UNIVERSITY OF CALIFORNIA
College of Engineering
Department of Materials Science & Engineering
Professor R. Gronsky

Fall Semester, 2005

Engineering 45 Midterm 01

Name:
(Please print)

INSTRUCTIONS

LATTICE seating................. Please be seated with *occupied* seats to your front and back, *vacant* seats to your left and right.
CLOSED BOOK format...... All you need are writing instruments and a straightedge. Please store all books, reference materials, calculators, PDAs, cell phones (OFF), and iPods.
NO DISRUPTION rule......... Questions cause too much of a disturbance to others in the room. Instead of asking questions, write any concerns or alternative interpretations in your answers.
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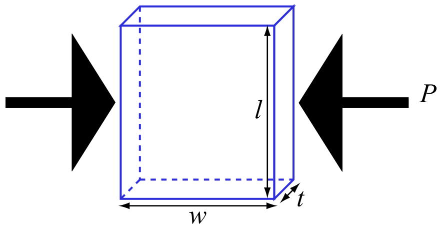
Do not open until "START" is announced.

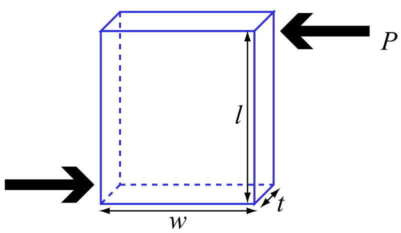
1. Mechanical Properties (20 points)
Mark ☒ the ballot box corresponding to the best answer.
Two (**+2**) points for correct answers, **-1** if wrong, **0** if blank.

(**a**) The compressive stress induced in the volume element shown below is defined by which expression?



☐ $\sigma = P / (w \times t)$
☐ $\sigma = P / (l \times w)$
☐ $\sigma = P / (l \times t)$

(**b**) The shear stress induced in the volume element shown below is defined by which expression?



☐ $\sigma = P / (w \times t)$
☐ $\sigma = P / (l \times w)$
☐ $\sigma = P / (l \times t)$

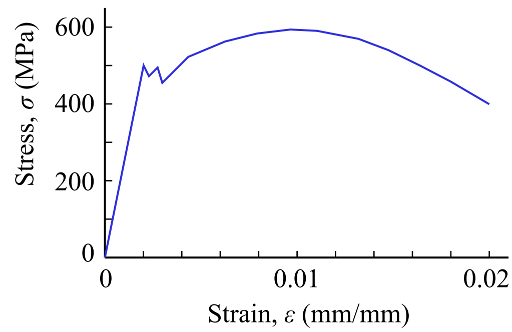
(**c**) In order to convert the data from a load *vs* elongation plot to a stress *vs* strain plot, the following information is essential.
☐ the cross-sectional area of the sample
☐ the yield strength of the sample
☐ the geometry of the sample

(**d**) Elastic deformation is________?
☐ linear
☐ recoverable
☐ time-dependent

(**e**) The gage length of a metallic alloy sample used in the standard uniaxial tensile test
☐ has the smallest cross-sectional area
☐ establishes the initial length of the sample
☐ calibrates the sample's elongation to failure

(**f**) "True" stress differs from "engineering" stress
☐ in the way tensile test data is collected
☐ in the way tensile test data is reported
☐ in the way tensile test data represents the actual sample

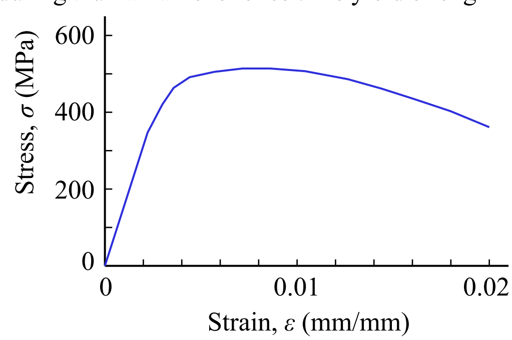
(**g**) The following data from a uniaxial tensile test of a low carbon steel sample indicates that



☐ it has a lower yield point of 450 MPa
☐ it has an 0.2% offset yield point of 450 MPA
☐ it fractured at precisely 0.02% offset

(**h**) For the same steel sample as above, an observer in the room would have observed necking in the sample
☐ just before the sample fractured at 400 MPa
☐ just when the sample yielded at 500 MPa
☐ just as the stress exceeded 600 MPa

(**i**) An aluminum alloy produced the following stress-strain plot during a uniaxial tensile test. Its yield strength is



☐ 400 MPa
☐ 450 MPa
☐ 500 MPa

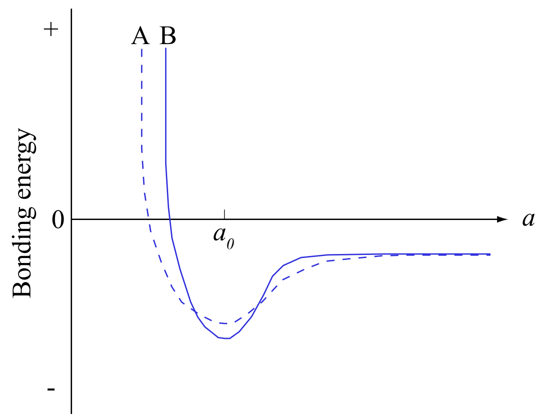
(**j**) Comparing the above plots from a steel sample and an Al alloy sample, it can be concluded that
☐ the Al alloy has greater elastic recovery after fracture
☐ the Al alloy has a larger elastic modulus
☐ the Al alloy deforms more before it fails

2. Bonding (20 points)
Mark ☒ the ballot box corresponding to the best answer.
Two (**+2**) points for correct answers, **-1** if wrong, **0** if blank.

(**a**) "Primary" bonds are formed
☐ by the transfer of primary electrons
☐ primarily between individual atoms or ions
☐ during primary chemical reactions

(**b**) "Secondary" bonds are so-named because
☐ they require secondary electrons to complete the charge transfer necessary for bonding
☐ they occur between groups of atoms after primary bonding has occurred
☐ they result in secondary reactions with reduced efficiency relative to primary bonds

(**c**) Consider the following bonding energy curves for two alloys, A and B.



