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UNIVERSITY OF TORONTO FACULTY OF APPLIED SCIENCE AND ENGINEERING **Final Examination, December 17, 2001** First Year - Programs 1, 2, 3, 4, 6, 7, 8, 9 **MSE 101 – Applied Science: Materials** Exam Type: A Examiners: T.W. Coyle, 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
Total:

Data & Equations

$\varepsilon_0 = 8.85 \times 10^{-12}\ C^2/J{\cdot}m$ $\quad h = 6.63 \times 10^{-34}\ J{\cdot}s = 4.13\times10^{-15}\ eV{\cdot}s$ $\quad k = 1.38\times10^{-23}\ J/K = 8.62\times10^{-5}\ eV/K$

$e = 1.602 \times 10^{-19}\ C$ $\quad m_e = 9.11 \times 10^{-31}\ kg$ $\quad c = 3 \times 10^8\ m/s$ $\quad N_A = 6.023 \times 10^{23}\ mol^{-1}$

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

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

$\nu = -\frac{\varepsilon_x}{\varepsilon_z} = -\frac{\varepsilon_y}{\varepsilon_z}$ $\quad \tau_R = \sigma \cos\phi \cos\lambda$ $\quad n\lambda = 2d\sin\theta$ $\quad \rho = \frac{n \cdot A}{V_C \cdot N_A}$

$$\rho = \frac{n'(\sum A_C + \sum A_A)}{V_C \cdot N_A} \qquad C_1(\mathrm{wt}\,\%) = \frac{\left(C'_1(\mathrm{mol}\,\%)\cdot A_1\left(\frac{g}{mol}\right)\right)}{\left(C'_1(\mathrm{mol}\,\%)\cdot A_1\left(\frac{g}{mol}\right)\right) + \left(C'_2(\mathrm{mol}\,\%)\cdot A_2\left(\frac{g}{mol}\right)\right)}$$

$$\bar{m} = \sum f_i m_i \qquad n_w = \frac{\overline{M}_w}{\bar{m}} \qquad E_{photon} = h\nu = \frac{hc}{\lambda} \qquad \lambda_{particle} = \frac{h}{mv}$$

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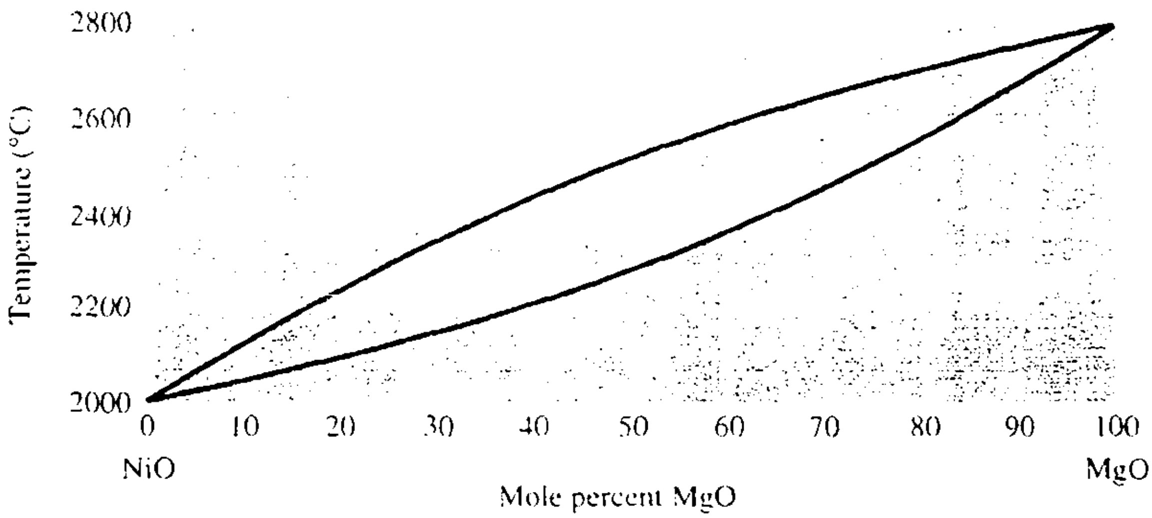
1. NiO and MgO form a complete range of solid solution as shown in the phase diagram below. The solid has the Rocksalt (or NaCl) crystal structure. The density of pure NiO is 6.67 $^{g}/_{cm^3}$. The density of pure MgO is 3.58 $^{g}/_{cm^3}$. The ionic radius of O^{2-} is r_A = 0.140 nm. The ionic radius of Ni^{2+} is r_C = 0.069 nm. The molar masses are: A_{Ni} = 58.69 $^{g}/_{mol}$; A_{Mg} = 24.31 $^{g}/_{mol}$; A_O = 16.00 $^{g}/_{mol}$.



