Name ________________________________

MBSE Core Competency Exam

Wednesday, June 7, 2023
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.
- 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.
- You will find some potentially useful tables at the end of this document.

Good luck!

Question 1

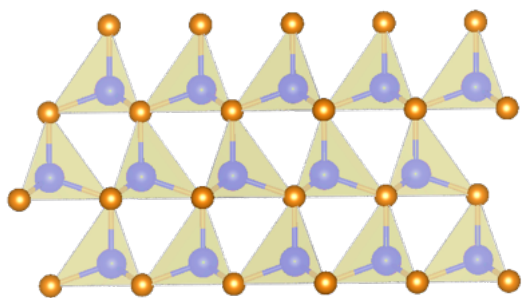
Structure, properties.

(a) Why does diamond have a Mohs hardness of 10, but graphite have a Mohs hardness of 1 despite their identical chemical composition (carbon)?

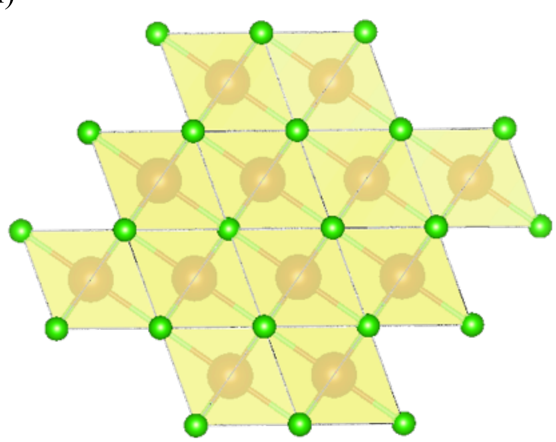
(b) Explain why a base-centered triclinic Bravais lattice does not exist. Sketch diagrams to aid your explanation.

(c) Identify the following crystal structures. State your reasoning for each identification. If you cannot remember the structural name, please describe connectivity, atomic arrangement, interstitial sites, and other details to the best of your ability to illustrate your reasoning. Most of the credit goes to the reasoning part.

(i)



(ii)



(d) TiO and ScN both adopt the rock salt structure. Explain why TiO is an electrical conductor, but ScN is an electrical insulator. Sketch the necessary diagrams to aid your explanation.

Question 2

Structure, thermodynamics, properties.

"The mechanical and electical properties of materials are dictated by defects — electronic, crystallographic, and microstructural."

Please construct a carefully reasoned argument in support of the above statement. Your answer should include careful descriptions of as many different defect types as possible, whether and how the presence of those defects can be controlled, and the impact of those defects on the stated properties.

Question 3

(a) ***Beta tin.***

Pure tin has multiple allotropes. White tin, also called β-tin, is the stable form of pure tin from 13 °C to 232 °C.

(i) Bulk β-tin has a melting temperature of 232 °C, while nanoparticles of β-tin melt at 177 °C. This difference is thermodynamic (as opposed to kinetic) in nature. Discuss possible reasons for the difference in melting temperatures.

(ii) Sketch qualitatively, taking care to represent noteworthy features, the Gibbs-free-energy curves $G(T)$ for the bulk-solid, nanoparticle, and liquid phases. Explain the reasoning you use to decide how to sketch the curves.

(iii) Can you determine from the information on your graph the difference between the melting enthalpies of the two solid phases? Explain.

(b) ***Thermoelectric effects.***

Describe and explain a thermoelectric effect, such as the Seebeck or Peltier effect.

Question 4

(a) ***Energy, structure, properties.***

A semiconductor LED, powered by a battery, is emitting red light. The LED (but not the battery) is immersed in liquid nitrogen, and the light becomes brighter and changes color to yellow.

Why do the brightness and color change as observed?

(b) ***Materials and biomaterials.***

The images on the following three pages are scans of pages from the book "*Science Fair Winners: Bug Science*", by Karen Romano Young, published by National Geographic Society, Washington. DC, 2009. The target audience is middle-school students and their teachers.

There are several glaring mistakes in the background information and the experimental design. Please identify as many of the mistakes as possible, describing what you perceive to be the errors, and suggesting appropriate corrections. (You do not need any background in biology to score 100% on this question, but bonus points are available for spotting misrepresentations of biological facts.)

workshop 18

STRONG AS SILK

(Test the strength of fibers)

the basics

WHAT MAKES A HIGH-PERFORMANCE FIBER? Scientists consider four factors: strength-to-weight ratio (how much they can hold relative to their weight), resistance to flame, resistance to chemicals, and tensile strength (their ability to hold against resistance, lift a weight, or withstand an impact).

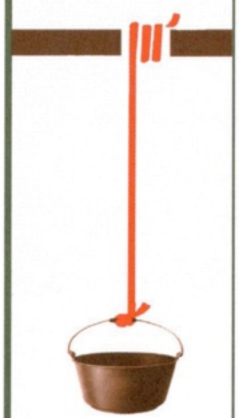
TIME NEEDED >
one day

SCIENCE >
biochemistry,
entomology,
textile engineering

SCIENCE CONCEPT >
fiber strength and weight

ADULT INVOLVEMENT>
none

workshop 18



the buzz

Scientists are using spider silk to create nanofibers—laboratory-made polymers that are extraordinarily strong. Although man-made fibers have taken over the toughest jobs—forming the basis of materials used in airbags for the *Mars Pathfinder*, parachutes for spaceships, racing sails for sailboats, bulletproof vests, even a triathlon bicycle—cell by cell silk made by spiders is still stronger than any man-made material.

the QUESTION >> How does the tensile strength of silk made by silkworms compare with that of other fibers?

the PLAN >> Compare the tensile strengths of different fibers, including silk, cotton, wool, and polyester.

the lingo

polymer—a natural or synthetic compound made up of small, simple molecules linked together in long chains of repeating units

you'll need

a method for testing tensile strength—One way is to use a machine called the Tensile Tester. Where would you find such a machine? Your school might have one in its lab, or a local scientific business might have one you could borrow, either by conducting your experiment in their lab or by bringing the Tensile Tester to your house or school.

