Name: _____**Solutions**_____ GTID: _____

MSE 2001 B: Principles and Applications of Engineering Materials

Midterm exam 2, June 24, 2014, 10am – 11am

Please read this cover sheet carefully before continuing with the exam.

Please remove everything from your desk except this test itself, writing instruments, and a calculator.

All pages are numbered at the bottom center of the page. Make sure that you have all 7 pages including this cover page (p.1). Work all problems in the spaces below the problem statement. You can use the back side of the pages for scratch, but I will not grade answers written on the back side. Do not remove the staple or tear out any pages.

I will not grade your exam if you fail to sign on the line below.

I acknowledge the above terms for taking this exam. I commit to uphold the ideals of honor and integrity by refusing to betray the trust bestowed upon me as a member of the Georgia Tech community. I pledge my honor that I have not violated the Honor Code during this examination.

Student's signature: _____

You may find the following formulas useful for this test:

$\cos(\text{angle}) = \frac{A \cdot B}{|A||B|}$; $\tau = \sigma cos\theta cos\varphi$;

$D(T) = D_0 \exp(\frac{-Q}{RT})$; $C_v = \exp\left(-\frac{Q_{fv}}{RT}\right)$

$\frac{C(x,t)-C_0}{C_S-C_0} = 1 - \text{erf}\left(\frac{x}{2\sqrt{Dt}}\right)$;

$n = 2^{N-1}$ and $n = \frac{1}{(D_{100})^2}$, where n is the number of grains/in^2 at 100x magnification

Z	erf(Z)	Z	erf(Z)
0	0	0.55	0.563
0.05	0.056	0.60	0.604
0.1	0.113	0.65	0.642
0.15	0.168	0.70	0.678
0.20	0.223	0.75	0.711
0.25	0.276	0.80	0.742
0.30	0.329	0.85	0.771
0.35	0.379	0.90	0.797
0.40	0.428	0.95	0.821
0.45	0.476	1.00	0.843
0.50	0.521	1.05	0.862

1. Circle the correct answer (20 points)

(1) The number of crystal vacancies increases with

(a) increasing temperature; (b) decreasing temperature

(2) An electrically neutral cation-anion vacancy pair is called

(a) the Schottky defect; (b) the Frenkel defect

(3) When an extra half-plane is introduced mid-way through the crystal, it leads to

(a) edge dislocation; (b) screw dislocation

(4) Which of the following is a valid slip system for a BCC metal?

(a) $\frac{a}{2}[\bar{1}\ 1\ 1](1\ 1\ 2)$ (b) $\frac{a}{2}[1\ 1\ 1](\bar{1}\ \bar{2}\ 3)$

(5) When pendant groups are randomly arranged along the backbone chain of a polymer, it's called

(a) syndiotactic (b) atactic

(6) In oxide glass formation, oxide polyhedral should share

(a) Edges; (b) Corners

(7) Na_2O is a

(a) network former; (b) network modifier

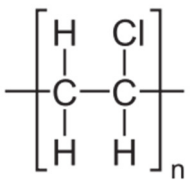
(8) Which type of diffusion will be easier (have a lower activation energy)?

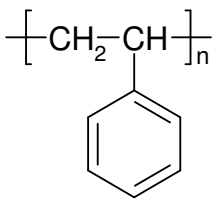
(a) C in BCC iron; (b) C in FCC iron

(9) When a small amount of Na_2O is added to MgO, what type of vacancy to be generated?

(a) Mg^{2+} vacancy; (b) O^{2-} vacancy

(10) Which polymer is more likely to be crystalline?

(a) 

(b) 

(11) When the degree of crosslinking in a thermoset polymer increases, the mass density of the polymer will

(a) increase (b) decrease

(12) The long-chain molecules in an elastomer tend to form random coils to give the system:

(a) a higher entropy (b) a lower entropy

(13) The activation energy for atomic diffusion at the grain boundary is ____ than that within the perfectly crystalline region.

