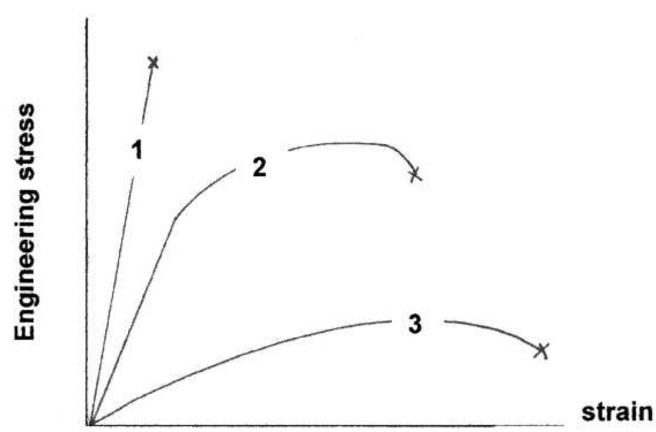
Name: Key

Mat E 272
Midterm Exam
October, 2001

**Part I. True / False (2 points each, 30 points possible)**

| | | |
|---|---|---|
| 1. | F | In a cubic lattice, the [111] direction and the (111) plane are parallel |
| 2. | F | An ionic bond is formed by the sharing of electrons between 2 atoms |
| 3. | F | Work hardening is a good strengthening method for high temperature applications |
| 4. | F | Dislocations can easily migrate across grain boundaries in polycrystalline metals |
| 5. | T | The Mohs scale classifies materials based on their ability to scratch other materials. |
| 6. | T | Interstitial alloying requires a solute much smaller than the solvent matrix |
| 7. | F | Annealing is performed to increase the hardness of metals |
| 8. | F | Brittle fracture is always preceded by extensive necking |
| 9. | T | Plastic deformation results from the breaking and reforming of atomic bonds |
| 10. | T | Fine-grained metals are stronger than coarse-grained metals of the same composition |
| 11. | F | The atomic packing efficiency of a BCC metal is greater than that of an FCC metal |
| | | For questions 12 - 15, refer to the $\sigma$-$\varepsilon$ plots shown below |
| 12. | F | The % elongation at failure of material 2 is greater than that of material 3 |
| 13. | T | Material 1 is more brittle than material 3 |
| 14. | T | Material 1 has a higher tensile strength than material 2 |
| 15. | F | Materials 2 & 3 become weaker after reaching ultimate tensile strength |



**Part II. Multiple choice (mark the <u>best</u> answer for each question) (2 points each, 34 points possible)**

1. Vacancies play an important role in:

   A _______ diffraction B _______ ionization C _______ diffusion D _______ vaporization

2. A solid in which all similar atoms lie in similar positions relative to their neighbors is said to be

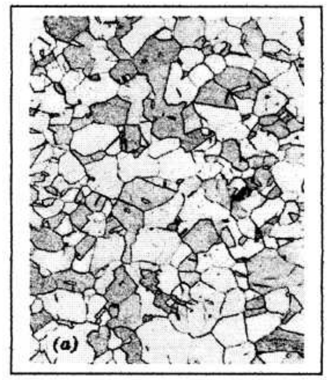
   A _______ crystalline B _______ amorphous C _______ dendritic D _______ ductile

3. Close-packed planes in the FCC unit cell are:

   A _______ <110> B _______ <111> C _______ <100> D _______ $\langle \bar{1}21 \rangle$

4. The most obvious features visible in the micrograph to the right are:

   A _______ grains
   B _______ slip lines
   C _______ Frenkel defects
   D _______ self-interstitials




5. Metallic solids are held together by

   A _______ attraction between ion cores
   B _______ electron sharing between adjacent atoms
   C _______ attraction between ion cores and a "sea" of free electrons
   D _______ electroweak interaction

6. Van der Waals bonding is due mainly to:

   A _______ attraction between electrostatic dipoles B _______ attraction between depleted covalent bonds C _______ hybrid s-p orbitals D _______ large size difference between atoms