☐ A has a higher tensile strength than B
☐ A has a lower elastic modulus than B
☐ A has a smaller lattice constant than B

(**d**) The "octet rule" predicts that Group IV elements
☐ form bonds with four near neighbors
☐ have eight bonding electrons
☐ reside in octahedral sites

(**e**) When compared with materials that form ionic bonds, metallic alloys
☐ melt at higher temperatures
☐ exhibit greater bond directionality
☐ have higher coordination numbers

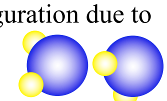
(**f**) During the formation of covalent bonds, a bonding model called "hybridization" explains why
☐ some bonds show both covalent and metallic character
☐ carbon has more than one isotope
☐ silicon atoms are tetrahedrally coordinated

(**g**) The metallic bonding model explains ductility on the basis of
☐ lack of bonding electrons, yielding weaker bonds
☐ excess of mobile electrons, causing fluid bonds
☐ lack of bond directionality

(**h**) The basis for the van der Waals interaction that causes molecular bonding is
☐ mutual charge symmetry
☐ induced electric dipoles
☐ distortion in electron orbitals

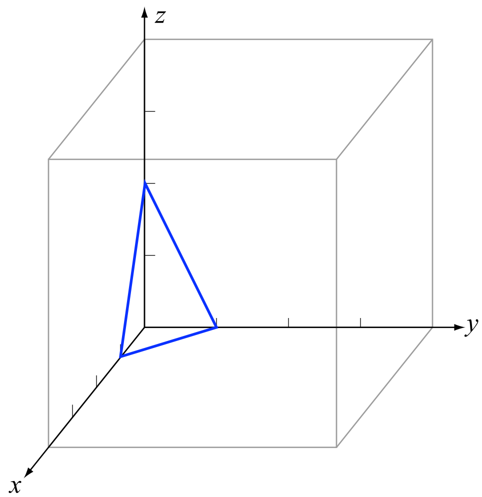
(**i**) One explanation for why graphite powder acts so well as a "solid lubricant" is
☐ carbon atoms in graphite are covalently bonded within planar layers but have weaker secondary bonds between layers
☐ finely-powdered carbon has many unsatisfied bonds at the particle surfaces, which act as a "sea of electrons" to cause lubrication
☐ when crushed into a fine powder, graphite establishes a "polar" distribution of charge, leading to Coulombic repulsion between powder particles

(**j**) The following schematic shows two water molecules in a "bonded" configuration due to

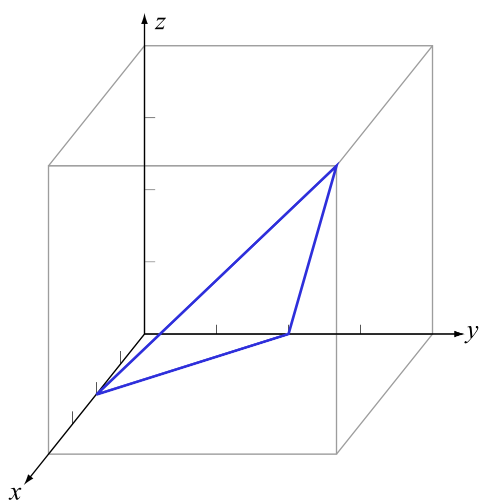


☐ 109.5° covalent bond angles
☐ a functional hydrogen bridge
☐ the ideal radius ratio, $0 < r/R < 0.155$

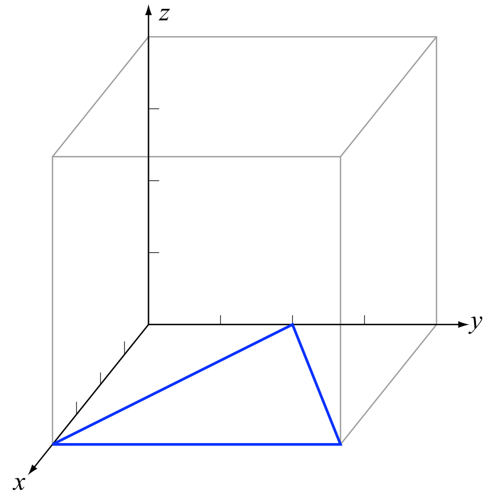
3. Lattice Planes (20 points)
The triangles drawn here are sections of planes through cubic and hexagonal lattices. Identify the relevant planes by their Miller indices or Miller-Bravais indices.
Four (**4**) points for *correct answers in the boxes* provided.



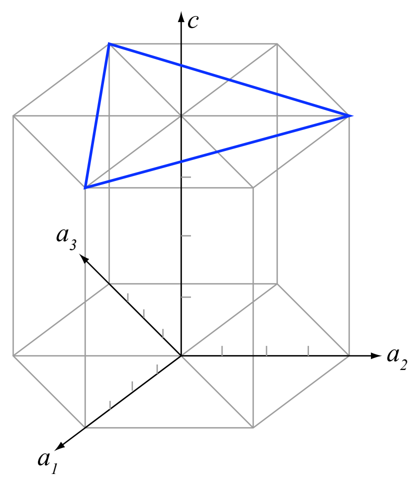
(a)



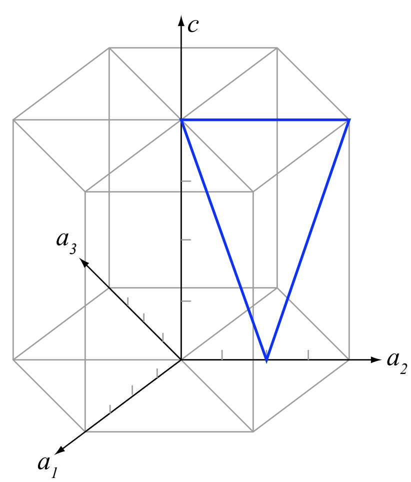
(b)



(c)

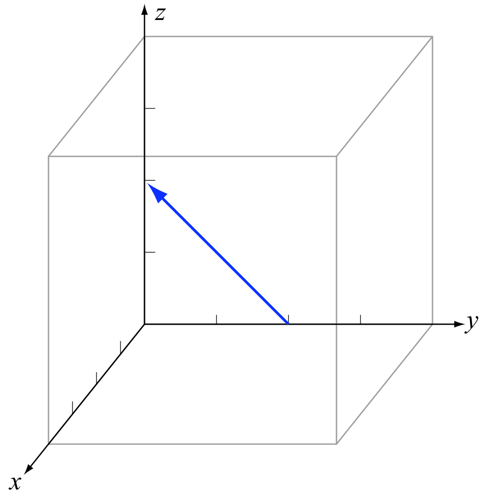


(d)

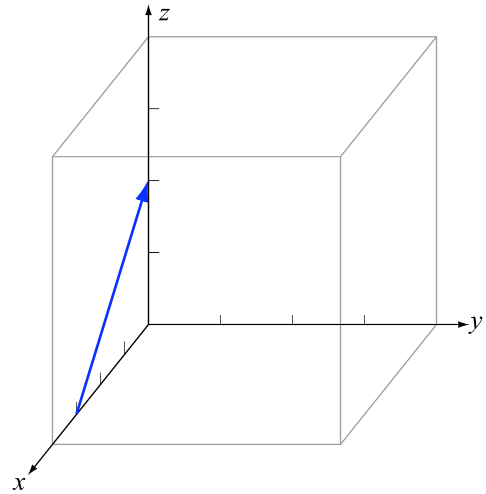


(e)

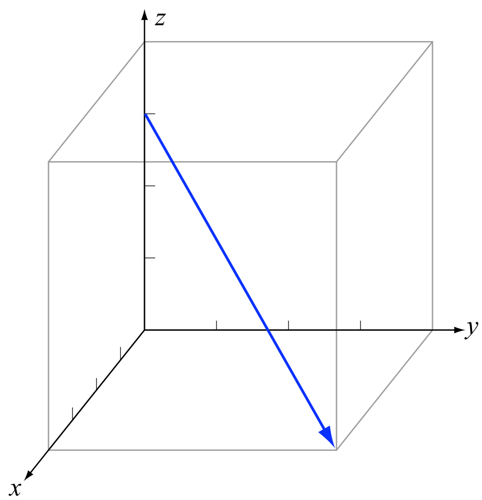
4. Lattice Directions (20 points)
Identify the following directions through both cubic and hexagonal lattices using the appropriate Miller index or Miller-Bravais index notation.
Four (**4**) points for *correct answers in the boxes* provided.



