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UNIVERSITY OF TORONTO FACULTY OF APPLIED SCIENCE AND ENGINEERING
Final Examination, April 16, 2001
First Year - Programs 1, 2, 3, 4, 6, 7, 8, 9
MMS 101 – Applied Science: Materials
Exam Type: A
Examiners: T.W. Coyle, U. Erb, G. Bendzsak
Answer all questions on these pages. **Marks for each question are given in the margin.** **Only approved calculators are permitted.**

Marks
#1:
#2:
#3:
#4:
#5
#6:
Total:

Data & Equations

$e = 1.602 \times 10^{-19}$ C $N_A = 6.023 \times 10^{23}$ mol^{-1} $k = 1.38\times10^{-23}$ J/K $= 8.62\times10^{-5}$ eV/K

$\varepsilon_0 = 8.85 \times 10^{-12}$ C²/J·m $c = 3 \times 10^8$ m/s $h = 6.63 \times 10^{-34}$ J·s $= 4.13\times10^{-15}$ eV·s

$V = IR$ $\varepsilon = \frac{V}{L}$ $\sigma = n\,|e|\,\mu_e + p\,|e|\,\mu_h$ $\ln\sigma = -\frac{E_g}{2kT} + \ln\sigma_o$

$\sigma = \frac{F}{A_o} = E\varepsilon$ $\varepsilon = \frac{l_i - l_o}{l_o}$ $\sigma_T = \frac{F}{A_i} = \sigma(1+\varepsilon)$ $\varepsilon_T = \ln\frac{l_i}{l_o} = \ln(1+\varepsilon)$

$\rho = \frac{n \cdot A}{V_C \cdot N_A}$ $\rho = \frac{n'(\sum A_C + \sum A_A)}{V_C \cdot N_A}$ $d = \frac{a}{\sqrt{h^2+k^2+l^2}}$ $n\lambda = 2d\sin\theta$

$U_r = \int_0^{\varepsilon_r} \sigma\, d\varepsilon$ $\tau_R = \sigma \cos\phi \cos\lambda$ $v = \mu_e\varepsilon$ $L = N\,d\sin(\theta/2)$

$\overline{M_n} = \sum x_i M_i$ $E = h\nu = \frac{hc}{\lambda}$

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1. The molecular bonding in sodium chloride (NaCl) is predominantly ionic. Assume that the attractive and repulsive energies between the two ions, as a function of the internuclear distance r, are given respectively by:

$$E_A = -\frac{e^2}{4\pi\varepsilon_0 r} \qquad and \qquad E_R = \frac{A}{r^n}$$

where : A and n are constants

Values for A and n can be obtained by using the results of an analysis of the particle-in-a-box problem with a parabolic potential energy distribution. The analysis gives relationships for the lowest energy level E_p, and the frequency of oscillation f_p between adjacent energy levels (all specified below).

$$E_p = \frac{h}{4\pi}\sqrt{\frac{(n-1)e^2}{4\pi\varepsilon_0 \mu r_o^3}} \qquad E_p = \frac{1}{2}hf_p \qquad \mu = reduced\ mass = \frac{m_1 m_2}{m_1 + m_2}$$

where :

m_1 = mass of sodium isotope Na^{23} = 22.99 amu

m_2 = mass of a chlorine isotope Cl^{35} = 35.35 amu

3 mks (a) Obtain an algebraic equation for the equilibrium separation distance r_o

3 mks (b) Find an expression for the bond energy E_o in terms of r_o

6 mks (c) Assuming that the results obtained from the particle-in-a-box analysis can be applied to this problem, derive two algebraic equations for n and A using the relationships between E_p, f_p and r_o

3 mks (d) Give numerical values for the constants A, n and energy E_o given that $f_p = 1.14\times10^{13}$ Hz, r_o = 0.251nm, and 1 amu = $1.66*10^{-27}$ kg

1. (cont.)

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2. (a) In a ruby laser, light from a xenon lamp excites electrons from the valance band to the conduction band. Wavelength of the component of radiation responsible for this transition is 0.56 μm. The observed wavelength of the emitted red laser light is 0.6943 μm. If the average beam power is 20 mW, how much heat is carried away by the phonons? ($W = {}^{J}/_{s}$)

5 mks

5 mks (b) Assume that a 1 m long aluminum wire, having a resistance of 0.02 Ω, carries a current of 10A. Estimate the drift velocity of the electrons through the wire given $\mu_e=1.22\times10^{-3}\ m^2/V\cdot s$.

