Name ___________________________________

MBSE Core Competency Exam

Wednesday, June 4, 2025
9:00 am – noon

Instructions:

- You have three hours in which to complete the exam.
- Answer all four questions — they all carry the same weight, and they all require approximately the same effort and length of answer. Note that the questions are arranged so that each appears on a separate page.
- Be sure to read each question carefully, and please ask for clarification if you don't understand the meaning.
- Please start your answer to each question on a new page.
- Include all the details of your thought process, along with any sketches, graphs, equations, and derivations needed to support your arguments. Be sure to label all sketches and graphs clearly, define all variables that you use, and clearly state all relevant assumptions.
- Your answers must contain only your own work. You may not consult any outside sources (written, spoken, or electronic) during the exam.
- The use of calculators is not allowed in this exam. (They aren't needed!)
- You will find some potentially useful tables at the end of this document.

Good luck!

Question 1

Bonding-structure-property relationships.

(a) You are tasked with developing an ultra-hard, ultra-incompressible ceramic material that has high thermal stability. Propose some candidate compounds, explaining carefully your reasons for why the proposed materials can be expected to meet the design considerations.

(b) Your colleagues have used the ceramics developed in (a) for cutting diamond. The results are sometimes successful, but not consistently so. Discuss the possible reasons for this variability, how you would investigate the underlying causes, and how you would help your colleagues to achieve more consistent results.

(c) Upon the successful execution of (a), you are now tasked with endowing the ceramic with solid-state ion conductivity. Describe and justify the additional design strategies that you would apply.

(d) Your demanding supervisor now requires that the ceramic also be electrically conductive. Describe and justify your revised design strategies to meet this additional requirement.

Question 2

Structure, physical properties.

Describe in as much detail as possible, and with reasons, the *shape* and *orientation* of the representation surface for electrical resistivity in

(a) a single flake of graphite

(b) a flawless diamond

(c) a single crystal of an orthorhombic material

(d) a single crystal of a monoclinic material

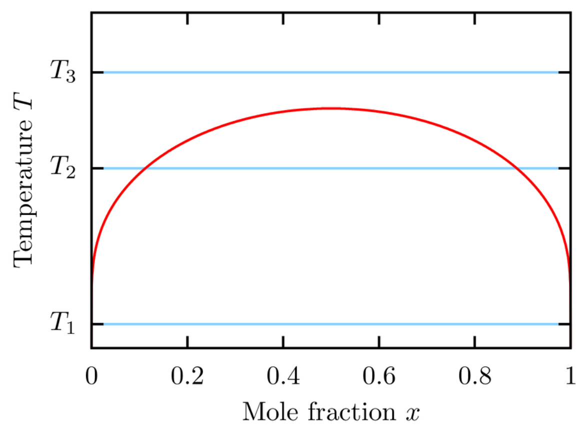
(e) a single strand of drawn nylon fiber

(f) a single layer of hexagonal boron nitride.

Question 3

Binary solution.

Suppose the phase diagram of a binary system at some fixed pressure P looks like this:



(a) In which areas of the phase diagram is the uniform solution stable, and in which areas is it unstable?

(b) Sketch qualitatively accurate graphs of the molar Gibbs free energy, $\hat{G}(x)$, of the uniform solution at each of the three fixed temperatures T_1, T_2, and T_3 shown on the diagram.

(c) Sketch qualitatively accurate graphs of
   (i) the molar Gibbs free energy $\hat{G}_0(x)$ of the completely unmixed system,
   (ii) the molar mixing energy $\Delta\hat{U}_{\text{mix}}(x)$ for the uniform solution, and
   (iii) the entropic contribution $-T_2\,\Delta\hat{S}_{\text{mix}}(x)$ to $\hat{G}$ for the uniform solution,
   all at temperature T_2 and pressure P. Draw all three graphs on the same set of axes.

(d) The **spinodal curve** partitions the areas of the phase diagram where the uniform solution is unstable into two kinds of areas: one where the solution is metastable and another where it is spontaneously unstable. What condition defines the spinodal curve?

(e) Sketch a qualitatively accurate spinodal curve on the phase diagram, and indicate the regions where the uniform solution is metastable and where it is spontaneously unstable.

(f) Discuss the phenomenon of spinodal decomposition, and contrast it with metastable phase separation.

Question 4

Rubber elasticity.

Consider a rectangular block of fully relaxed rubber that has dimensions l_0 (length), b_0 (breadth) and t_0 (thickness) along cartesian reference axes X, Y and Z respectively. If the block is stretched along X by an extension ratio λ_x, it can be shown that W, the work done, is given by

$$W = \frac{1}{2}NkT\left[\lambda_x^2 + \frac{2}{\lambda_x} - 3\right]l_0 b_0 t_0$$

where N is the number of polymer chains per unit volume, k is Boltzmann's constant, and T is absolute temperature.

