2017 Battle Of Valley Forge

Material Science Exam

School Name: ____________________________ Team Number: ______

Participant 1: __________________________

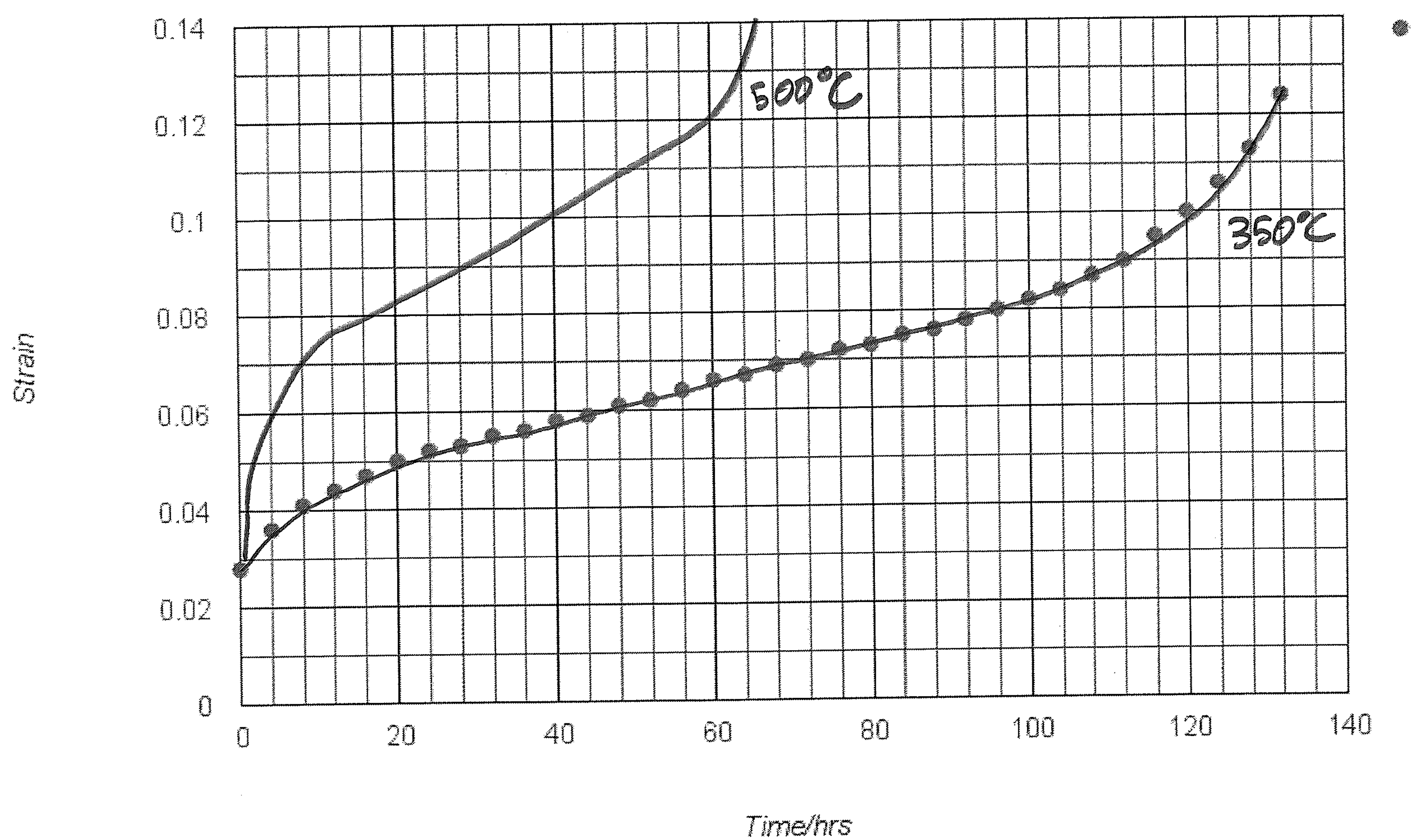
Participant 2: __________________________

This exam is organized into three parts.

