**Homework #2: Assigned on 9/17, Due on 9/27 before class.**

*(Use lecture slides as well as assigned readings (Ratner, Callister, and Black) to answer the questions)*

1. **(30 points)** Please review lecture slides and supplemental reading from chapters 4 and 7.8 of the *Biomaterials Science* text by Ratner et al. Using your own words, answer the following questions *as concisely as possible.*
   1. What is the purpose and sequence of inflammation? Be concise!

**6 pts total**

**(2 pts) Purpose: contain and neutralize the injury (initialize healing)**

**(4 pts 🡪 +2 pts for all steps included, +2 pts for correct order) Sequence:**

1. **activation of coagulation factors,**
2. **increased blood flow,**
3. **infiltration of immune cells,**
4. **leads to chronic inflammation and wound healing (remodeling)**

**Acute Inflammation 🡪 Chronic Inflammation 🡪 Granulation/Tissue Remodeling**

If give above answer simplified without details included instead just give 3 points

* 1. What are fibrous capsules and how may they contribute to atrophy around an implant?

**6 points total**

**(3 pts)** Fibrous capsules are acellular, collagen-dense capsules that “wall off” (isolate) foreign bodies

**(2 pts)** They limit blood supply/nutrition

* 1. Why are implants often hosts for infection?

**6 points total**

Foreign body, bacterial adhesion, surgery = intrinsic risks for introducing infection, fibrous capsules block immune cell access to infection

**4 examples mentioned: Full credit (6 pts)**

**3 examples: 5 pts**

**2 examples: 4 pts**

**1 examples: 3 pts**

* 1. What are cytokines and what are their most prominent activities?

**6 points total**

**(3 pts)** Description of cytokines & role in the immune system response

**(3 pts)** Provides examples of cells that release cytokines and their functions (Macrophages – initiate inflammatory immune response, neutrophils – IL-8 to attract more neutrophils, cytokines are also released by epithelial cells that lead to vasodilation, cytokines released by T-helper cells, etc.)

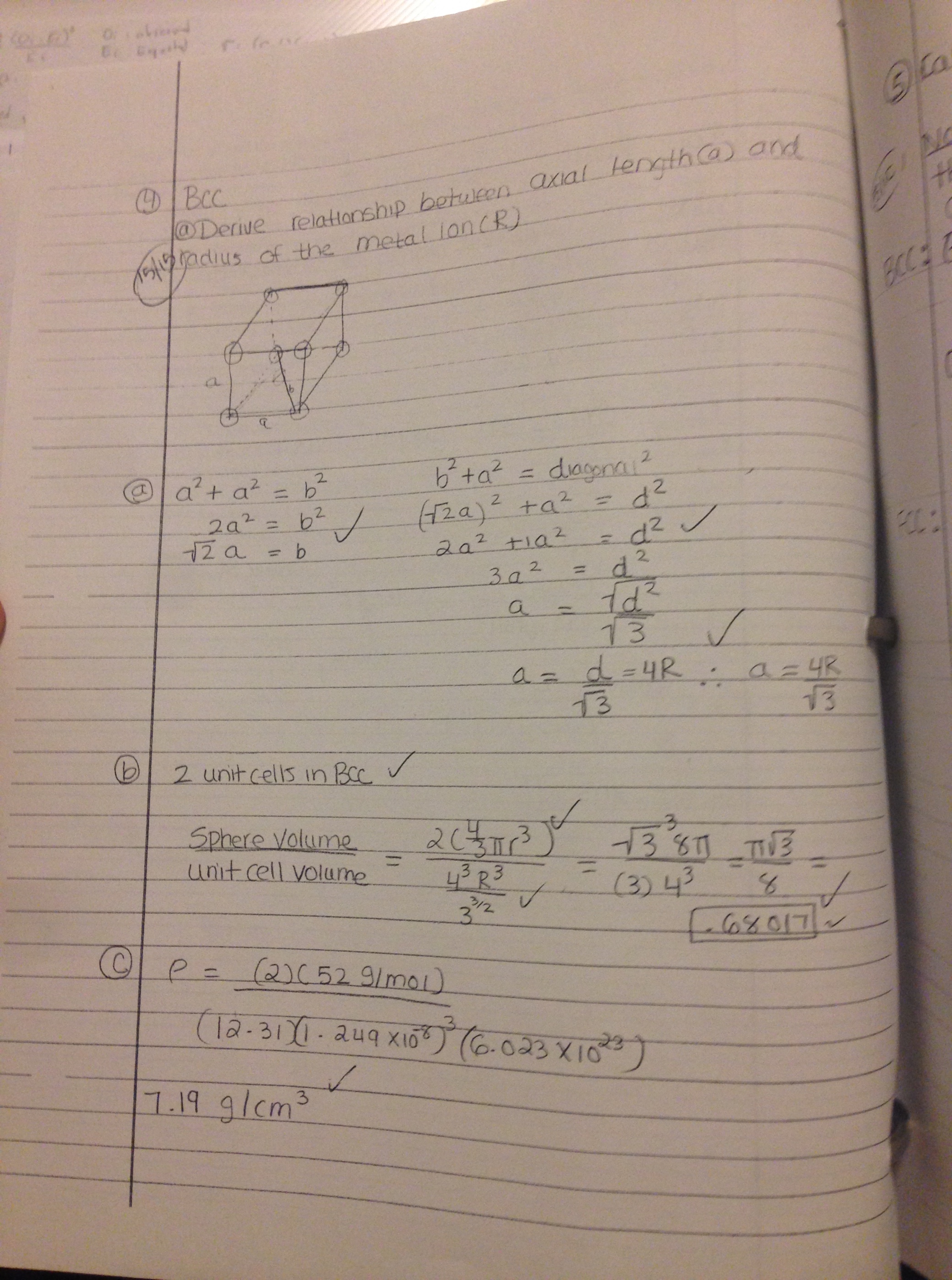
* 1. What is the purpose of blood coagulation, and how may this be problematic in the context of blood-materials interactions?