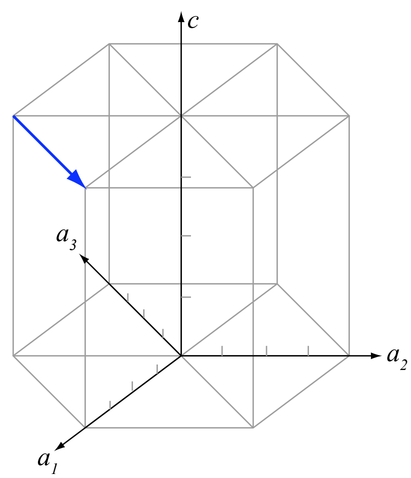
(a)



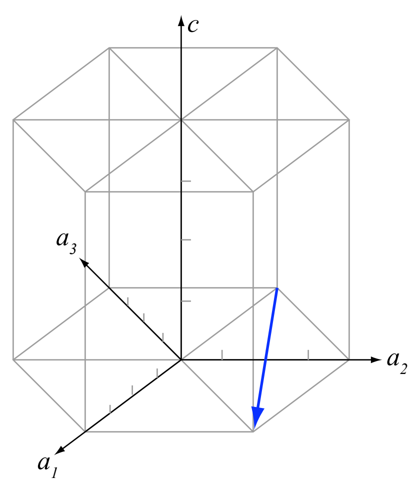
(c)



(b)



(d)

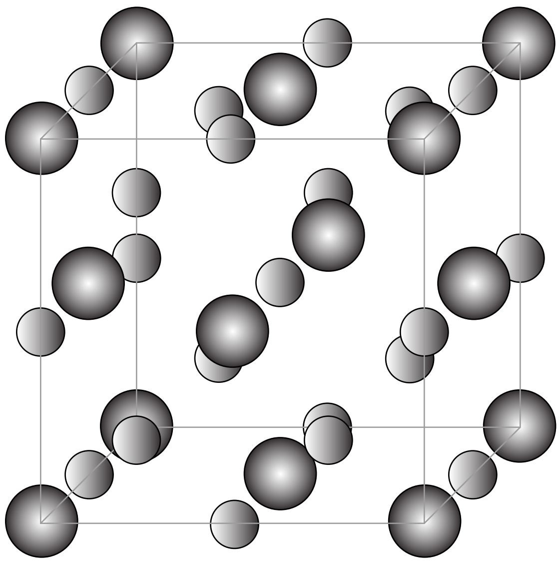


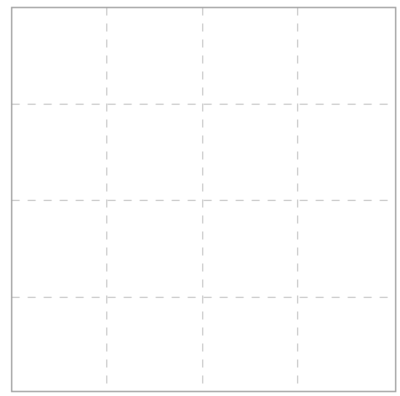
(e)

5. Crystal Structure (20 points)

An alloy of nickel and tin adopts a number of different structures, one of which is cubic, designated by the *Strukturbericht* symbol $D\mathrm{O}_3$, where the first index *D* is reserved for the more "complicated" crystal structures. In this case, the larger Sn atoms are located at all face-centered-cubic lattice sites, and the smaller Ni atoms are found in all of the tetrahedral interstices and all of the octahedral interstices. A perspective sketch of the positions is shown below on the left.

(**a**) On the grid provided to the right, draw a cube-axis projection of the structure, and label the "elevation" of each atom from the bottom plane (elevation "0") to the top plane (elevation "1"). [*Hint*: On this scheme, for example, the side faces would be occupied by a single Sn atom at elevation "½."] (**5** points)





$r_{Ni} = 0.125$ nm $r_{Sn} = 0.158$ nm

(**b**) How many Sn atoms are there in this unit cell? Ans: (**2** points)
(Show how you "count" the atoms occupying the lattice points in the unit cell)

How many Ni atoms are there in this unit cell? Ans: (**2** points)
(Show how you "count" the atoms occupying the interstitial sites in the unit cell)

Now write the "chemical formula" with the stoichiometry of the Ni-Sn alloy shown here. Ans: (**1** point)

(**c**) Using your evaluation above, specify both a Bravais lattice and motif that fully describes this $D0_3$ crystal structure.

Lattice: (**5** points) Motif: (**5** points)

Worksheet

No points will be given or deducted for work shown here. Please enter answers in the spaces provided.

DO NOT WRITE BELOW THIS LINE

Problem #	Possible Points	Your Score
1	20	
2	20	
3	20	
4	20	
5	20	
Total	100	

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1. Mechanical Properties (20 points)

Instructions: Mark ☒ the ballot box corresponding to the best answer.
Scoring: +2 points for correct answers, -1 for incorrect answers, 0 for blanks

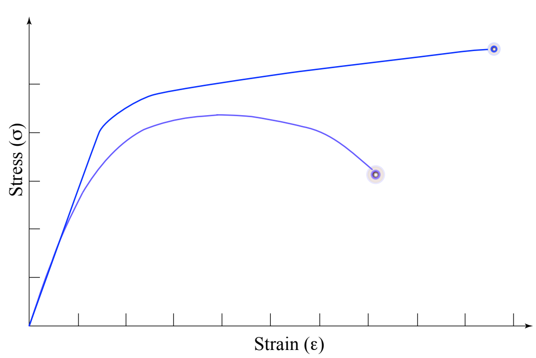
(a) Elastic deformation is
- ☐ linear
- ☐ constant
- ☐ temporary

(b) Hardness is
- ☐ resistance to fracture
- ☐ resistance to penetration
- ☐ resistance to elastic deformation

(c) The slope of the linear portion of a stress-strain curve defines
- ☐ elasticity
- ☐ Young's modulus
- ☐ the proportionality limit

(d) Engineering stress is
- ☐ always lower than true stress
- ☐ equal to true stress at high strain
- ☐ sometimes higher than true stress

(e) On stress-strain plots below, yield stress
- ☐ is found by 0.2% offset
- ☐ is where the curves bifurcate
- ☐ is higher for higher values of strain



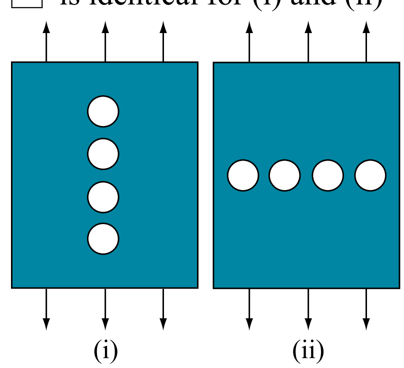
(f) Poisson's ratio describes
- ☐ tension-induced contraction
- ☐ compression-induced expansion
- ☐ both of the above behaviors

(g) Cyclic loading at low stress can
- ☐ cause failure by fatigue
- ☐ increase resistance to fatigue
- ☐ be a combination of both effects

