Question	Mark
Q1	/10
Q2	/10
Q3	/10
Q4	/10
Q5	/10
Q6	/10
Q7	/10
Q8	/7
Q9	/13
Q10	/10
Total	/100

UNIVERSITY OF TORONTO

FACULTY OF APPLIED SCIENCE AND ENGINEERING

FINAL EXAMINATION, 15 APRIL 2008

First Year

APS 104S

INTRODUCTION TO MATERIALS AND CHEMISTRY

Exam Type A

Examiners: U. Erb, G. Hibbard, K. Lian, H. Ruda

NAME: ____
Last First

STUDENT NO: ____

INSTRUCTIONS:

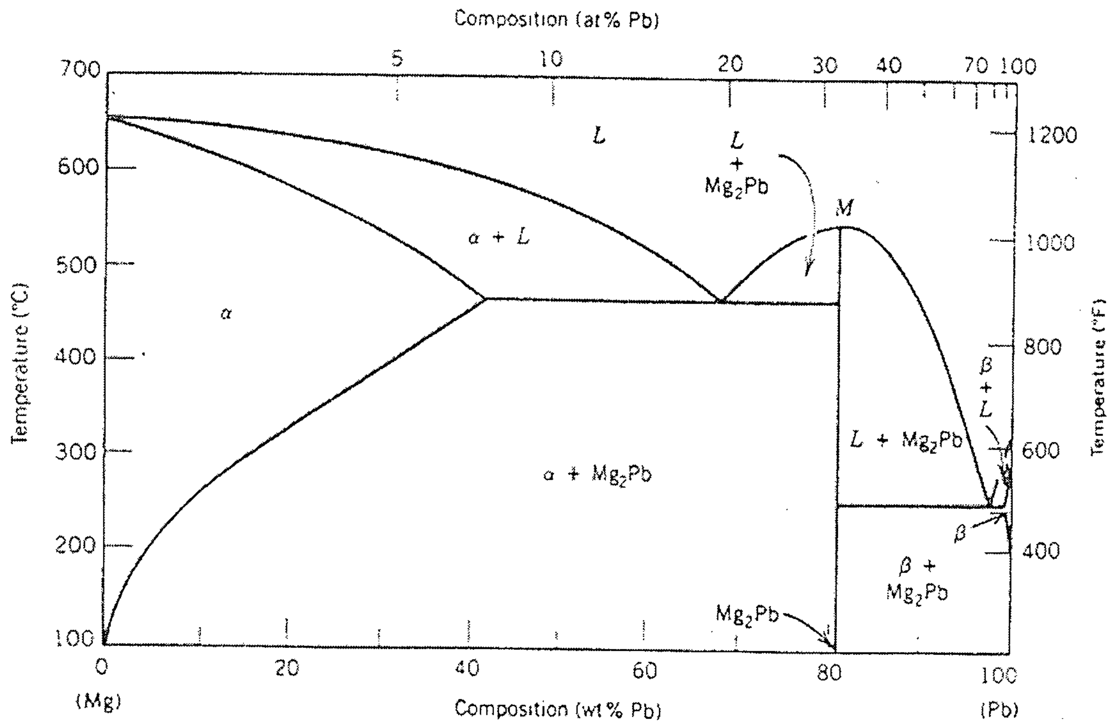
- This is a Type A examination. Only non-programmable calculators are allowed.
- Answer all ten questions.
- All work is to be done on the pages of this booklet.
- When answering the questions include all the steps of your work on these pages. For additional space, you may use the back of the preceding page.
- Do not unstaple this exam booklet.
- A Formula Sheet is attached to the end of this exam booklet; if you wish, you may tear-off this sheet *only*.

Name: ________________

Student No: ________________

QUESTION 1: *Phase Diagrams*

Refer to the Mg-Pb phase, diagram below, when answering this question.



(a) Determine the composition and amounts of all phases present at equilibrium in a Mg-Pb alloy of composition 75 wt % Pb at the following temperatures:

(i) 600^0C **(2.5 marks)**

(ii) 400^0C **(2.5 marks)**

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(b) What is the percentage of pro-eutectic to eutectic Mg_2Pb for this alloy at about 5°C below the Eutectic temperature? **(2.5 marks)**

(c) Draw the microstructure of this alloy at 400^0C labeling all the phases present. **(2.5 marks)**

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QUESTION 2: ***Phase Diagrams***

Refer to the Fe-Fe$_3$C phase diagram, given below, when answering this question.