5 mks (c) The electrical conductivity of an intrinsic semiconductor is 4 times larger at $55^{0}C$ than at $25^{0}C$. Calculate the band gap for this semiconductor

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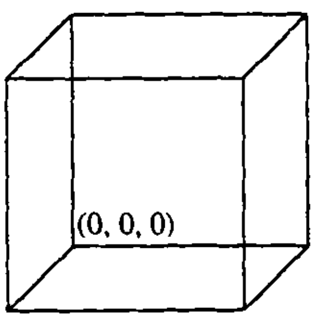
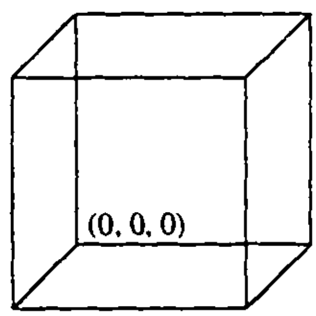
3. (a) Using Bragg's law calculate the diffraction angles (2θ) for the <u>first four peaks</u> in an X-ray diffraction pattern for aluminum, which has the FCC (face centered cubic) structure with a lattice parameter a = 0.404 nm, using monochromatic X-rays having a wavelength of 0.1542nm. Remember, the reflection rules state that for FCC crystals h,k,l must all be either odd or even for diffraction to occur. Enter all relevant data in the following table.

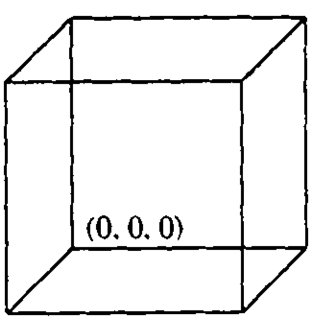
8 mks

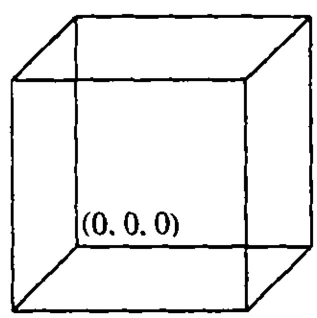
Miller indices for diffracting plane	d-value [nm]	2θ [deg.]

6 mks Draw the four planes identified above in part (a) in the cubic unit cells below. Draw only one plane in each cube. Label each plane.









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4. The combinations of slip planes and slip directions are termed slip systems. For a particular crystal structure the slip planes are the planes having the most dense atomic packing while the slip directions correspond to the directions with the highest linear density in these planes.

12 mks (a) For this problem consider the case of a FCC (face centered cubic) crystal. There are four non-parallel planes of closest packing with three directions of highest linear density in each plane, thus giving a total of 12 possible slip systems. In the following table, list the 12 slip systems using correct crystallographic notations for planes and directions.

Slip plane (hkl)	Slip direction [uvw]

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4. (b) For an applied tensile stress in the [100] direction, which slip system(s) would be most likely to operate? To answer this question you must find the resolved shear stress, τ_R, for each of the 12 systems for an arbitrary value of tensile stress.

6 mks

Slip system (hkl)[uvw]	$\cos\phi$	$\cos\lambda$	τ_R

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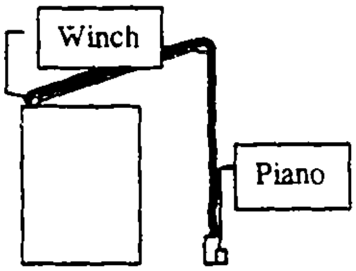
Material	Diameter (mm)	Elastic Modulus (GPa)	Poisson's Ratio	Yield Strength (MPa)	Tensile Strength (MPa)
Nylon	8	3.00	0.39	55	75.9
Steel	3	207	0.30	490	590

5. We need to lift a piano to the 2^{nd} floor deck of a new house because the stairway is too narrow to carry it up the stairs. The piano weighs 250 Kg. We could use a nylon rope or a steel cable. The distance from the piano to the winch is 30 m.