(h) A transition from ductile to brittle failure can occur in plain carbon steels
- ☐ at low strain rates
- ☐ at low temperatures
- ☐ at low carbon concentrations

(i) Creep deformation
- ☐ results in surprise failure
- ☐ occurs at all temperatures
- ☐ depends upon melting point

(j) Stress concentration in the samples below with through holes
- ☐ is higher for (i)
- ☐ is higher for (ii)
- ☐ is identical for (i) and (ii)



2. Bonding (20 points)

Instructions: Mark ☒ the ballot box corresponding to the best answer.
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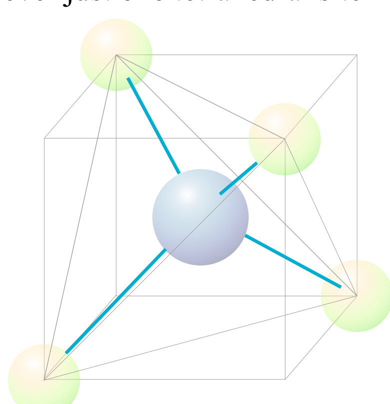
(a) Primary bonds are chemical bonds
- ☐ when they involve different ions
- ☐ if they cause a chemical change
- ☐ for all atoms and ions

(b) Secondary bonds are
- ☐ less likely than primary bonds
- ☐ more likely to be physical bonds
- ☐ equally likely to be chemical bonds

(c) During covalent bonding, the electrons that form bonds are known as
- ☐ core electrons
- ☐ valence electrons
- ☐ a "sea" of electrons

(d) Bonds lengths in ionic solids are
- ☐ determined by coulombic forces
- ☐ modeled by a zero energy state
- ☐ established by a zero force condition

(e) The bonding configuration below is
- ☐ common to Group IV elements
- ☐ also called body centered cubic
- ☐ never just one tetrahedral site



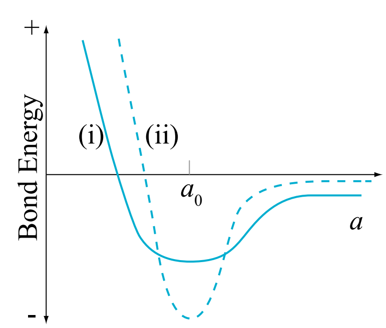
(f) Long chain polymers are bonded by
- ☐ covalent bonds within chains
- ☐ secondary bonds among chains
- ☐ a combination of both bond types

(g) Metallic bonds are
- ☐ localized
- ☐ non-directional
- ☐ formed between ion cores

(h) A dipole bond differs from an ionic bond in that it
- ☐ is directional
- ☐ fluctuates over time
- ☐ does not require electron transfer

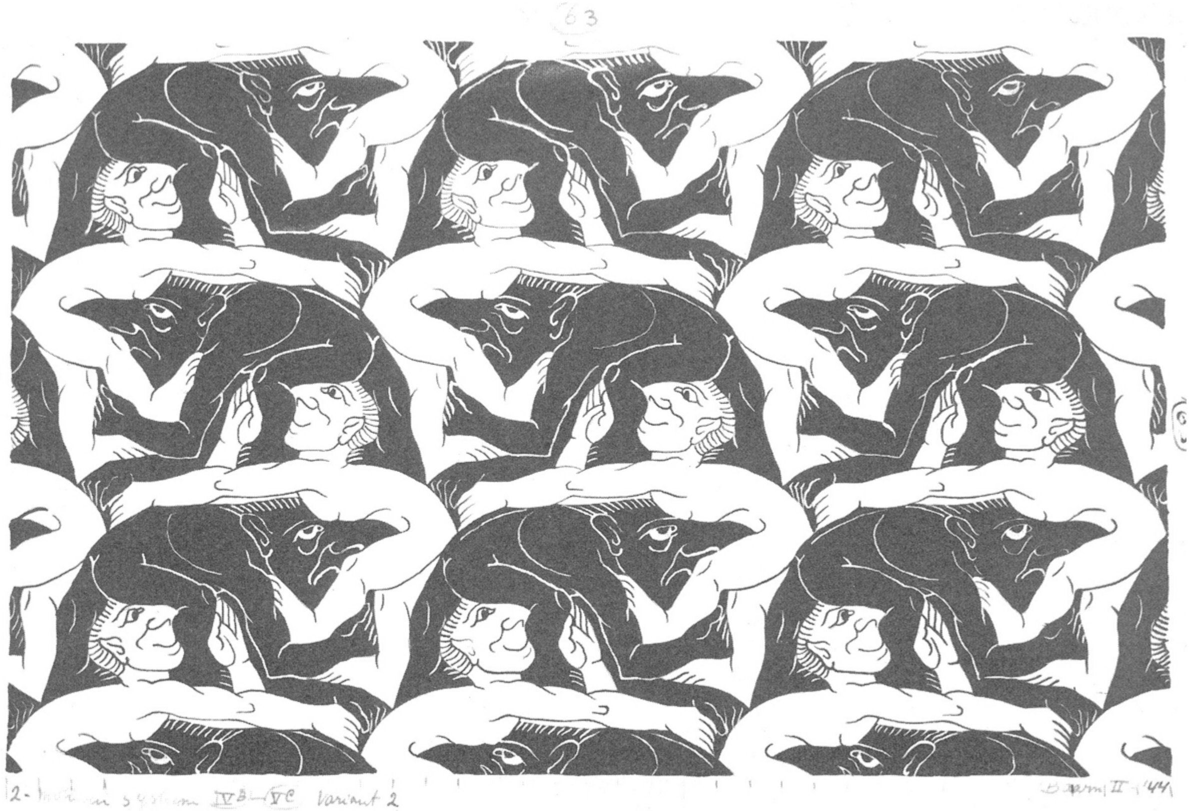
(i) A "hydrogen bridge" refers to
- ☐ the dipole bonding in liquid water
- ☐ any covalent bond with hydrogen
- ☐ electron sharing between H atoms

(j) From the plots below,
- ☐ (i) melts before (ii)
- ☐ (i) is softer than (ii)
- ☐ (i) has a larger lattice constant



3. Lattice and Motif (20 points)

(**a**) Show directly on this figure[1] by M.C. Escher using bold dots (●) the points of a lattice suitable to define its regular structure (allowing for small variations in hand drawings).



(**b**) Outline on the same figure a primitive unit cell appropriate to your choice of lattice.