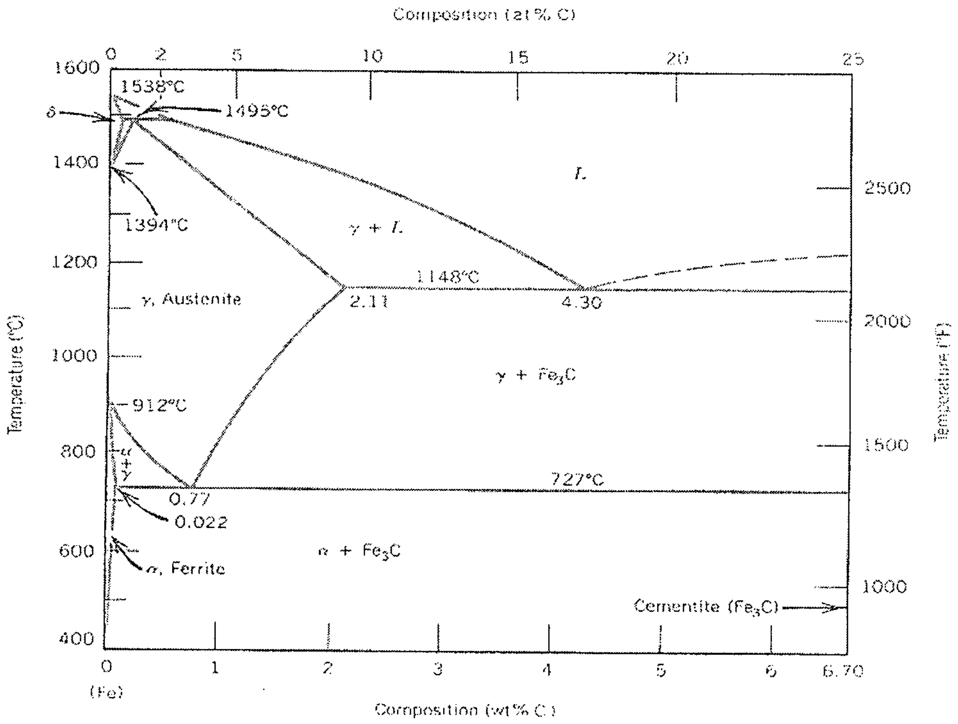

Figure 9.20 The iron–iron carbide phase diagram. (Adapted from *Metals Handbook, Metallography, Structures and Phase Diagrams*, Vol. 8, 8th edition, ASM Handbook Committee, T. Lyman, Editor, American Society for Metals, 1973, p. 275.)

1. Write the reactions for the eutectic and eutectoid reactions using phases shown in the phase diagram, and include the pertinent compositions and temperatures. **(2 Marks)**

2. Identify the phase(s) present for a 3wt% C alloy at 1400°C and 1200°C. **(2 Marks)**

3. For the alloy discussed in (2), draw a graph showing the relative amounts by weight of all phases present as a function of temperature, on cooling from 1400°C to 1000°C. **(4 Marks)**

4. Explain what are *pro-eutectoid and hyper-eutectic* alloys. **(2 Marks)**

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QUESTION 3: ***Atomic Bonding in Solids***

Assume that the repulsive interaction energy between a pair of ions separated by a distance R, is given by $Ae^{-R/\rho}$ where A has a value of 2.22 eV and $\rho = 3.5\text{x}10^{-9}$ m, and that the attractive interaction energy between the two ions is given by B/R, where $B = 7.78\text{x}10^{-11}$ $\text{eV}\cdot\text{m}$. Note: $e^{x} = 1 + \sum_{i=1}^{n} \frac{x^{i}}{i!}$.