I.	Mechanical Properties of Materials	30 pts
II.	Polymers	30 pts
III.	Crystal Structures	30 pts

- Each part is worth the same amount of points. You may complete them in any order.
- Ties will be won by the team with the highest score on a single part of the exam.
- If at any time you have questions during the exam, please raise your hand immediately.

Strain vs Time



Part I: Mechanical Properties of Materials

A. Creep Testing

An engineer performs a creep test by subjecting a 2.00m strand of copper wire to a constant load (L) at T=350°C over a period of 132 hours until failure. Strain vs. time data was as follows.

Time (hrs)	Strain
0	0.028
4	0.036
8	0.041
12	0.044
16	0.047
20	0.050
24	0.052
28	0.053
32	0.055
36	0.056
40	0.058
44	0.059
48	0.061
52	0.062
56	0.064
60	0.066
64	0.067

Time (hrs)	Strain
68	0.069
72	0.070
76	0.072
80	0.073
84	0.075
88	0.076
92	0.078
96	0.080
100	0.082
104	0.084
108	0.087
112	0.090
116	0.095
120	0.100
124	0.106
128	0.113
132	0.124
	Failure

1. Plot the data on the graph provided. (5pts)

2. Indicate the areas on the graph that represent primary, secondary, and tertiary creep. (1 pt)

3. Determine the minimum creep rate for this material. Show work. (2 pts)

$$\frac{0.073 - 0.058}{80\ hr - 40\ hr} = 3.75 \times 10^{-4}\ hr^{-1}$$

4. If the melting point of copper is 1085°C, what is the minimum temperature (in °C) that you would expect to observe creep in copper? (1 pt)

1085°C → 1328 K $0.4(1328\ K) = 531.2k \rightarrow 258°C$

(continued on next page)

5. Determine the length of the wire at failure. Show work. (2 pts)

$\frac{\Delta l}{l_0} = 0.124$ $\Delta l = (2.00m)(0.124) = 0.248m$

$l = 2.25m$

6. How does the creep rate change during stage I (primary creep)? What is the main reason for this? (2 pts)

It decreases due to work hardening or an increase in the number of dislocations.

7. Draw a new curve on the same graph that represents the creep curve of the same material but at 500°C rather than 350°C. (2 pts)

See graph

B. Other Mechanical Properties Questions

8. A piece of copper originally at 305mm long is pulled in tension with a stress of 276 MPa. If the deformation is entirely elastic, what will be the resultant elongation? (Young's modulus for copper is 110. GPa) (3 pts)

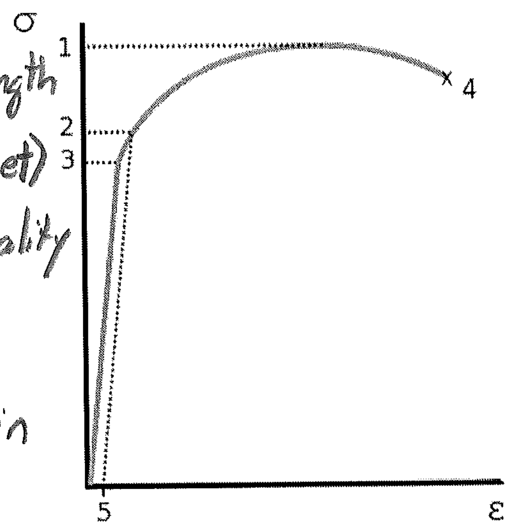
$$\sigma = \varepsilon E = \left(\frac{\Delta l}{l_0}\right) E$$

$$\Delta l = \frac{\sigma l_0}{E} = \frac{(276\ MPa)(305mm)}{110. \times 10^3 MPa} = 0.77mm$$

9. What will be the length of the above wire when the stress is removed? (1 pt)

305mm (no plastic deformation)

10. On the stress/strain diagram below, correctly label points 1-5. (5 pts)



1 - Ultimate tensile strength

2 - yield strength (offset)

3 - Limit of Proportionality

4 - Failure

5 - 0.02 offset strain

11. The diagram below shows the stress/strain curves of three different materials to fracture. One is a metal, one is a polymer, and one is a ceramic.

a. Assign the correct material to each curve. (3 pts)

b. Which is the strongest? (1 pt)