7. Electronegativity is a measure (or indication) of

   A _______ the excess number of electrons over protons B _______ number of electrons in the valence shell C _______ strength with which electrons are attracted to an atom D _______ net charge on an atom

8. If a load (or force) of 5 N is applied longitudinally (along the principal axis) of a rectangular bar of length 10 cm, width 2 cm, and thickness 0.5 cm, the (engineering) stress on the specimen would be:

   A _______ 5 $N/m^2$ B _______ 20,000 $N/m^2$ C _______ 50,000 $N/m^2$ D _______ 25,000 $N/m^2$

9. Within the elastic limit:

   A _______ strain is produced by bond breaking and reforming B _______ strain is proportional to $(\text{stress})^{1/2}$ C _______ elastic modulus is a constant D _______ slip is initiated

10. For extensive solid solubility to occur, two elements must have:

    A _______ similar hardness B _______ similar elastic modulus C _______ similar atomic size D _______ similar electronegativity E _______ Both A & C F _______ Both B & D G _______ Both C & D

11. If a 100 mm rod is plastically deformed under tension to a final length of 101 mm, the corresponding strain would be:

A _______ 0.01 % B _______ 0.1 % C _______ 1.0 % D _______ 10 %

12. Interstitial atoms are usually:

A _______ similar in size to the solvent atoms B _______ trivalent C _______ small, relative to the size of the solvent atoms D _______ large, relative to the size of the solvent atoms

13. Slip planes are close-packed planes because:

A _______ the atomic orbitals overlap B _______ higher density of atoms lowers the stress per atom C _______ there are more close-packed planes than any other D _______ the interplanar separation is greatest

14. The equilibrium fraction of vacancies in a crystal:

A _______ increases exponentially with temperature B _______ decreases exponentially with temperature C _______ increases linearly with temperature D _______ decreases linearly with temperature E _______ is independent of temperature

15. In steady-state diffusion, the flux is directly proportional to:

A _______ temperature B _______ number of atoms per unit volume C _______ concentration gradient D _______ volume

16. The Miller indicies of a crystallographic plane are proportional to:

A _______ the intercepts of the plane on the coordinate axes B _______ the reciprocal of the intercepts on the coordinate axes C _______ the direction cosines between axes D _______ the inverse of the normalized unit cell volume

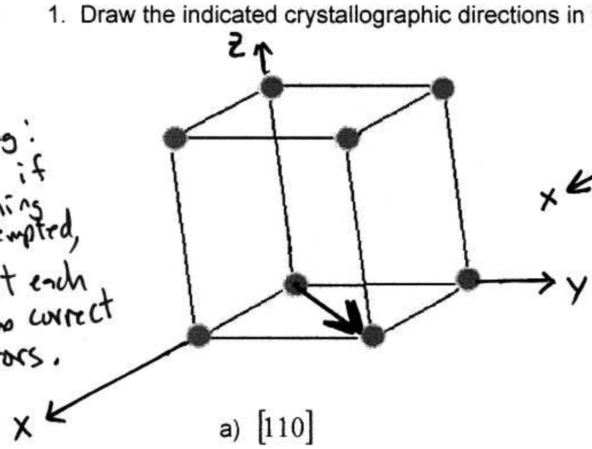
17. Dislocation strain fields can :

A _______ be attractive B _______ be repulsive C _______ separate themselves from the dislocation D _______ be either repulsive or attractive

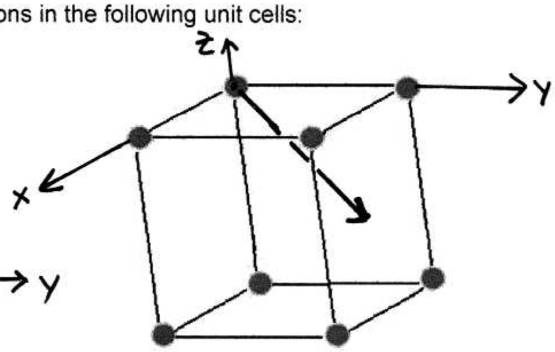
**Part III. Short answer (3 points each)**