2 mks (a) What would be the chemical composition of the first liquid to appear when heating a solid of overall composition 65 mol% MgO from room temperature?

6 mks (b) For an overall composition of 25 mol% MgO, what percentage **by weight** would be liquid at 2200°C? (Note, you will need to convert from mol % to weight %.)

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6 mks 1. (c) From the density and other data given, show by calculation that the ionic radius of Mg^{2+} is $r_C = 0.071$ nm.

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10 mks 1. (d) The melting points of pure NiO and pure MgO can be found on the phase diagram. The melting point of a material is closely related to the bond energy E_0. The energy versus separation curve for the Ni^{2+} - O^{2-} bond and the Mg^{2+} - O^{2-} bond can be described by the following equation:

$$E_N = -\frac{(Z_A e)(Z_C e)}{4\pi\varepsilon_0 r} + \frac{A}{r^n}$$

Assuming A and n are the same for NiO and MgO, calculate E_0 for NiO and MgO and compare with their melting points. Note: $r_0 = r_A + r_C$

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2. Germanium is an intrinsic semiconductor with a band gap of $E_g = 0.67$ eV. The conductivity of pure Ge at room temperature (300K) is $\sigma = 2.2\ (\Omega\cdot\text{m})^{-1}$. The atomic number of Ge is 32. Boron is used as an acceptor dopant in Ge. The acceptor energy level, E_a, lies 0.010 eV above the top of the conduction band. The atomic number of B is 5. The electron and hole mobilities in Ge are: $\mu_e = 0.38\ \frac{m^2}{Vs}$ and $\mu_h = 0.18\ \frac{m^2}{Vs}$.

3 mks (a) In the space below explain, based on the electronic structures of Ge and B, why B would be an acceptor in Ge.

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4 mks (b) The quantum numbers for one of the electrons in B have been entered in the second column of the table below. Fill in the table by entering allowable quantum numbers for each of the remaining 4 electrons in a B atom.

n	1				
ℓ	0				
m_ℓ	0				
m_s	$+½$				

3 mks (c) If Ge is doped with B atoms at a concentration of 2×10^{24} $^{\text{atoms}}/_{\text{m}^3}$, what is the conductivity when the acceptors are *saturated*?

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10 mks 2. (d) In pure intrinsic Ge what would the concentration of holes be at 177°C (450K)?

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3, Iron has a body centred cubic (BCC) structure at low temperatures referred to as α-Fe. The atomic radius of Fe is $r = 0.124$ nm. The elastic modulus of α-Fe has a value of $E = 125$ GPa in the [100] direction. The primary slip system is $\{110\}\langle\bar{1}11\rangle$.

4 mks (a) Calculate the centre to centre separation (in nm) of two Fe atoms along the [100] direction in unstressed α-Fe.

4 mks (b) Calculate the separation (in nm) along the [100] direction under a tensile stress of 150 MPa.

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8 mks 3. (c) If yield occurs when the applied tensile stress in the [100] direction is 180 MPa, what is the critical resolved shear stress (τ_{CRSS}) for the primary slip system?

4 mks (d) The 0.2% offset yield strength of polycrystalline α-Fe is 200 MPa. What is the strain at this point?

4. Transmission electron microscopes are powerful tools for the characterization of materials. In these instruments a beam of electrons is accelerated down an evacuated column through an electrical potential, *P*, and impinges on a very thin sample of material. The energy of the electron is: $E = P \cdot e = m \cdot v^2$. Several types of responses occur as a result of the interaction of the electrons with the solid.

4 mks (a) The incident electron may eject a core electron from an atom in the sample. When a higher energy electron fills that vacant energy level, x-rays of a characteristic wavelength are emitted. If the emission results from a transition from the n = 2 energy level (L shell) to the n = 1 energy level (K shell), what would be the wavelength of the electromagnetic radiation? Assume the energy of the n = 1 orbital is -1.3×10^{-16} J and the n = 2 orbital is -4.36×10^{-17} J.