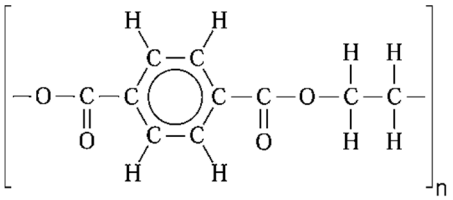
(a) higher (b) lower

(14) The viscosity of a fluid increases with

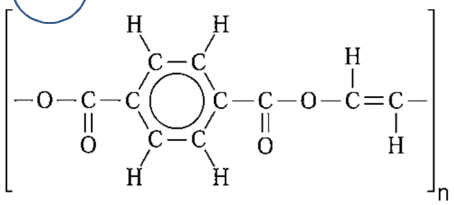
(a) increasing temperature; (b) decreasing temperature

(15) Which of the following two PET polymers can be used to form a thermoset polymer?

(a)



(b)

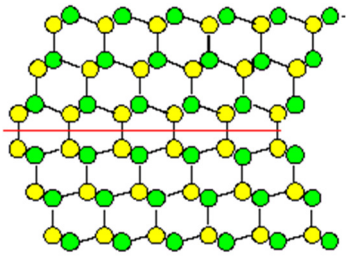


(16) For a specific type of metal alloy, the strength of the alloy will ___ when the ASTM grain size number increases.

(a) increase (b) decrease

(17) This type of planar defect is called

(a) twin boundary (b) low angle boundary



(18) HCP metals are usually not as ductile as the FCC metals.

(a) True (b) False

(19) The atomic transport of Al atoms in Cu is by

(a) interstitial diffusion (b) vacancy exchange diffusion

(20) In HCP metals slip always occurs within the closely packed “Basal” planes.

(a) True (b) False

2. Fill in the Blanks (10 points)

(1) The two types of solid solutions are substitutional solid solution and _____ solid solution. [interstitial]

(2) In Hume-Rothery rules, the size difference between the solute and solvent atoms must be no greater than _____ for the formation of substitutional solid solution. [15%]

(3) Plastic deformation occurs on _____ plane and along _____ direction. [the highest density; close packed;]

(4) The length of the Burger's vector of an FCC crystal is _____ and that of a BCC crystal is _____. (Lattice parameter for both is a) [sqrt(2)*a/2; sqrt(3)*a/2;]

(5) _____ state represents a state of material in the absence of long-range order above the glass transition temperature. [Rubbery]

(6) Name three factors that affect crystallinity in polymers: _____; _____; _____.
[The size of the side groups; the extent of chain branching; tacticity; the complexity of repeating unit, the degree of secondary bonding]

3. (10 points)
In a certain crystalline material the vacancy concentration at 25°C is one fourth that at 80°C. At what temperature would the vacancy concentration be 3 times that at 80°C?

$$C_v(25^\circ C) = \exp\left(-\frac{Q_v}{298.R}\right);\quad C_v(80^\circ C) = \exp\left(-\frac{Q}{353.R}\right).$$ **Dividing (1) by (2) we get:**

$$\frac{C_v(25^\circ C)}{C_v(80^\circ C)} = \frac{1}{4} = \exp\left[-\frac{Q}{R}\left(\frac{1}{298} - \frac{1}{353}\right)\right].$$ **Solving for Q, we get: Q = 22033.56 *J/mole***

$$C_v(80^\circ C) = \exp\left(-\frac{22033.56}{8.31 \times 353}\right) = 5.46 \times 10^{-4}$$

The problem requires computing a temperature at which $C_v = 3C_v(80^\circ C) = 1.63 \times 10^{-3}$

So $1.63 \times 10^{-3} = \exp\left(-\frac{22033.56}{8.31 \times T}\right)$; **solving for T, we get: T = 413.05K or 140.05°C**

4. (10 points)
Carburization of a thick steel plate can be analyzed by Fick's second law. The initial bulk concentration of carbon in the steel is C_0, and the carbon concentration at surface is maintained at $C_s = 9C_0$. The diffusion coefficient at the carburization temperature is $D = 10^{-6}\ \mathrm{cm}^2/\mathrm{s}$. Find the depth from the surface where the carbon concentration reaches $3C_0$ after 1 hour.