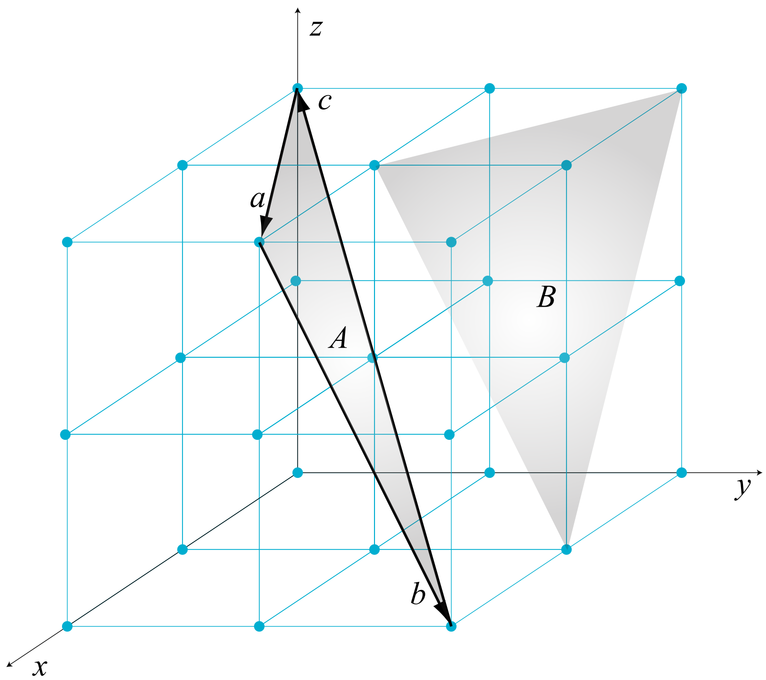
(**c**) Outline on the same figure a non-primitive unit cell containing two (2) lattice points.

(**d**) Outline on the same figure a motif appropriate to your choice of lattice that suitably defines the regular structure of this figure. How many "human figures" comprise your motif? Number of figures = ________.

[1] "Study of Regular Division of the Plane with Human Figures, 1944" in *The World of M.C. Escher*, J.L. Locher, Ed., Harry N. Abrams, Inc., Publishers, New York (1971), p. 90.

4. Lattice Directions and Planes (20 points)

Identify the indices of the directions labeled in lower case letters (at heads of the arrows) and the Miller indices of the planes labeled in upper case letters (at the center of the planes) for the simple cubic and simple hexagonal lattices below. Note that plane *A* is contains directions *a*, *b*, and *c* and plane E contains directions *d* and *e*.



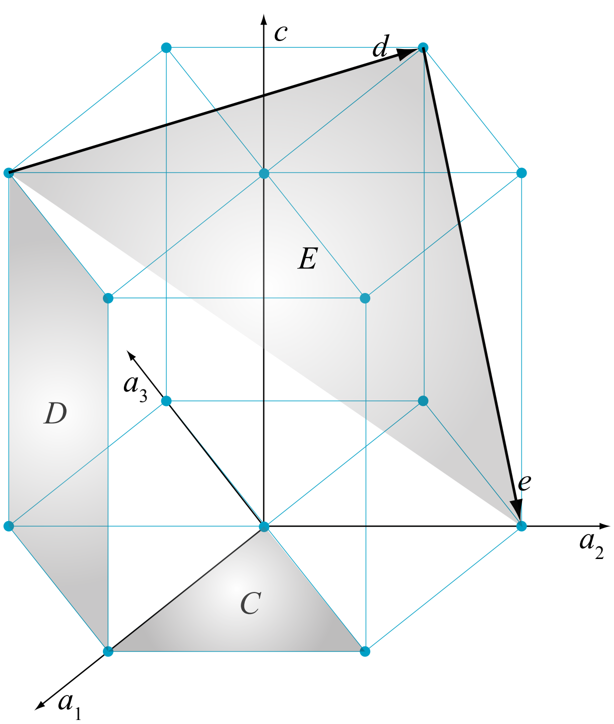
a

b

c

d

e



A

B

C

D

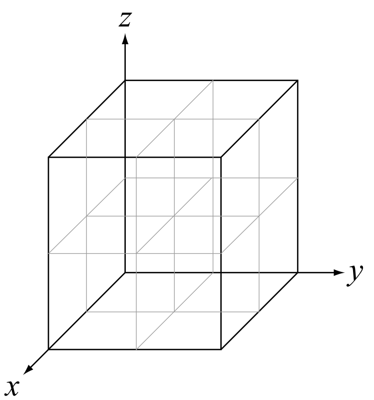
E

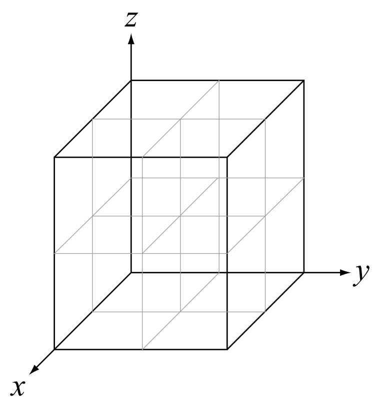
5. Common Crystal Structures (20 points)

Indium (In) is a metal with a tetragonal structure (a = b < c; α = β = γ = 90°) that is at times defined in two (2) different variants, namely,

(**a**) Two (2) atoms per unit cell, one at 0,0,0 and another at ½, ½, ½.

(**b**) Four (4) atoms per unit cell, one at 0,0,0, another at 0, ½, ½, another at ½, 0, ½, and another at ½, ½, 0.





Sketch all of the atoms within the unit cell described in (**a**). Specify the lattice and motif.

Lattice =

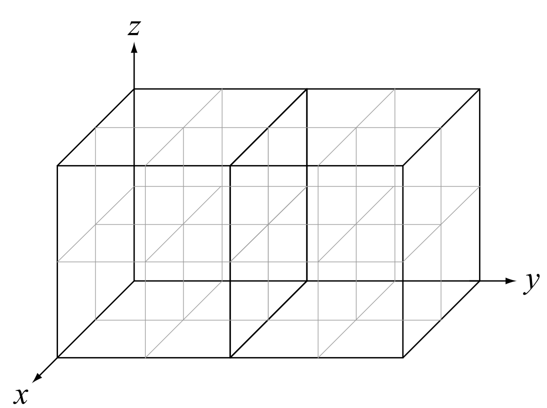
Motif =

Sketch all of the atoms within the unit cell as described in (**b**). Specify the lattice and motif.

Lattice =

Motif =

(**c**) Now show with a sketch how both of these two descriptions are equivalent. (*HINT*: The *c* lattice parameter is the same in both cases, but *a* and *b* are different).



(d) What are the indices of the first diffraction peak from a simple tetragonal structure with the same parameters as indium? (HINTS: Bragg's Law applies, that is, $n\lambda = 2d \sin\theta$, and all reflections are "allowed" by structure factor rules.) Ans: ________

Worksheet

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3	20	
4	20	
5	20	
Total	**100**	

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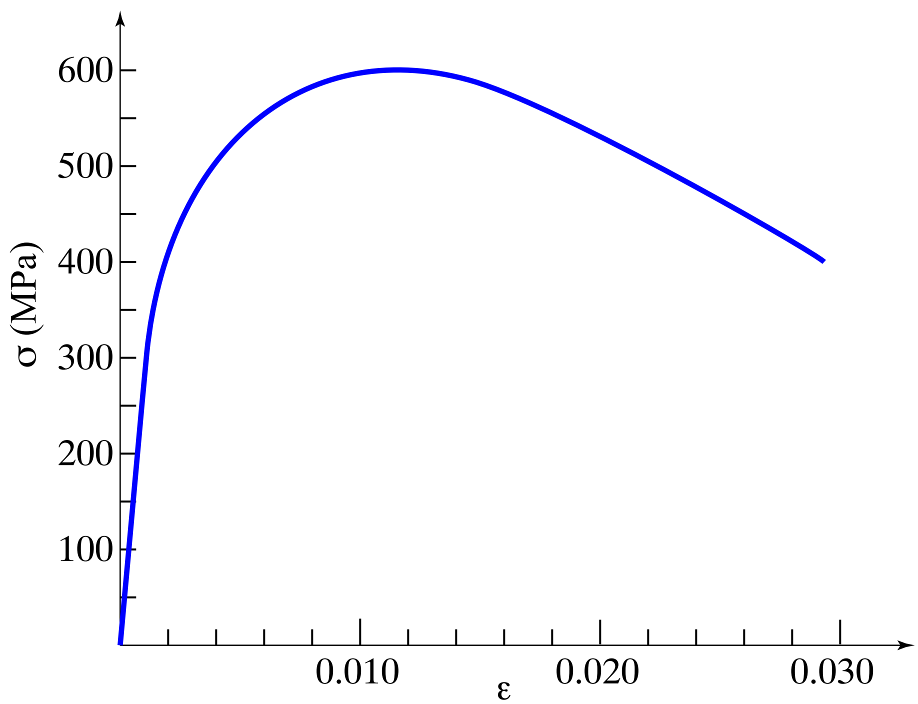
1. Mechanical Properties (20 points)