(a) Write an expression for the variation in the potential energy of the ions as a function of R. **(2 Marks)**

(b) Given that $\rho >> R_0$, where R_0 is the equilibrium separation between the ions, find:

(i) R_0 in units of nm (i.e., 10^{-9} m), **(3 Marks)** and

(ii) The energy required to break the bond between the two ions in units of eV **(3 Marks)**

(c) Provide an expression for the interaction force between the ions, and draw a graph of this force versus R **(2 Marks)**

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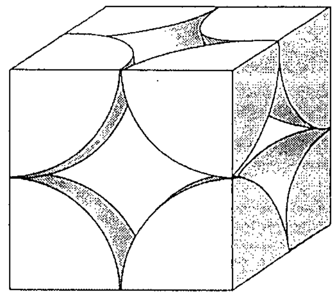
QUESTION 4: ***Crystal Structures***

Atomic Packing Factor

(a) The α-polymorph of the element Polonium has the simple cubic structure with a lattice parameter a = 0.3345 nm and an atomic weight of 210 g/mol. Calculate the atomic packing factor of this metal. **(5 marks)**



Hard sphere unit cell representation of the simple cubic structure. Note that there is of course 1 additional atom located at the origin of the unit cell (far left bottom corner) which is not shown in this schematic diagram.

Space for Calculations:

Answer *(Tick only 1 box)*:		
i) 0.61 ☐	**ii)** 0.52 ☐	**iii)** 0.59 ☐
iv) 0.68 ☐	**v)** 0.74 ☐	**vi)** 0.48 ☐

(b) Calculate the density of α-Polonium. Tick only 1 box. **(5 marks)**.

Space for Calculations:

Answer (*Tick only 1 box*):		
i) 54.6 g/cm^3 ☐	**ii)** 23.8 g/cm^3 ☐	**iii)** 12. 9 g/cm^3 ☐
iv) 9.3 g/cm^3 ☐	**v)** 4.3 g/cm^3 ☐	**vi)** 2.1 g/cm^3 ☐

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QUESTION 5: ***Planar Density, Linear Density***

a) The atomic radius of the metal lead is 0.1750 nm. The crystal structure is FCC. How many atoms per mm^2 are there on the (100) plane of lead? **(5 marks)**

Space for Calculations:

Answer (*Tick only 1 box*):

i) 3.5×10^9 atoms/mm^2 ☐ **ii)** 5.1×10^8 atoms/mm^2 ☐

iii) 9.6×10^{11} atoms/mm^2 ☐ **iv)** 8.2×10^{12} atoms/mm^2 ☐

b) FCC copper has a lattice parameter $a = 0.3615$ nm . What is the linear density of atoms per cm along the [011] direction of copper. **(5 marks)**

Space for Calculations:

Answer (*Tick only 1 box*):

i) 2.1×10^3 atoms/cm ☐ **ii)** 7.9×10^9 atoms/cm ☐

iii) 3.9×10^7 atoms/cm ☐ **iv)** 3.9×10^6 atoms/cm ☐

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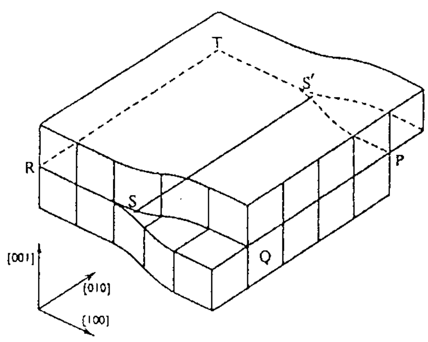
QUESTION 6: *Defects in solids*

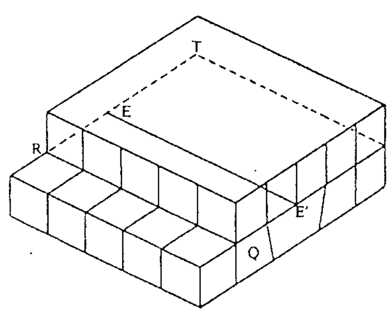
a) In the following list identify the 4 defects that are point defects by ticking appropriate boxes. Tick only 4 boxes. **(2 marks)**

i) Screw dislocation	☐	**ii)** Schottky defect	☐
iii) Twin boundary	☐	**iv)** Low angle boundary	☐
v) Vacancy	☐	**vi)** Edge dislocation	☐
vii) Interstitial impurity	☐	**viii)** Substitutional impurity	☐
ix) High angle boundary	☐	**x)** External surface	☐