1. Draw the indicated crystallographic directions in the following unit cells:

Grading: 1 point if something is attempted, 1 point each for the correct vectors.




a) $[110]$

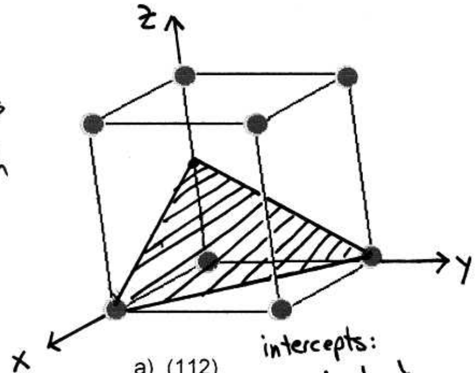



b) $[12\bar{1}]$

components: $\frac{1}{2}$ $1$ $-\frac{1}{2}$

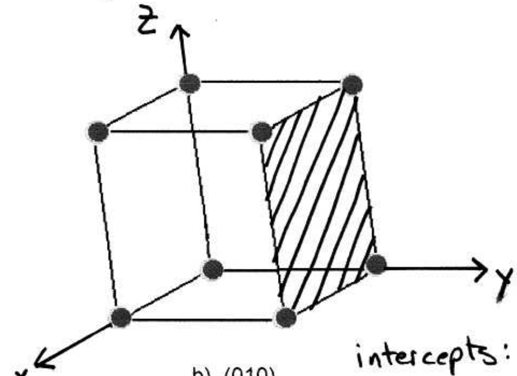
2. Shade in the indicated crystallographic planes in the following unit cells:

Grading
1 point if something is attempted
1 point each for correct plane.




a) (112)

intercepts: 1, 1, $\frac{1}{2}$




b) (010)

intercepts: $\infty$, 1, $\infty$

**Part IV (15 points)**

The bearing surface of a steel crankshaft is machined from a steel (iron – carbon) alloy initially containing 0.2 weight % carbon, which provides a hardness of approximately 43 HRC. While this alloy provides adequate toughness, the wear resistance is poor, which leads to premature failure. In order to improve wear resistance while preserving toughness, a process called carburization is employed. When heated in the presence of CO (or of methane, $CH_4$), carbon atoms dissolve into the iron, raising the carbon concentration in a thin surface layer. Diffusion is relatively slow, which means that a steep concentration gradient just below the surface soon develops. Thus, a hard, wear resistant surface layer is formed while retaining a tough interior.

The design specification for this part calls for a surface hardness of 60 HRC within a 1 mm (0.001 m) surface layer.

a) Using Fig. 1 (shown on page 6), determine the minimum carbon concentration that will achieve the desired hardness:

5 points → 0.5 to 0.6 wt. % C

b) Assume the surface concentration of carbon is maintained at a constant value of 2.2 wt. %. Using the solution to Fick's second law (discussed in class and provided below), and a maximum furnace temperature of 900°C (1173 K), determine the time required in order to achieve the desired hardness of 60 HRC at a depth of 1 mm (0.001 m) below the surface. (a table of error function values is shown on page 6; you may use this to help estimate the answer, but you do not need to interpolate.)

$$\frac{C_x - C_o}{C_s - C_o} = 1 - erf\left\{\frac{x}{2\sqrt{Dt}}\right\}$$

Take the diffusion coefficient of C in $\alpha$-Fe at 1173 K as $1.7\times10^{-10}$ m²/s.

(This is D, not $D_o$)

(show your work on page 7 and write your answer on the blank below)

8 points for correct assignment of variables
1 point for final answer

$C_x = 0.55$

$C_o = 0.20$

$C_s = 2.20$

$$\frac{0.55-0.20}{2.2-0.2} = 1 - erf\left(\frac{1\times10^{-3}}{2\sqrt{(1.7\times10^{-10})t}}\right)$$

$0.175 = 1 - erf(\ )$

$erf(\ ) = 0.825$

so $\frac{x}{2\sqrt{Dt}} = 0.96$, $x = 1\times10^{-3}$ m, $D = 1.7\times10^{-10}$ m²/s.