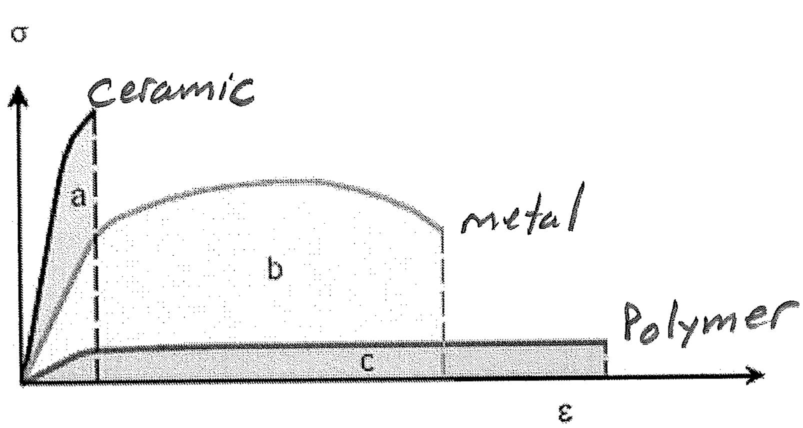
Ceramic

c. Which is the most ductile? (1 pt)

Polymer

d. Which has the most material toughness? (1pt)

metal



Part 2: Polymers

A. Making Putty

Procedure:

- Wear gloves.
- Pour 20 ml of the Elmer's glue solution into a plastic cup.
- Add 10 ml of the cross-linker (borax solution).
- Immediately begin stirring the solutions together using the wooden stick.
- After a couple of minutes of mixing, the putty should be taken out of the cup and kneaded in the hands. Don't worry about the material sticking to your gloves as these pieces will soon mix with the larger quantity with which you are working. Continue to knead until the material is no longer watery and can keep its shape when formed into a ball.
- The putty is non-toxic and safe to handle so you can put it in a zip-lock bag and take it home.

Questions

1. What happens to the properties of the product after it is immersed (in the Ziploc bag) into ice water for 60 sec? Why? (2 pts)

   more solid, harder
   $T < T_g$ (glass transition temp.)

2. What happens to the properties of the product after it is immersed (in the Ziploc bag) into hot water for 60 sec? Why? (2 pts)

   more liquid, runny
   $T > T_g$

3. What happens when a balled up sample of the product is dropped onto the ground from shoulder height? (1 pt)

   Bounces

4. What happens when a balled up sample of the product is allowed to sit on the table for 30 sec? (1 pt)

   Flattens, spreads out

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5. What happens when a sample of the product is pulled apart slowly? (1 pt)

Stretches / Does not break

6. What happens when a sample of the product is pulled apart quickly? (1 pt)

Breaks immediately

7. Describe the difference between a Newtonian fluid and a non-Newtonian fluid. Which one is this? Use observations to support your answer. (6 pts)

A Newtonian fluid's viscosity is only dependent on T, whereas a non-Newtonian fluid's viscosity is dependent on both T and force applied.

T changes viscosity (steps 1, 2)

Force changes viscosity (steps 3-6)

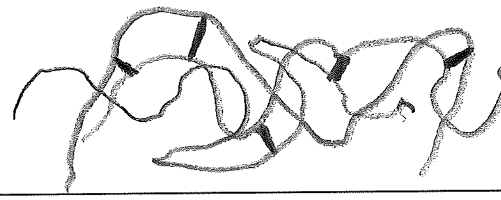
So this is non-Newtonian.

B. Balloon

Rubber balloons are most usually made of vulcanized latex polymers.

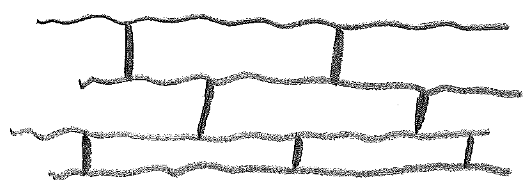
8. Draw a picture of the molecular structure of relaxed balloon rubber. (No atomic detail is necessary. Just lines and labels as necessary. Underneath your drawing, write 1-2 sentences describing the important factors that your drawing is trying to depict.) (3 pts)

- coiled, overlapping polymer chains
- crosslinking
- description



9. Draw a second picture of balloon rubber which has been stretched out to 2-3 times its original length. (No atomic detail is necessary. Just lines and labels as necessary. Underneath your drawing, write 1-2 sentences describing the important factors that your drawing is trying to depict.) (3 pts)

- straighter polymer chains
- crosslinking
- description



10. Hold one end of a relaxed balloon in each hand a few inches in front of your nose. Quickly(!) stretch the balloon as far as you can and then touch the balloon to your forehead or cheek. Record your observations here. (1 pt)

It gets warm.