(a) Which thermodynamic property of the rubber is evaluated to obtain the above equation?

(b) Starting from the above equation, show how the *force* responsible for stretching is related to λ_x.

(c) Using your result from (b), show how *nominal stress* and *nominal strain* are related during the uniaxial stretching of rubber.

(d) Use your result from (c) to explain why
   (i) when a car engine is started on a very cold day, the fan belt often squeaks for a few minutes,
   (ii) party balloons are easier to inflate if they are first placed in a refrigerator, and
   (iii) heart attacks are more prevalent in a heat wave.

Useful Information

Crystal system	Characteristic/ defining symmetry	Viewing directions			Point group / crystal class (full symbol)
		1st letter	*2nd letter*	*3rd letter*	
Triclinic	1-fold symmetry	1 or $\bar{1}$			1 or $\bar{1}$
Monoclinic	One 2-fold (diad)	*b (c)*			$2, m, \frac{2}{m}$
Orthorhombic	Three 2-folds (diad)	*a*	*b*	*c*	$222, 2mm, \frac{2}{m}\frac{2}{m}\frac{2}{m}$
Tetragonal	One 4-fold (tetrad)	*c*	*a*	[110]	$4, \bar{4}, \frac{4}{m}$ $422, 4mm, \bar{4}2m, \frac{4}{m}\frac{2}{m}\frac{2}{m}$
Trigonal	One 3-fold (triad)	*c*	*a*	[210]	$3, \bar{3}$ $32, 3m, \bar{3}\frac{2}{m}$
Hexagonal	One 6-fold (hexad)	*c*	*a*	[210]	$6, \bar{6}, \frac{6}{m}$ $622, 6mm, \bar{6}2m, \frac{6}{m}\frac{2}{m}\frac{2}{m}$
Cubic	Four 3-folds (triad)	*a*	[111]	[110]	$23, \frac{2}{m}\bar{3}$ $432, \bar{4}3m, \frac{4}{m}\bar{3}\frac{2}{m}$

Periodic Table of the Elements

1 **H** 1.0080																		2 **He** 4.0026
3 **Li** 6.94	4 **Be** 9.0122												5 **B** 10.81	6 **C** 12.011	7 **N** 14.007	8 **O** 15.999	9 **F** 18.998	10 **Ne** 20.180
11 **Na** 22.990	12 **Mg** 24.305												13 **Al** 26.982	14 **Si** 28.085	15 **P** 30.974	16 **S** 32.06	17 **Cl** 35.45	18 **Ar** 39.95
19 **K** 39.098	20 **Ca** 40.078		21 **Sc** 44.956	22 **Ti** 47.867	23 **V** 50.942	24 **Cr** 51.996	25 **Mn** 54.938	26 **Fe** 55.845	27 **Co** 58.933	28 **Ni** 58.693	29 **Cu** 63.546	30 **Zn** 65.38	31 **Ga** 69.723	32 **Ge** 72.630	33 **As** 74.922	34 **Se** 78.971	35 **Br** 79.904	36 **Kr** 83.798
37 **Rb** 85.468	38 **Sr** 87.62		39 **Y** 88.906	40 **Zr** 91.224	41 **Nb** 92.906	42 **Mo** 95.95	43 **Tc** (97)	44 **Ru** 101.07	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.76	52 **Te** 127.60	53 **I** 126.90	54 **Xe** 131.29
55 **Cs** 132.91	56 **Ba** 137.33	↔	71 **Lu** 174.97	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.84	75 **Re** 186.21	76 **Os** 190.23	77 **Ir** 192.22	78 **Pt** 195.08	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.38	82 **Pb** 207.2	83 **Bi** 208.98	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** (226)	⇔	103 **Lr** (266)	104 **Rf** (267)	105 **Db** (268)	106 **Sg** (267)	107 **Bh** (270, 278?)	108 **Hs** (271?)	109 **Mt** (278, 282?)	110 **Ds** (281)	111 **Rg** (282, 286?)	112 **Cn** (285)	113 **Nh** (286)	114 **Fl** (289, 290?)	115 **Mc** (290)	116 **Lv** (293)	117 **Ts** (294)	118 **Og** (294)
		↔	57 **La** 138.91	58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.36	63 **Eu** 151.96	64 **Gd** 157.25	65 **Tb** 158.93	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.05		
		⇔	89 **Ac** (227)	90 **Th** 232.04	91 **Pa** 231.04	92 **U** 238.03	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)		