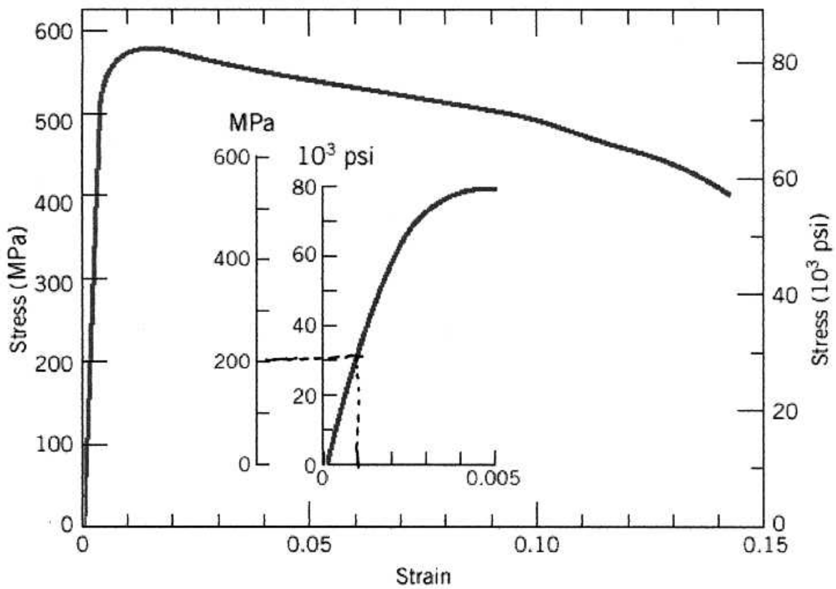
t = $\boxed{\sim 26 \text{ Minutes (36 if use } erf(x) \approx x)}$

c) If the furnace temperature is slightly decreased, will the carburization process take more time, less time, or about the same time? (assuming the diffusion coefficient remains essentially unchanged)

1 point → about The same

Part V (15 points)

A tensile test was performed on a plain carbon steel wire (circular cross section). The results are shown in the following figure:




If the wire initially had a diameter of 0.010 m and length of 0.125 m, calculate the following:

A) Young's modulus (or modulus of elasticity)

$$E = \underbrace{\text{Slope}}_{\text{Slope in linear portion: 3 points}} = \frac{\Delta\sigma}{\Delta\epsilon} = \underbrace{\frac{200\ MPa - 0}{0.001 - 0}}_{\text{correct numbers substituted in: 3 points}} = \underbrace{200\times10^{3}\ MPa}_{\text{final result: 1 point}} = 200\ GPa$$

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B) The resulting elongation (or change in length) when a load of 30,000 N is applied

eqn: 3 points
Area: 1 point
sub: 2 points
result: 1 point

$$\sigma = E\epsilon$$

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

so $$\Delta l = \frac{F \cdot l_o}{A \cdot E}$$

$$A = \frac{\pi d^2}{4} = \frac{\pi}{4}(0.010)^2 = 7.85\times10^{-5}\ m^2$$

so $$\Delta l = \frac{(30000)(0.125)}{(7.85\times10^{-5})(200\times10^{9})}\ m = 0.0002\ m$$