11. Hold one end of a fully stretched balloon in each hand a few inches in front of your nose. Quickly(!) relax the balloon and then touch it to your forehead or cheek. Record your observations here. (1 pt)

It gets cold.

(continued on the next page)

12. Inflate the balloon until it is about the size of a cantaloupe. Tie off the end of the balloon. (Ask for help if you need it.) Use your fingers to place a thin film of petroleum jelly onto a skewer. With a twisting motion, pierce the balloon with the skewer near the knot. Pass the skewer all the way through the balloon until it exits opposite to the knot. Record your observations here. (1 pt)

Skewer does not pop the balloon. Balloon remains inflated

13. If you tried to pass a second skewer through the balloon at a right angle to the first one, what would you expect to happen? (1 pt)

It would pop.

14. With reference to your two drawings, explain the three phenomena you just observed (steps 10, 11, and 12) in terms of the structure of polymers. (6 pts)

- Polymer chains are higher in entropy when relaxed (coiled) and lower in entropy when stretched.
- $\Delta S = \frac{q_{rev}}{T} > 0$ so when ΔS is positive (relaxing) q must also be > 0 (endothermic) so the polymer will absorb heat (get cold) as it relaxes.
- In areas of the balloon which are not stretched much, there is less force pulling on the crosslinks and more crosslinks per unit area. The skewer can break some crosslinks and push some polymer chains aside without the balloon ripping apart.
- This would not be the case on the side of the balloon where there are fewer chains and crosslinks which are already under greater stress.

Part III: Crystal Structures

A. Metallic Crystal Lattices

1. The metal manganese has a simple cubic structure. If the manganese atom has a radius of 0.112nm, what is the volume of a unit cell of Manganese? Show work. (2 pts)

$a = 2r = 0.224\,nm$ or $2.24 \times 10^{-8}\,cm$

$V = a^3 = 1.12 \times 10^{-23}\,cm^3$

How many atoms are there in a unit cell of Manganese? (1 pt)

1

What is the volume of Manganese atoms contained in a unit cell? Show work. (2 pts)

$V = \frac{4}{3}\pi r^3 = 5.88 \times 10^{-24}\,cm^3 \times 1 =$

$r = 1.12 \times 10^{-8}\,cm$

$5.88 \times 10^{-24}\,cm^3$

What is the packing efficiency of the Manganese crystal lattice? Show work. (2 pts)

$\frac{5.88 \times 10^{-24}\,cm^3}{1.12 \times 10^{-23}\,cm^3} \times 100 = 52.5\%$

0.525 okay

2. At 1042°C metal X undergoes a change from a BCC to a FCC arrangement. The density of a metallic solid can be given by

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

where

n = number of atoms associated with each unit cell

A = molar mass

V_c = volume of the unit cell

N_A = Avogadro's number 6.023×10^{23}

a. If the density of X at room temperature is 9.57 g/cm³ and it's molar mass is 155.62 g/mol (completely fictitious) determine the atomic radius of X. Only answers with all supporting work will be accepted. (5 pts)

$$9.57 \ \mathrm{g/cm^3} = \frac{(2 \text{ atoms})(155.62 \ \mathrm{g/mol})}{V\,(6.023 \times 10^{23} \ \mathrm{atoms/mol})}$$

$$V = 5.40 \times 10^{-23} \ \mathrm{cm^3} = a^3$$

$$a = 3.78 \times 10^{-8} \ \mathrm{cm}$$

$$\frac{\sqrt{3} \cdot a}{4} = r = 1.64 \times 10^{-8} \ \mathrm{cm}$$

b. Using the radius of X that you calculated above (and assuming it remains constant), calculate the new density of X at 1042°C. (3 pts)

