer is A.

14.



Use the lever rule.

$$\text{fraction solid} = \frac{x_2 - x}{x_2 - x_1} = \frac{n}{w}$$

$$= \frac{35\% - 20\%}{35\% - 10\%}$$

$$= 0.6\quad(60\%)$$

Answer is C.

15. Annealing is used to relieve stress, recrystallize the grain, and increase grain growth. Annealing removes the dislocations caused by work hardening that makes a material tough.

Answer is D.