or 0.2 mm

C) Would you classify this material as brittle or ductile? ductile ← 1 point

## Supplemental Information

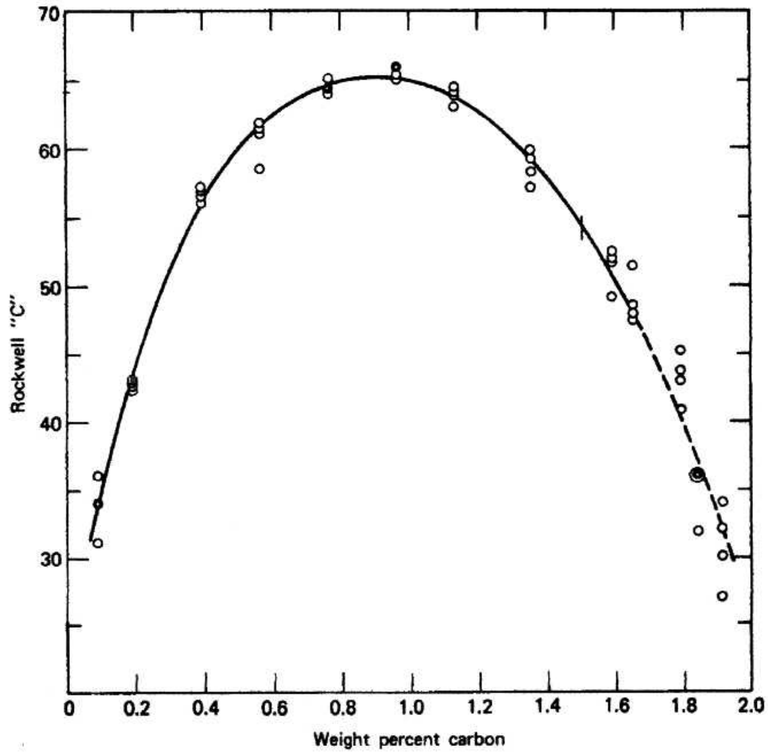


Figure 1. Rockwell "C" hardness as a function of carbon content for iron-carbon alloys. (From A. Litwinchuk, "Densities, Microstructures, and Hardness of As-Quenched Iron Carbon Alloys," M. S. Thesis, Iowa State University Library, 1973.)

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**Table 5.1 Tabulation of Error Function Values**

| $z$ | $erf(z)$ | $z$ | $erf(z)$ | $z$ | $erf(z)$ |
|---|---|---|---|---|---|
| 0 | 0 | 0.55 | 0.5633 | 1.3 | 0.9340 |
| 0.025 | 0.0282 | 0.60 | 0.6039 | 1.4 | 0.9523 |
| 0.05 | 0.0564 | 0.65 | 0.6420 | 1.5 | 0.9661 |
| 0.10 | 0.1125 | 0.70 | 0.6778 | 1.6 | 0.9763 |
| 0.15 | 0.1680 | 0.75 | 0.7112 | 1.7 | 0.9838 |
| 0.20 | 0.2227 | 0.80 | 0.7421 | 1.8 | 0.9891 |
| 0.25 | 0.2763 | 0.85 | 0.7707 | 1.9 | 0.9928 |
| 0.30 | 0.3286 | 0.90 | 0.7970 | 2.0 | 0.9953 |
| 0.35 | 0.3794 | 0.95 | 0.8209 | 2.2 | 0.9981 |
| 0.40 | 0.4284 | 1.0 | 0.8427 | 2.4 | 0.9993 |
| 0.45 | 0.4755 | 1.1 | 0.8802 | 2.6 | 0.9998 |
| 0.50 | 0.5205 | 1.2 | 0.9103 | 2.8 | 0.9999 |

**Formulae and constants:**

Volume of sphere = $(4/3)\pi R^3$

Area of circle = $\pi R^2 = \pi d^2/4$

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

$$D = D_o e^{-\frac{Q}{kT}}$$

$$\frac{N_V}{N} = e^{-\frac{Q_V}{kT}}$$

$$D = \frac{nA}{V_{UC} N_A}$$

Boltzman's constant: (k) $= 8.62 \times 10^{-5}$ eV/atom-K

$= 1.38 \times 10^{-23}$ J/atom-K

$= 1.38 \times 10^{-16}$ erg/atom-K

Gas constant (R) = 8.31 J/mol-K

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

Temperature (K) = 273 + T(°C)

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**Use this space for calculations**