You can also use:

a doorway or basement rafter
duct tape or screw-in steel eyelets
a small bucket—with a handle
sand
a scale—kitchen or laboratory
fibers—silk thread, cotton thread, polyester thread, wool yarn, raffia—anything you want to compare. Consider comparing natural and man-made fibers, as well as raw versus processed fibers (such as raw wool versus wool yarn).

what to do

1. **GET YOUR EMPTY BUCKET AND WEIGH IT.**

2. **CUT A 24-INCH STRAND OF EACH FIBER.** Attach the top three inches of the strand to the rafter or doorway and the bottom three inches to the handle of the bucket. To be accurate you have to attach each fiber in the same way to the top of the doorway or rafter. For example, if you knot or tape it, be sure to do it in the same way for each fiber.

3 ADD SAND TO THE BUCKET LITTLE BY LITTLE TO MAKE THE FIBER STRETCH. Measure how far each strand stretches before the fiber breaks. (It doesn't count if your knot or tape comes undone; the fiber must stretch to the breaking point.)

4 WHEN THE FIBER BREAKS, WEIGH THE BUCKET AND SAND. Subtract the weight of the bucket to get the weight of sand needed to break this fiber.

NOTE: *Your doorway or rafter experiment will result in a weight measurement. Measure this weight in grams; scientists use the metric system. The tensile strength you get from the Tensile Tester will use a standard of measurement called pascals.*

WORKSHOP RESOURCE >>

The Mooring and Rigging Group at Woods Hole Oceanographic Institution has a horizontal tensile machine to test every fiber it puts on its ships, submarines, and moorings.

To see it, type *Woods Hole tensile* into a search bar and look for www.whoi.edu.

> **"If we compare spider dragline silk to Kevlar, we find that the silk has lower strength and stiffness, but ten times greater toughness."**

—Christopher Viney, Paul Yager, and Kimberly Carlson, *from the project description for the Silk Protein Project conducted at the University of Washington in Seattle*

> Why would spider silk need to be stronger than, say, human hair?

CONSIDER THIS! PRESENT THIS!

> Show a video of fiber-making insects. Search the Internet for videos of insects spinning silk, webs, and cocoons.

> **GO THE EXTRA MILE!** Are you good at knitting, crocheting, braiding, or weaving? Compare the tensile strengths of multiple joined strands of the same fiber.

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 Elements

1 H 1.00794																	2 He 4.002602
3 Li 6.941	4 Be 9.012182											5 B 10.811	C 12.0107	7 N 14.00674	8 O 15.9994	9 F 18.9984032	10 Ne 20.1797
11 Na 22.989770	12 Mg 24.3050											13 Al 26.581538	14 Si 28.0855	15 P 30.973761	16 S 32.066	17 Cl 35.4527	18 Ar 39.948
19 K 39.0983	20 Ca 40.078	21 Sc 44.955910	22 Ti 47.867	23 V 50.9415	24 Cr 51.9961	25 Mn 54.938049	26 Fe 55.845	27 Co 58.933200	28 Ni 58.6534	29 Cu 63.545	30 Zn 65.39	31 Ga 69.723	32 Ge 72.61	33 As 74.92160	34 Se 78.96	35 Br 79.504	36 Kr 83.80
37 Rb 85.4678	38 Sr 87.62	39 Y 88.90585	40 Zr 91.224	41 Nb 92.90638	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.90550	46 Pd 106.42	47 Ag 196.56655	48 Cd 112.411	49 In 114.818	50 Sn 118.710	51 Sb 121.760	52 Te 127.60	53 I 126.90447	54 Xe 131.29
55 Cs 132.90545	56 Ba 137.327	57 La 138.9055	72 Hf 178.49	73 Ta 180.94.79	74 W 183.84	75 Re 186.207	76 Os 190.23	77 Ir 192.217	78 Pt 195.078	79 Au 196.56655	80 Hg 200.59	81 Tl 204.3833	82 Pb 207.2	83 Bi 208.58038	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra (226)	89 Ac (227)	104 Rf (261)	105 Db (262)	106 Sg (263)	107 Bh (262)	108 Hs (265)	109 Mt (266)	110 (269)	111 (272)	112 (277)		114 (289) (287)		116 (289)		118 (293)

58 Ce 140.116	59 Pr 140.50765	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.964	64 Gd 157.25	65 Tb 158.92534	66 Dy 162.50	67 Ho 164.93032	68 Er 167.26	69 Tm 168.93421	70 Yb 173.04	71 Lu 174.967
90 Th 232.0381	91 Pa 231.035888	92 U 238.0289	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)	103 Lr (262)