Refer to the following stress-strain plot derived from a standard uniaxial tensile test of a high performance titanium alloy to answer the following questions. Show all work.



a. What is the yield strength of this alloy?

b. What is its ultimate tensile strength?

c. What is the elastic modulus of this alloy?

d. What is its ductility (% elongation at failure)?

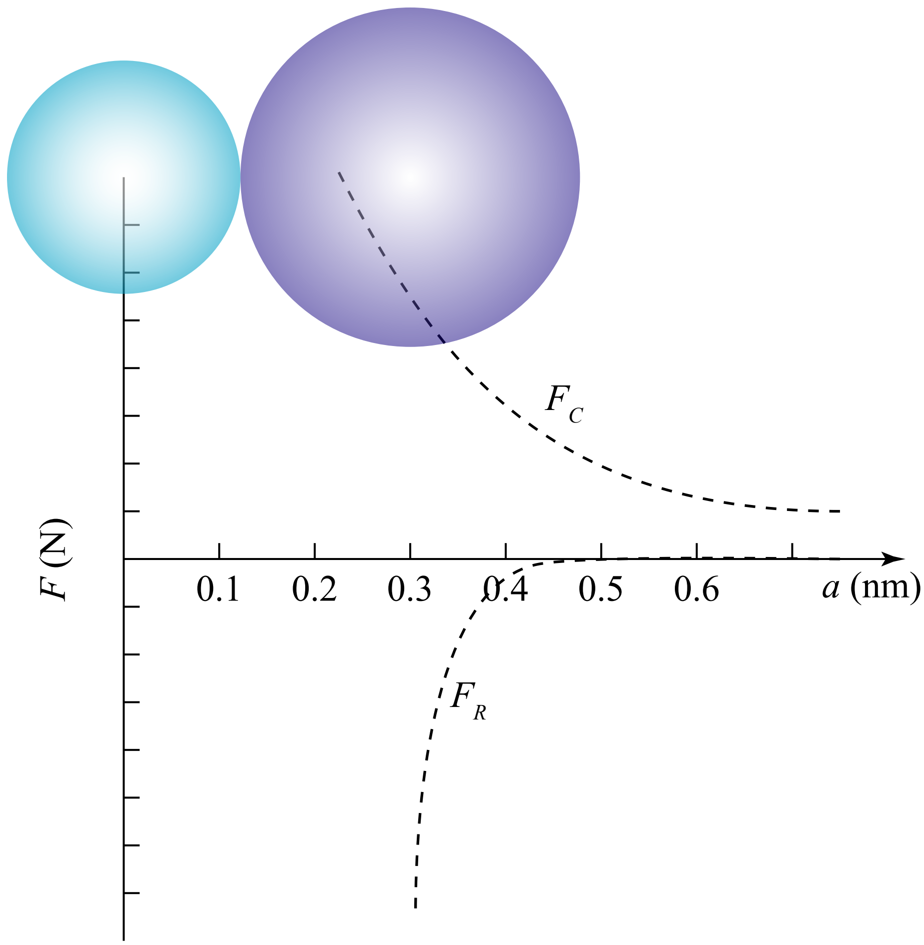
2. Bonding (20 points)

a. In problem 1 above, the titanium alloy is described as having metallic bonding. How does the nature of the metallic bond explain *both* elastic behavior in the initial stages of deformation, *and* plastic behavior during the continued deformation of this material?

b. Covalent bonding is described as "directional." What does this mean, and what determines the direction associated with the bond?

2. Bonding (20 points)

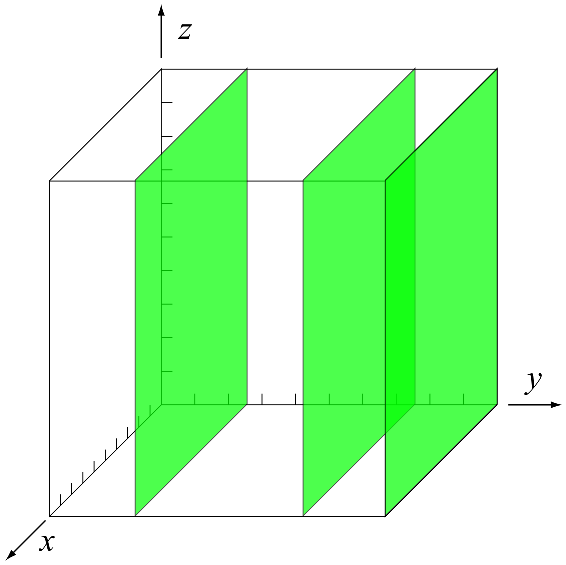
c. Refer to the force diagram below describing the contributions of the Coulombic interaction and repulsive interaction between a cation at the origin and an anion at its "equilibrium" separation distance of 0.3 nm. Show directly on the plot why this is the equilibrium spacing.



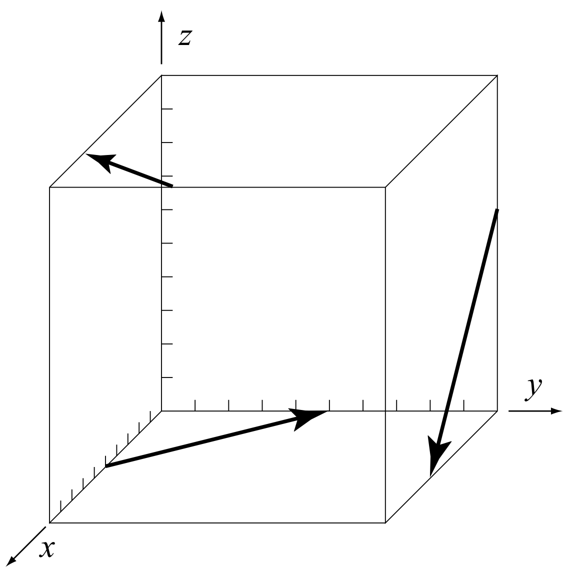
d. Why is the bond energy associated with secondary bonds no greater than 25% of the bond energy associated with primary bonds?

3. Lattice Geometry (20 points)

a. Identify the family to which the following three planes in a cubic lattice belong. Use Miller index notation.