$\frac{C(x,t)-C_0}{C_S-C_0} = 1 - \mathrm{erf}\left(\frac{x}{2\sqrt{Dt}}\right)$;

Left side: $(3C_0-C_0)/(9C_0-C_0)=0.25$, so the erf function equals 0.75. Check the table, we see $\frac{x}{2\sqrt{Dt}}$ is approximately 0.82.

So x = 0.82*2*sqrt($10^{-6}\ \mathrm{cm}^2/\mathrm{s}$ * 3.6x10^3 s) = 0.1 cm

5. (15 points)
An FCC single crystal is oriented with an external force applied along the [001] direction. The applied normal stress is 1 MPa. Calculate the resolved shear stress acting on the (111) slip plane and in the $[0\bar{1}1]$ and $[\bar{1}10]$ slip directions, respectively. Which of these two slip systems will become active first?

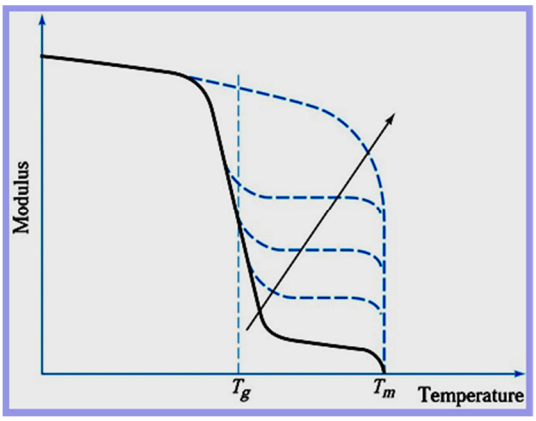
$\tau = \sigma \cos\theta \cos\phi$. In both cases, $\cos\phi = \frac{[0\ 0\ 1]\cdot[1\ 1\ 1]}{|[0\ 0\ 1]|\cdot|[1\ 1\ 1]|} = \frac{1}{\sqrt{3}}$

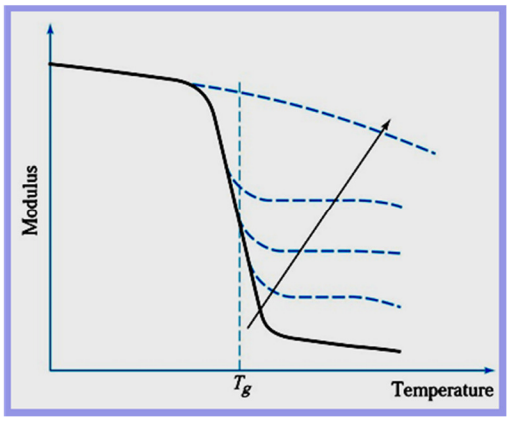
Case 1: $[0\bar{1}1]$. $\cos\theta = \frac{[0\ 0\ 1]\cdot[0\ \bar{1}\ 1]}{|[0\ 0\ 1]|\cdot|[0\ \bar{1}\ 1]|} = \frac{1}{\sqrt{2}}$, $\tau = \sigma \cos\theta \cos\phi = \frac{1}{\sqrt{6}}$ (or 0.41) MPa

Case 2: $[0\bar{1}1]$. $\cos\theta = \frac{[0\ 0\ 1]\cdot[\bar{1}\ 1\ 0]}{|[0\ 0\ 1]|\cdot|[\bar{1}\ 1\ 0]|} = 0, \tau = \sigma \cos\theta \cos\phi = 0$

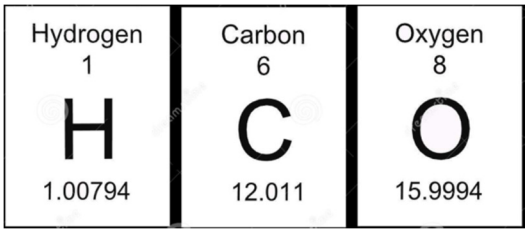
So the $[0\bar{1}1](111)$ system will be triggered first.

6. (10 points)
Sketch the relationship between the elastic modulus and temperature for a glass forming system as affected by (a) increasing the degree of crystallization and (b) increasing the degree of cross-linking. On your plot make sure you include the glass transition temperature, T_g and when appropriate, the melting temperature T_m.