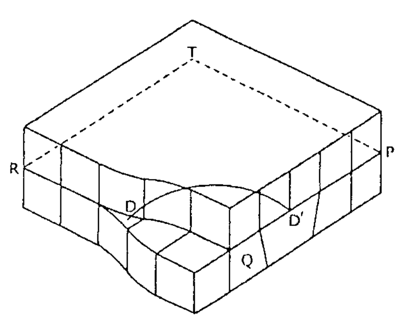
b) Write down the names of the following defects. Also indicate the Burgers vectors on each drawing. **(3 marks)**



Name of defect $S - S'$:



Name of defect $E - E'$:



Name of defect $D - D'$:

c) What is the fraction of atom sites that are vacant for copper just below its melting point (1357K)? The energy for vacancy formation in copper is 0.9 eV/atom. Tick only 1 box. **(5 marks)**

Space for Calculations:

Answer (*Tick only 1 box*):

i) 4.56×10^{-4} ☐	**ii)** 9.12×10^{-4} ☐
iii) 3.91×10^{-8} ☐	**iv)** 7.58×10^{-8} ☐
v) 9.32×10^{4} ☐	**vi)** 4.56×10^{-18} ☐

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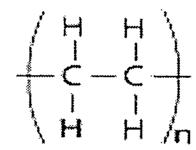
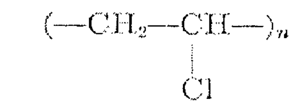
QUESTION 7: ***Polymer Structures***

Refer to the following polymer structures when answering this question.



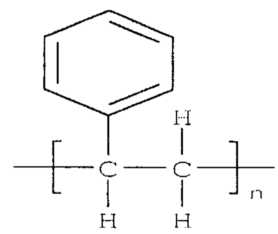
polyethylene

(a)



Polyvinyl chloride

(b)



Polystyrene

(c)

Given atomic weight: C = 12.01 g/mol. H = 1.01 g/mol, and Cl = 35.45 g/mol.

(i) What is the monomer (or precursor), that forms polymer (b)? Write out the chemical formula to describe the monomer/precursor. **(1 mark)**

(ii) Calculate the molecular weight of the repeating unit in polymer (c). **(1 mark)**

(iii) Polymer (a) often possesses two types of structures, high density (HDPE) and low density (LDPE).

a. Which one of these has a more branched structure? **(1 mark)**

b. Which one of these should have a higher mechanical strength? **(1 mark)**

(iv) Comparing polymers (a) and (c), which one would have a high degree of crystallinity? **(1 mark)**

(v) If polymer (b) is cooled down at 2 different rates (fast and slow) during solidification,

a. At which rate, fast or slow, will it have a higher degree of crystallinity? **(1 mark)**

b. Which one will have a lower density? **(1 mark)**

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(vi) Given the following table for polymer (b),

Mean M_i (g/mol)	x_i	
10^4	0.5	
10^5	0.4	
10^6	0.1	

Calculate:

a. Number-average molecular weight (M_n) **(1 mark)**

b. Degree of polymerization. **(2 marks)**

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QUESTION 8: ***Mechanical Properties***

Fill-in the blanks (**1 mark each**):

a. The reversible, non permanent deformation is called __________________deformation.

b. For a material with poisson's ratio of 0.5, it's volume change is _________.

c. Ductility is a measure of the degree of _______________deformation that has been sustained at fracture.

d. In general, the elastic modulus of ceramics is _____________ than that of the polymers. Ceramics are dominated by ________ bonds, while polymers are dominated by _____________bonds.

e. For a material with a poisson's ratio of 0.3, its shear modulus G is about ______E.

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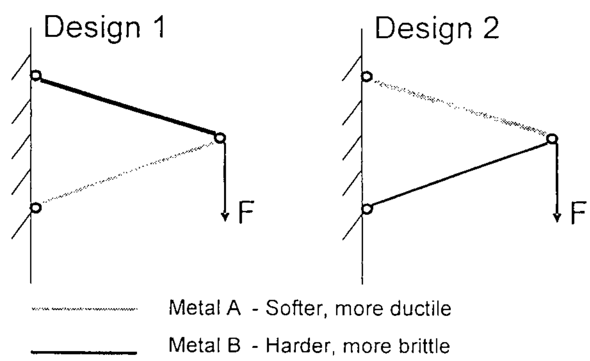
QUESTION 9: *Mechanical Properties*

Answer the following questions:

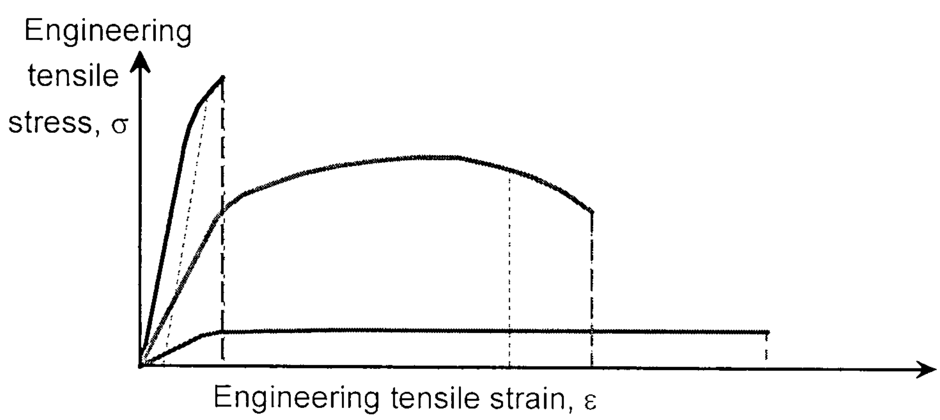
(a) Two cylindrical nickel wires A and B have diameter ratio of 1:2 (i.e. d_A:d_B = 1:2). What is the ratio of their strain (ε_A : ε_B) when applied the same force along the long axis? Assume that the deformation is elastic. **(2 marks)**

(b) State the two reasons where porosity negatively influences the flexural strength of ceramic materials. **(2 marks)**

(c) The figure on the right shows two designs with the same parameters. Which one is better? **(2 marks)**



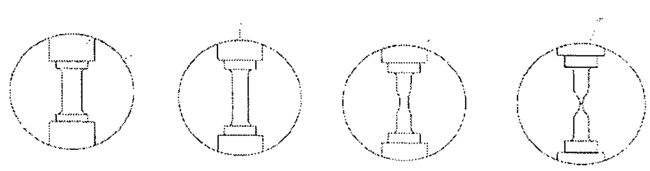
(d) With reference to the following stress-strain curves:



a. Identify which curve represents the following materials: ceramic, metal and polymer. Clearly indicate the material on the graph. **(3 marks)**

b. Mark the tensile strength on the stress-strain curve that represents metals. **(1 mark)**

c. Clearlv label the following 4 scenarios (a to d) on the curve that represents metals. **(2 marks)**



(a) (b) (c) (d)

d. When the strength of a metal is cited in design, which of the following parameter is commonly preferred: tensile strength, yield strength, or fracture strength? **(1 mark)**

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QUESTION 10: *Strengthening Mechanisms in Metals*

a) Describe the following strengthening mechanisms, including an explanation as to how dislocations are involved in each of the strengthening techniques. **(3 marks - 1 mark each)**

Grain size reduction

Solid-solution strengthening

Strain hardening

b) From the plot below (see next page) of yield strength versus (grain diameter)$^{-1/2}$ for a 70Cu–30Zn cartridge brass determine the values for the constants σ_0 and k_y in the equation $\sigma_y = \sigma_0 + k_y d^{-1/2}$ **(5 marks)**

c) Predict the yield strength of this alloy when the average grain diameter is 2.0×10^{-3} mm. **(2 marks)**