4 mks (a) What is the maximum load that can be supported without permanent deformation by (i) the nylon rope and (ii) the steel cable?

4 mks (b) Calculate the elongation of 30m of steel cable when supporting 250 Kg.

4 mks (c) Calculate the **true stress** in the nylon rope when supporting a load of 250 Kg.

4 mks (d) If both the nylon rope and steel cable were attached to the piano at the same time so that the strain in each was the same, what would the stress be in the rope and in the cable when the piano was lifted?

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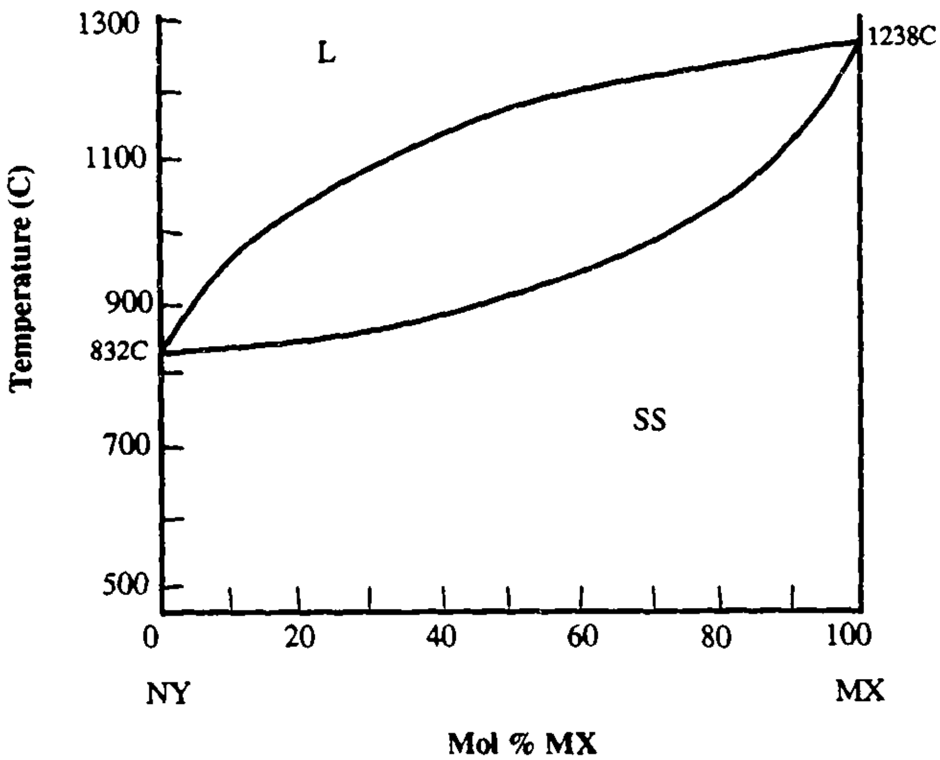
6. (a) **MX - NY phase diagram.** MX and NY are compound semiconductors that have room temperature band gap energies of 1.42 and 2.25 eV, respectively. The two compounds form solid solutions in all proportions, and the band gap of the alloy varies approximately linearly with composition as described by the equation below. Single crystals of MX-NY are formed by very slowly solidifying from the liquid under carefully controlled conditions.

$$E_g = X_{MX}(2.25\,\text{eV}) + (1 - X_{MX})(1.42\,\text{eV}) \text{ where } X_{MX} = \frac{\#\text{mol MX}}{\#\text{mol MX} + \#\text{mol MX}}.$$

2 mks (i) What is the melting point of pure MX?

2 mks (ii) At what temperature would the first liquid appear when heating a solid of composition 75 weight % MX?

4 mks (iii) If light emitting diodes (LED's) were to be made from the first solid to form during cooling, what liquid composition would be required to produce LED's with a band gap of 1.80 eV?



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(b) **Al-Cu phase diagram.** High strength Al-Cu alloys are widely used in the aerospace industry.

8 mks (i) Fill in the table below by describing the microstructure and phase composition expected at 300°C for each of the overall compositions given.