$$r = 1.64 \times 10^{-8} \ \mathrm{cm}$$

$$a = \frac{4r}{\sqrt{2}} = 4.63 \times 10^{-8} \ \mathrm{cm}$$

$$V = a^3 = 9.92 \times 10^{-23} \ \mathrm{cm^3}$$

$$\rho = \frac{(4 \text{ atoms})(155.62 \ \mathrm{g/mol})}{(9.92 \times 10^{-23} \ \mathrm{cm^3})(6.023 \times 10^{23} \ \mathrm{atoms/mol})}$$

$$\rho = 10.4 \ \mathrm{g/cm^3}$$

B. Ionic Crystal Lattices

Ionic crystal lattices can most often be thought of as either simple cubic or face centered cubic arrays of anions with cations occupying either some or all of the cubic, tetrahedral, or octahedral holes within them. This is governed not only by the stoichiometric ratio of cations to anions but also by the "radius ratio rule" whereby the radii of the cations (r+) and anions (r-) are compared using the following table.

If r+/r- is...	then the anions are arranged in...	and the cations occupy...
x>0.732	SC	Cubic holes
0.732>x>0.414	FCC	Octahedral holes
0.414>x>0.235	FCC	Tetrahedral holes

3. Using the ionic radius data given, determine which of the following situations (A-H) apply for each of the ionic crystals listed below. Answer choices may be used more than once. (10 pts)

A. SC anions with all of the cubic holes occupied by cations
B. SC anions with 1/2 of the cubic holes occupied by cations

C. FCC anions with all of the octahedral holes occupied by cations
D. FCC anions with 1/2 of the octahedral holes occupied by cations
E. FCC anions with 1/4 of the octahedral holes occupied by cations

F. FCC anions with all of the tetrahedral holes occupied by cations
G. FCC anions with 1/2 of the tetrahedral holes occupied by cations
H. FCC anions with 1/4 of the tetrahedral holes occupied by cations

Ionic Crystals

a) NaCl C
b) Li_2S F
c) BaO A
d) LiBr G (*)
e) $CdCl_2$ D

4. Modeling an ionic crystal lattice (5 pts)

- Using the Styrofoam balls (bromides) and blue bead(s) (lithium ions) provided, make a unit cell model of the ionic crystal LiBr.
- Attach the Styrofoam balls together with the toothpicks (careful they're sharp!) and place the blue bead(s) in the appropriate position(s).
- Under no circumstances can you alter any of the Styrofoam balls other than by sticking toothpicks through them. It is okay that some parts of some of your balls might fall outside of the unit cell.
- When you are done, write your school name and team number on the "flag" and bring your model to the front of the room for grading.