8 mks (b) Since the incident electrons have a wave character, they may be diffracted by the atomic planes in the solid as described by Bragg's Law. For electrons accelerated through an electrical potential of P = 200kV:

(i) find the deBroglie wavelength for these electrons;

(ii) find the diffraction angles (2θ) for the peaks corresponding to the two most closely spaced diffracting planes in silver. Ag has an FCC crystal structure with a lattice parameter of a = 0.407 nm. Note that for an FCC structure, the Miller indices *h*, *k*, and *l* must all be either odd or even for a diffraction peak to occur.

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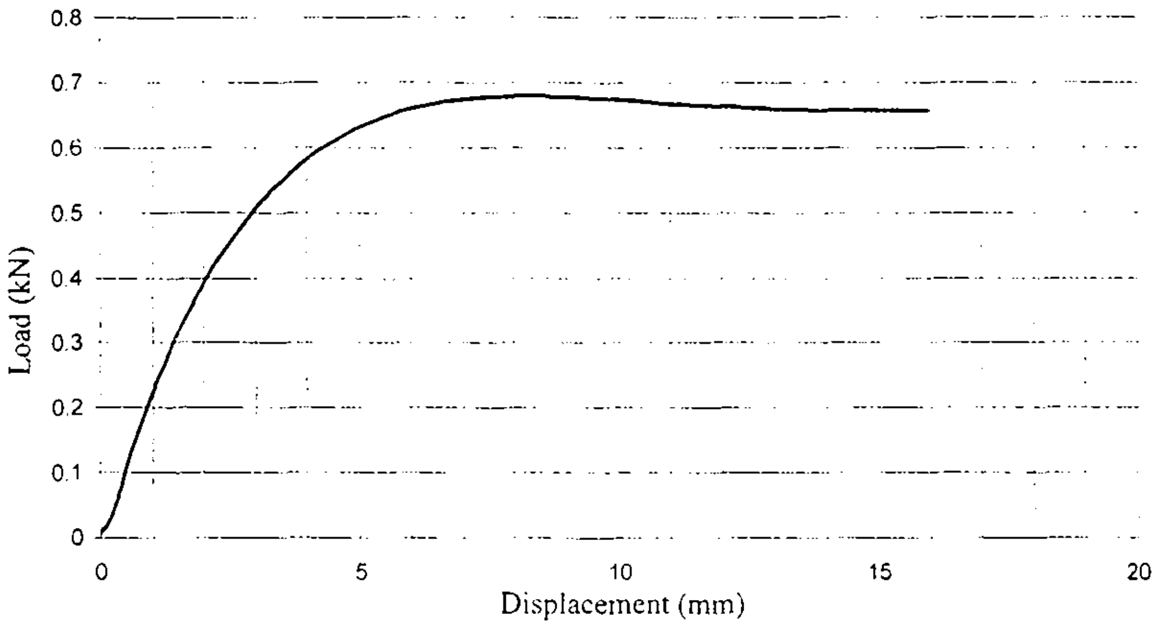
5. A company blends 50 mol % ethylene (C_2H_4) and 50 mol % vinyl chloride (C_2H_3Cl) to form a block copolymer. Each block is 3 mers long, and the polyvinyl chloride blocks are isotactic. Sheets 20.0 mm thick are manufactured from this material, from which 10.0 mm diameter cylinders are stamped to be used as supports in a mechanical loading device. The cylinders are subjected to a compressive force of 500 N.



6 mks (a) The compressive force versus displacement curve measured for one of the copolymer cylinders is shown above. Find the elastic modulus, E, and the yield strength.

6 mks (b) Calculate the thickness and diameter of the cylinder under the compressive load of 500N. Poisson's ratio is 0.35.

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4 mks 5. (c) What would you expect to happen if the polymer cylinders remained under the compressive load of 500N for an extended period of time?

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4 mks (d) Draw the structure of the original polymer. Include at least two blocks of each type of mer.

4 mks (e) If the weight average molecular weight of the polymer is 24,000 $^{g}/_{mol}$, what is the weight average degree of polymerization? The molar masses are: A_C = 12.01 $^{g}/_{mol}$; A_H = 1.008 $^{g}/_{mol}$; A_{Cl} = 34.45 $^{g}/_{mol}$.