7. (15 points)
Consider a hypothetical polymer $(C_5H_8O_2)_n$ that is composed of only two types of chains: 90% of the chains in this sample have a degree of polymerization n=1,000, and 10% of the chains have n=10,000. Calculate the polydispersity for this polymer sample.



The molecular weight of each mer is 5*12+8*1+2*16 = 100 g/mol
M1 = 1000 x 100 g/mol = 10^5 g/mol
M2 = 10000 x 100 g/mol = 10^6 g/mol

Mn = (0.9 x 10^5 + 0.1 x 10^6) / (0.9+0.1) = 1.9 x 10^5 g/mol

Mw = (0.9 x 10^5 x 10^5 + 0.1 x 10^6 x 10^6) / (0.9 x 10^5 + 0.1 x 10^6) = 5.7 x 10^5 g/mol

PD = Mw / Mn = 3.02

8. (10 points)
In a two-dimensional crystal with square lattice (see Figure A below), the atoms interact with each other ONLY through the first nearest neighbors. The interaction energy per nearest neighbor (or the interaction energy per bond) is ε_0 and the total interaction energy per atom is $4\varepsilon_0$.

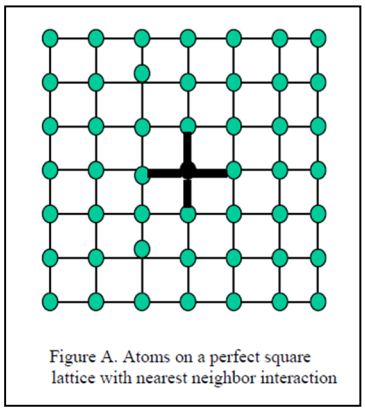


Figure A. Atoms on a perfect square lattice with nearest neighbor interaction

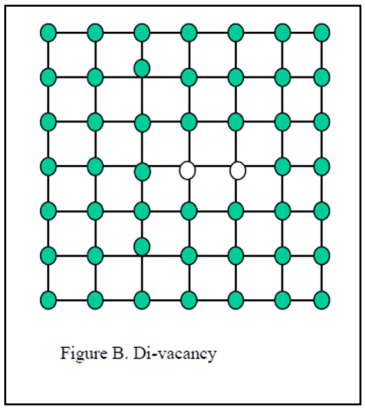
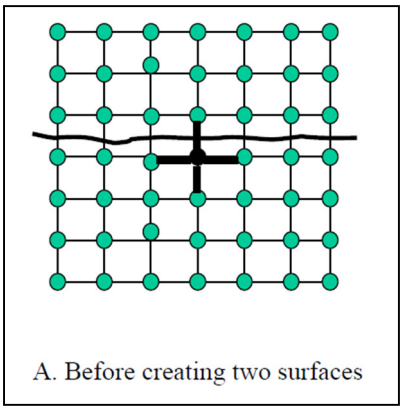


Figure B. Di-vacancy

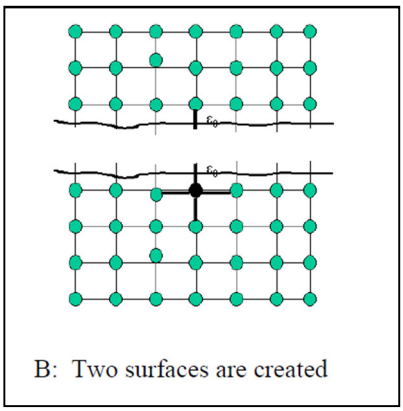
(a) If you take two atoms away, you create a di-vacancy (Figure B). What is the formation energy for creating this di-vacancy?

[In total there are 6 broken bonds associated with this di-vacancy.
So the formation energy is 6 ε_0]

(b) If you remove a half of the sample away to create a free surface (see figure below), what is the surface energy? (Note: You could express it as the energy per atom at surface)



A. Before creating two surfaces



B: Two surfaces are created

[There is one broken bond associated with each atom at surface. So the surface energy per surface atom is ε_0]
[You can add a "-" sign before the answers]