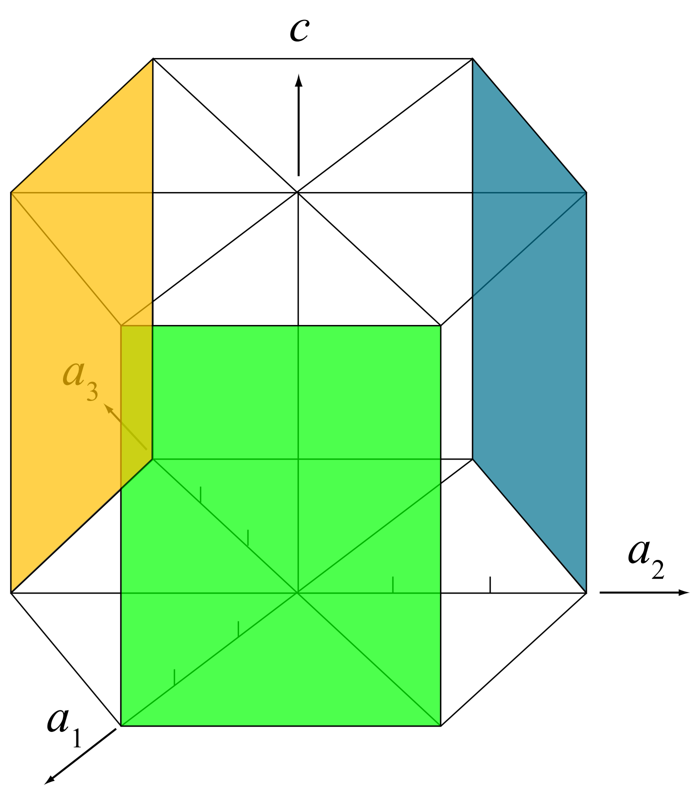


b. What symmetry-related directions through the same cubic lattice are indicated below? Use Miller index notation.



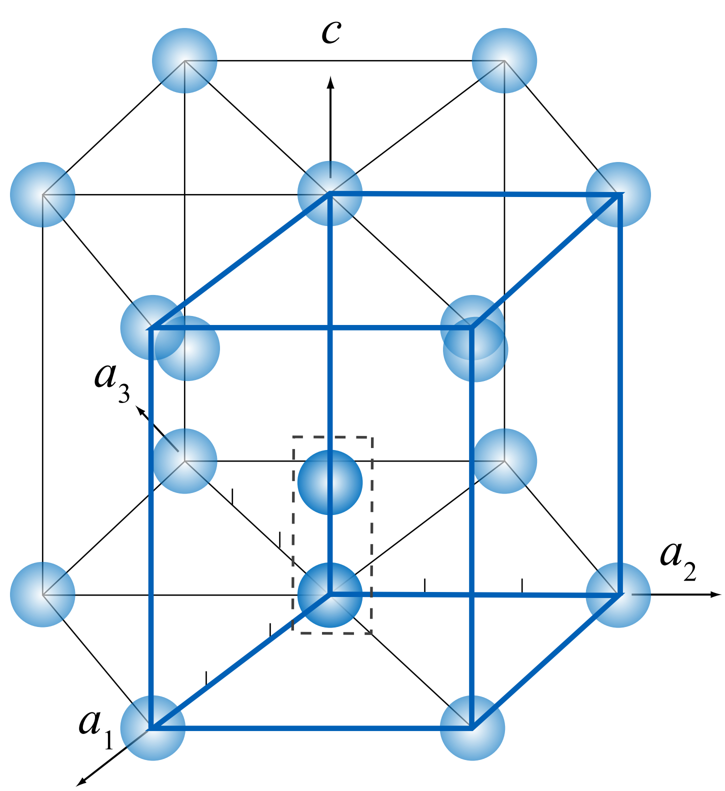
3. Lattice Geometry (20 points)

c. Identify the symmetry-related families to which the following three planes in a hexagonal lattice belong.
Use Miller-Bravais notation.



3. Lattice Geometry (20 points)

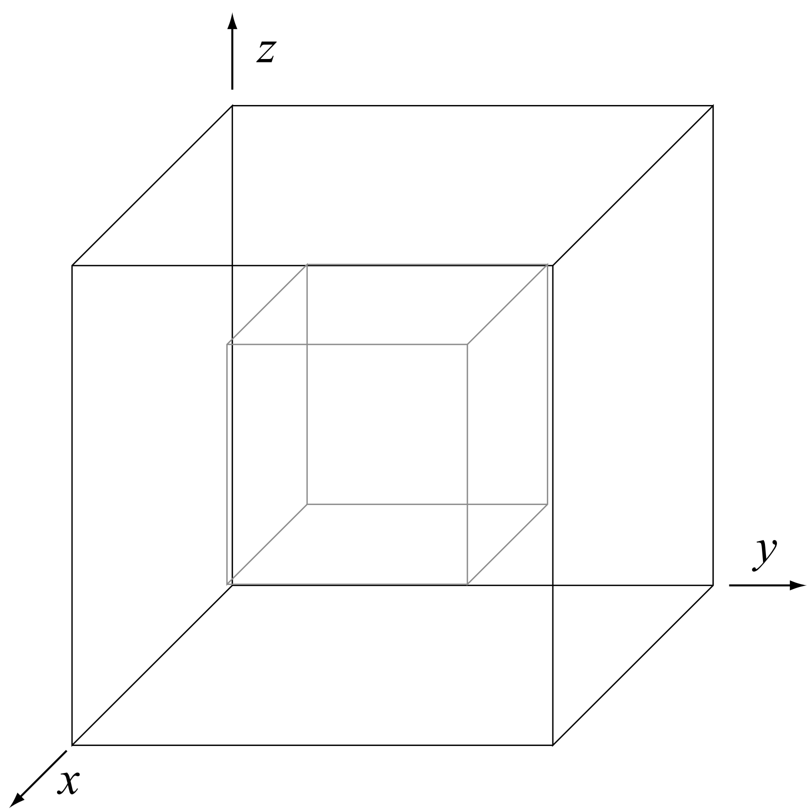
d. The hexagonal close packed (HCP) structure is illustrated below. Its Bravais lattice is simple hexagonal, adorned with a two-atom motif, one atom at 0,0,0, and a second atom at ⅔, ⅓, ½ relative to the simple hexagonal unit cell outlined below. All of the (0002) planes are closest-packed (see problem 5 below), consequently the second atom of the motif rests on a triangular bed of three atoms in the basal plane, one of which is the 0,0,0 atom. The motif is outlined (dashed line) in the sketch below. Identify the lattice direction connecting the two atoms comprising the motif in the HCP structure.
Use Miller-Bravais notation.



4. Crystal Structure (20 points)

One form of copper oxide has a cubic structure with copper atoms at locations ¼, ¼, ¼; ¼, ¾, ¾; ¾, ¼, ¾; and ¾, ¾, ¼. The oxygen atoms are at 0,0,0 and ½, ½, ½. These are confirmed by a diffraction experiment, where Bragg's Law is the operating equation, $n\lambda = 2d \sin\theta$. The structure factor rules for cubic structures allow all *hkl* reflections for a simple cubic lattice. For a body-centered cubic lattice, $h+k+l$ must sum to an even number, and for a face-centered cubic lattice, *h*,*k*,and *l* must be "unmixed," all even or all odd.

a. On the following template showing an inner cube with the locations of all tetrahedral interstices at its corners, populate a unit cell with Cu and O atoms in their appropriate locations to generate this copper oxide structure.



b. What is the chemical formula of this structure?