Overall composition (weight % Cu)	Sketch of microstructure (label all phases)	Relative amount of each phase	Composition of each phase (weight % Cu)
0.5			
3.0			

6 mks (ii) In the space below, briefly describe three strengthening mechanisms **other than strain hardening** which could contribute to the strength of an aluminum alloy containing 3.0 weight % Cu.

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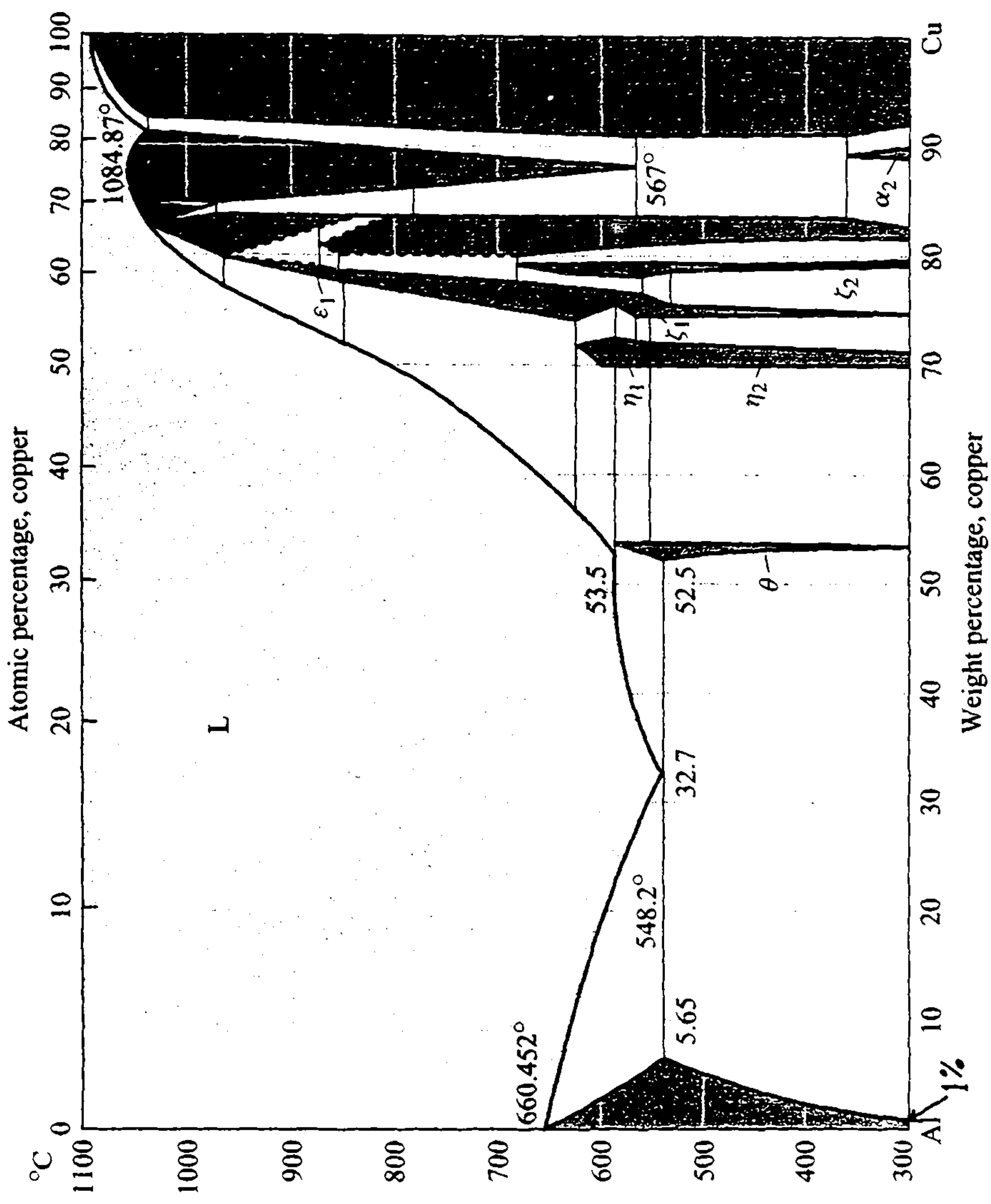

Al-Cu phase diagram