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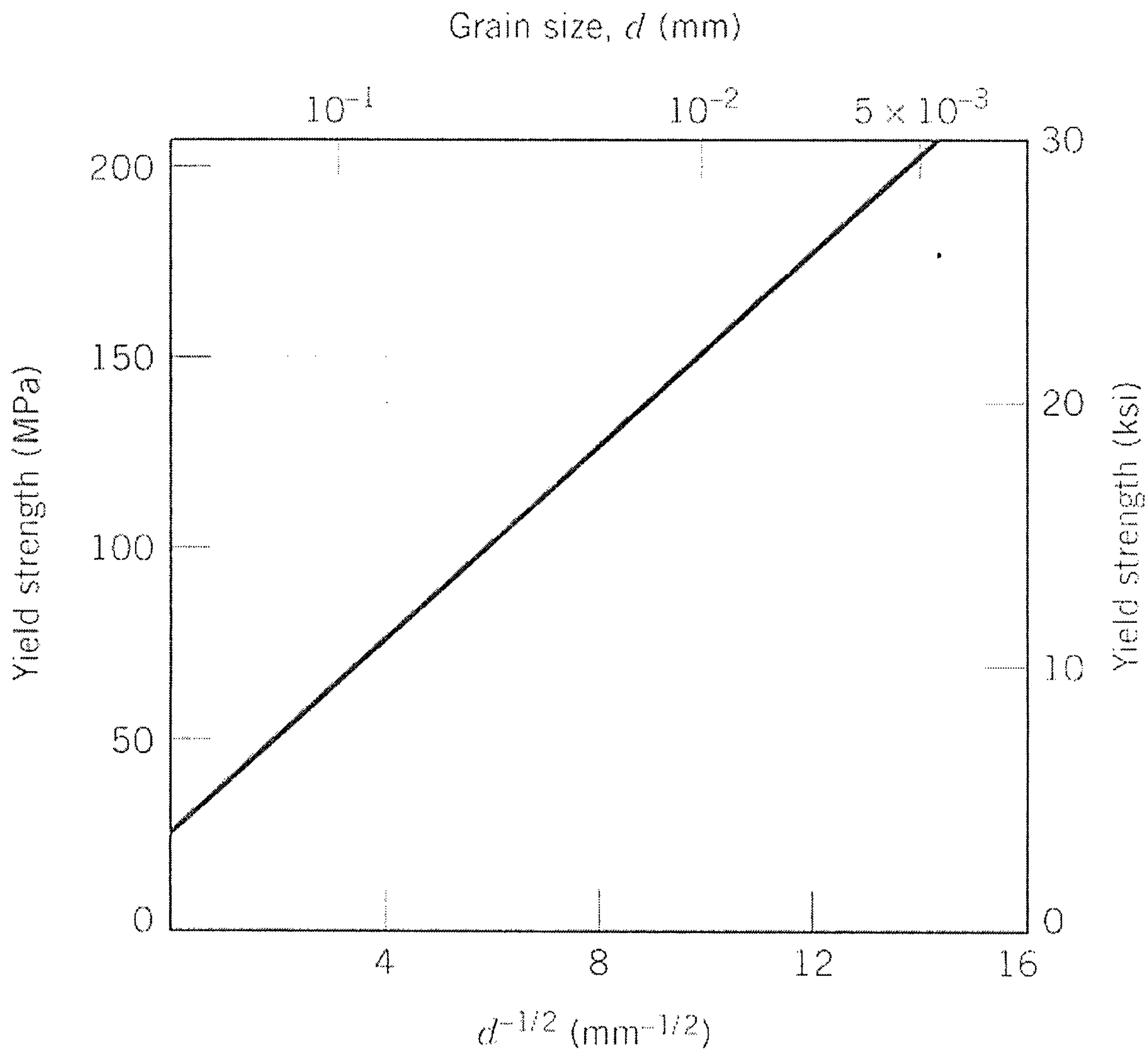

Plot showing the influence of grain size on the yield strength of a 70Cu-30Zn brass alloy. Note that the grain diameter increases from right to left and is not linear.

Some Useful Relations/Formulas and Constants *(you may tear-off this sheet only)*

$$AtomicPackingFactor = \frac{TotalSphereVolume}{TotalUnitCellVolume}$$

$$LinearDensity = \frac{NumberOfAtomsCentredOnDirectionVector}{LengthOfDirectionVector}$$

$$PlanarDensity = \frac{NumberOfAtomsCentredOnAPlane}{AreaOfPlane}$$

$$V = \frac{4\pi r^3}{3}$$

$$\rho = \frac{nA}{V_C N_A}$$

$$N_V = N \exp(-\frac{Q}{kT})$$

$$N_A = 6.023 \times 10^{23} \text{ molecules/mol}$$

$$k = 8.62 \times 10^{-15} \text{ eV/(atom K)}$$

$$DP = M_n/m$$

$$M_n = \Sigma x_i M_i$$

$$G = E/2(1 + \nu)$$

$$\sigma_y = \sigma_0 + k_y d^{-1/2}$$

$$e^x = 1 + \sum_{i=1}^{n} \frac{x^i}{i!}$$