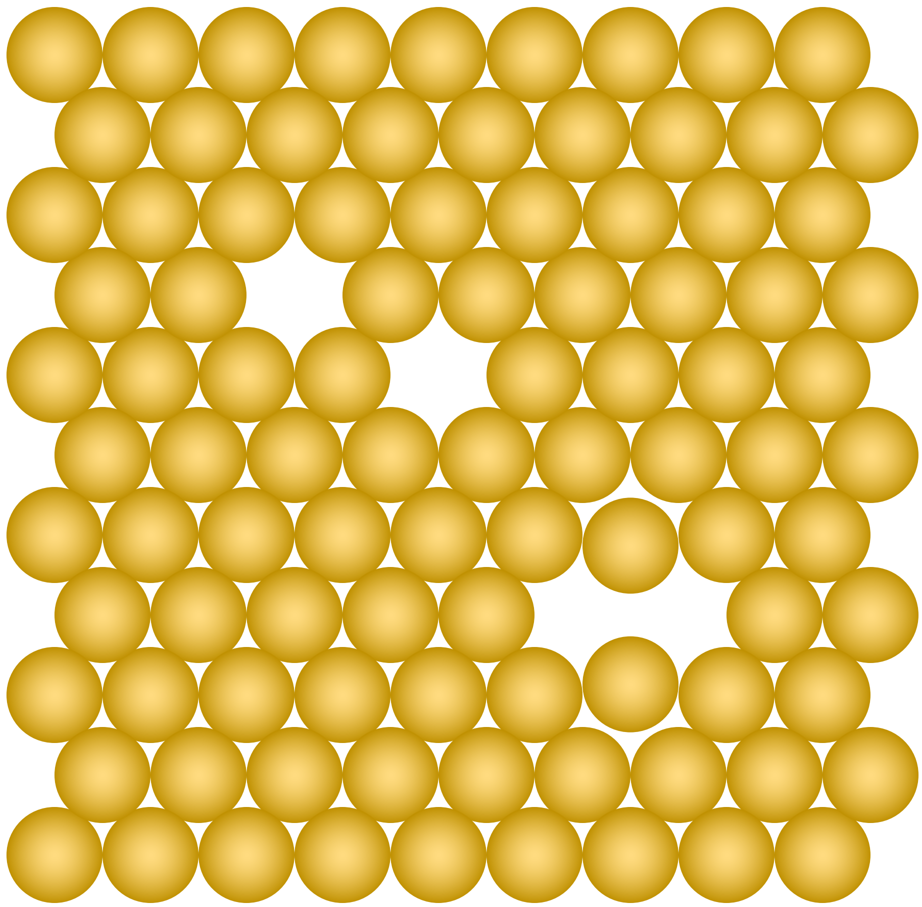
c. Specify a lattice and motif that defines this structure?

d. In a diffraction experiment with this structure as the sample, what are the indices of the first three diffraction peaks? Recall that for cubic structures,

$$d_{hkl} = \frac{a_0}{\sqrt{h^2 + k^2 + l^2}}$$

5. Crystalline Defects (20 points)

a. Refer to the following illustration of the atomic configuration in the (0002) planes of an HCP structure showing two vacancies in the upper left and a defect called a "divancy" in the lower right. It should be evident that a divacancy is simply a cluster of two vacancies. Explain, using this illustration, why divacancies are energetically favored over two isolated vacancies. In your answer, consider the energy associated with breaking atomic bonds.



b. The concentration of vacancies C_V in a solid is a strong function of temperature, obeying an Arrhenius expression,

$$C_V = A \exp\left(\frac{-E_V}{kT}\right)$$

where A is a constant, E_V is the vacancy formation energy, k is Boltzman's constant, and T is the absolute temperature. Explain why it is customary to plot ln C_V vs. $1/T$ when data is collected on vacancy concentration as a function of temperature. What insight does this provide?

c. Creep is defined as plastic deformation at high temperatures under constant load that occurs over a long period of time. Ceramics are normally used as high temperature materials due to their high melting point, but are also subject to creep, believed to be due to "grain-boundary sliding." Comment on the effect of grain size on creep deformation of ceramics. Is it more desirable to design creep-resistant ceramics with small grains or large grains, and why?

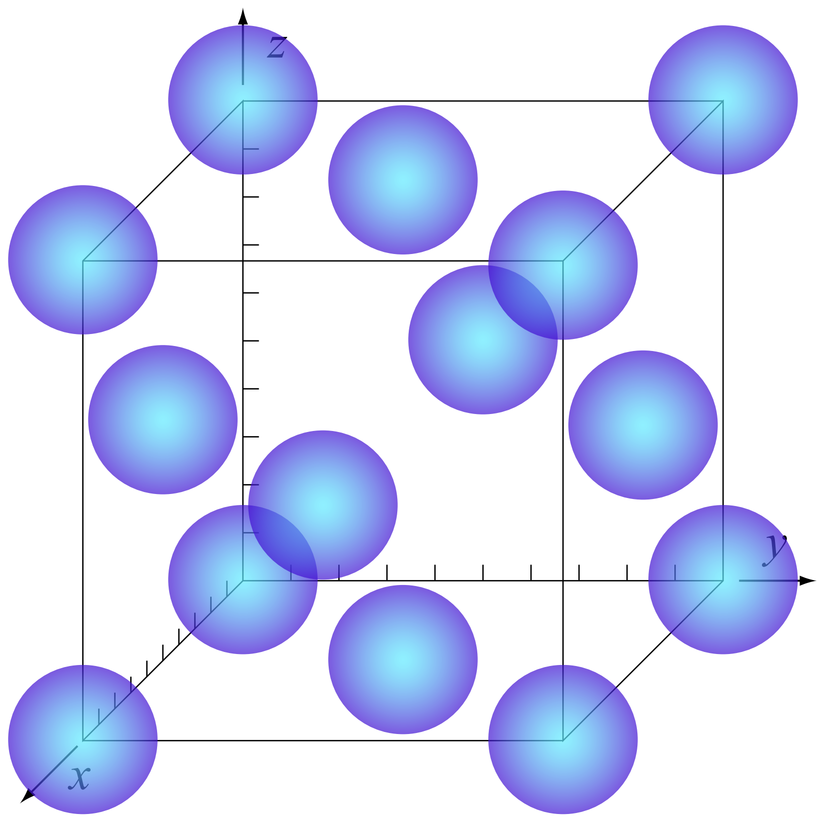
d. In an FCC crystal, active slip systems consist of close-packed {111} planes and the <011> directions in those planes. Following an electron microscopy investigation, it is discovered that a dislocation in a Ni-based superalloy (FCC) has a Burgers vector

$$\vec{b} = \frac{a}{2}[\bar{1}10]$$

and a line direction vector

$$\vec{\xi} = [\bar{1}\bar{1}2]$$

Is this an edge or screw dislocation?
What is its slip plane?



Worksheet

Problem	Possible	Score
1	20	
2	20	
3	20	
4	20	
5	20	
TOTAL	100	