School Name: ______________________ Team Number: _____

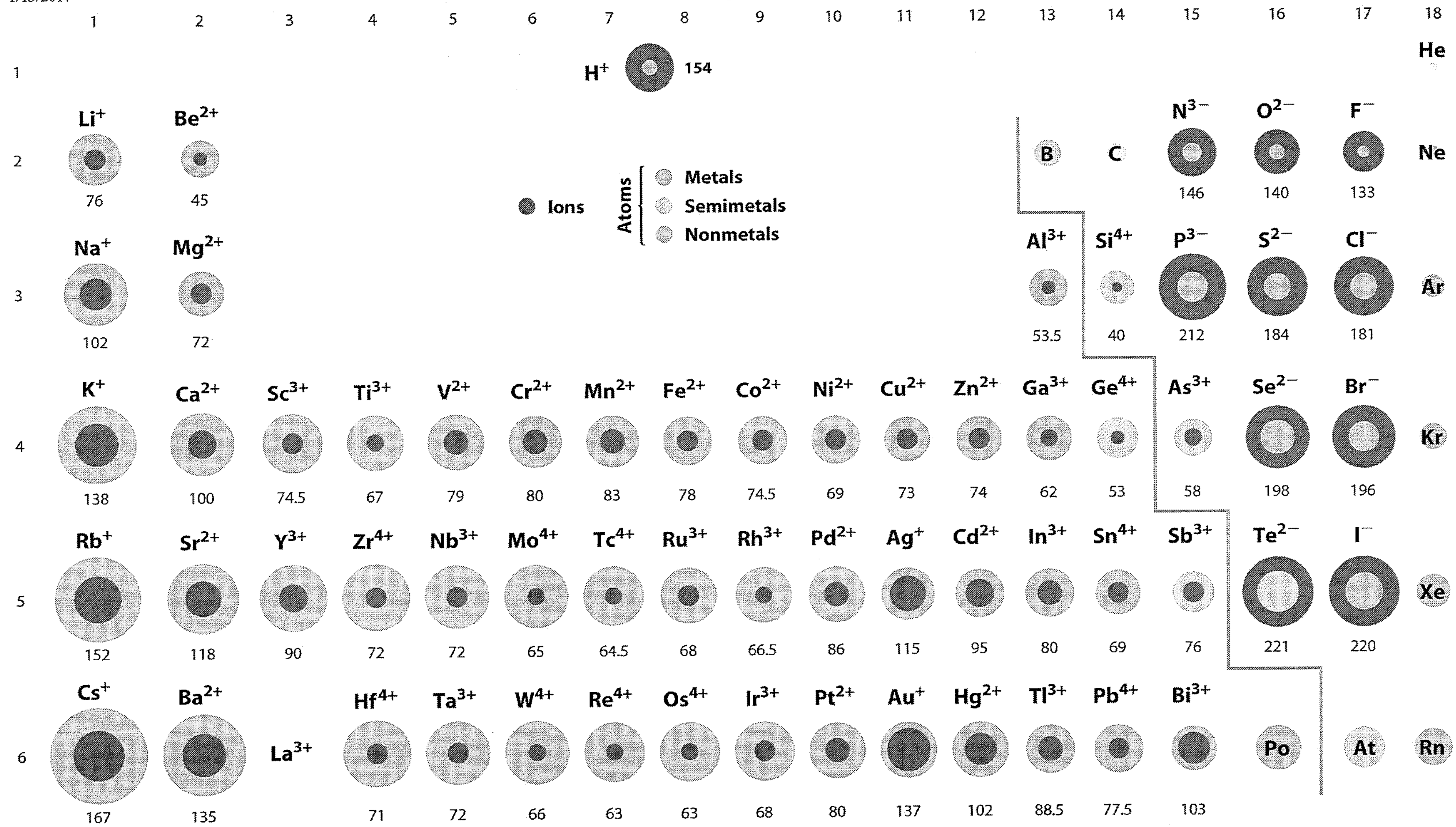
LiBr Crystal Structure Rubric

_____ _____ Styrofoam balls in FCC configuration

_____ Correct ratio of cations/anions 1:1

_____ Cations in tetrahedral holes only

_____ Cations in tetrahedral arrangement


1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
1 H+ 154 He
2 Li+ 76 Be2+ 45 B C N3− 146 O2− 140 F− 133 Ne
Ions
Atoms
Metals
Semimetals
Nonmetals
3 Na+ 102 Mg2+ 72 Al3+ 53.5 Si4+ 40 P3− 212 S2− 184 Cl− 181 Ar
4 K+ 138 Ca2+ 100 Sc3+ 74.5 Ti3+ 67 V2+ 79 Cr2+ 80 Mn2+ 83 Fe2+ 78 Co2+ 74.5 Ni2+ 69 Cu2+ 73 Zn2+ 74 Ga3+ 62 Ge4+ 53 As3+ 58 Se2− 198 Br− 196 Kr
5 Rb+ 152 Sr2+ 118 Y3+ 90 Zr4+ 72 Nb3+ 72 Mo4+ 65 Tc4+ 64.5 Ru3+ 68 Rh3+ 66.5 Pd2+ 86 Ag+ 115 Cd2+ 95 In3+ 80 Sn4+ 69 Sb3+ 76 Te2− 221 I− 220 Xe
6 Cs+ 167 Ba2+ 135 La3+ Hf4+ 71 Ta3+ 72 W4+ 66 Re4+ 63 Os4+ 63 Ir3+ 68 Pt2+ 80 Au+ 137 Hg2+ 102 Tl3+ 88.5 Pb4+ 77.5 Bi3+ 103 Po At Rn