**6 points total**

**(3 pts)** Forms fibrin clot to prevent blood loss and localize inflammatory response

**(3 pts)** Exaggerated immune response, thrombosis/embolism, improper mechanical fixation and function of the implant

1. **(25 points)** Assume that a metal with a BCC structure has atom contact along the body diagonal.
2. Derive the relationship between the axial length (a) and the radius of the metal ion (R)

**5 points total**

**(3 pts)** Correct formulas

**(2 pts)** Correct final relationship

Let *a* be the axial length and let *b* be the distance of the diagonal of a face. Then from the Pythagorean theorem:

The body diagonal, *d*, is equal to 4R:

Define *d* using the Pythagorean theorem:

Substituting *b* and *d*:

1. Show that the atomic packing factor of a BCC metal is 0.68

**10 points total**

**(7 pts)** Correct formulas

**(3 pts)** Correct numbers

Let VA be the volume of atoms in a unit cell and VU be the volume of the unit cell.

First, find the number of atoms in a unit cell. Since it is a BCC structure:

Take the volume of 1 atom to be the volume of a sphere (4/3πr3). Thus, the volume of 2 atoms (assuming radius of unit cell is the radius of an atom R) is:

From part a, we know the relationship between *a* and *R*. Substituting in:

VU is simply the volume of a cube with sides of length *a*:

Thus:

1. Calculate the density for Chromium, a BCC metal with an *ionic* radius of 0.063 nm.

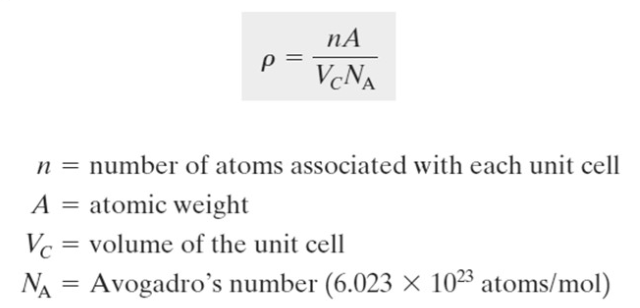
**10 points total**

**(5 pts)** Correct formulas

**(5 pts)** Correct numbers

**(-2 pts)** Using ionic radius instead of atomic radius

Recall formula for theoretical density:



Since Chromium is a BCC metal, **n=2**.

Look up the atomic weight: **ACr=51.9 g/mol**.

Avogadro’s number **NA = 6.023\*1023 atoms/mol**

Calculate the volume of the unit cell:

In this formula, R = atomic radius, not ionic radius! **(Take 2 pts off for using ionic radius**)

Look up the atomic radius of chromium: RCr=128pm=1.28\*10-10 m

Thus:

Plugging everything into the equation:

**Note:** if students used ionic radius instead, they should have the following calculations:

1. **(25 points)** Stainless steel is one of the most common types of material used inside and outside of the body**.**
2. What is the elemental composition of AISI 316L?

**7 points total**

**(1 pt)** Mention any trace element

**(6 pts)** 1 ptfor each non-trace element mentioned

60-65% Fe, 17-20% Cr, 12-14% Ni, 2-3% Mo, 2% Mg, <0.03% C

Trace elements: Cu, N, P, Si, S, Mn

1. Explain the function of the major alloying elements: Cr, Ni and Mo

**6 points total**

**(2 pts)** Cr – forms passivation oxide layer, Cr2O3, which helps to **prevent corrosion** (also stabilizes BCC form of SSL – α ferrite)

**(2 pts)** Ni – **increases corrosion resistance** (also stabilizes FCC form of SSL – γ austenite)

**(2 pts)** Mo – **prevents pitting corrosion**, especially in Cl- containing solutions(also stabilizes BCC form)

1. Calculate the %cold work (%change in area) of a stainless steel rod with an initial diameter of 0.07 m and a length of 0.18 m. The final diameter of the rod was 0.05 m and the cold worked length was 0.30 m.

**6 points total**

**(3 pts)** Correct formula

**(3 pts)** Correct numbers

1. What other treatment is needed after cold work to relieve internal stresses?

**6 points total**

Annealing (Recovery, Recrystallization, and Grain Growth)

|  |  |
| --- | --- |
| **Stress (MPa)** | **Strain (%)** |
| 98  150  260  300  450  600  680  780  840  850  855  710  Failure | 0.06  0.10  0.17  0.20  0.30  0.40  0.50  0.60  0.70  0.80  0.90  1.00 |

1. **(20 points)** The following tensile testing data was obtained for an unknown specimen:
2. Plot the stress-strain curve, and clearly label the elastic and plastic deformation regions.

**5 points total**

**(1 pt)** Correct slope

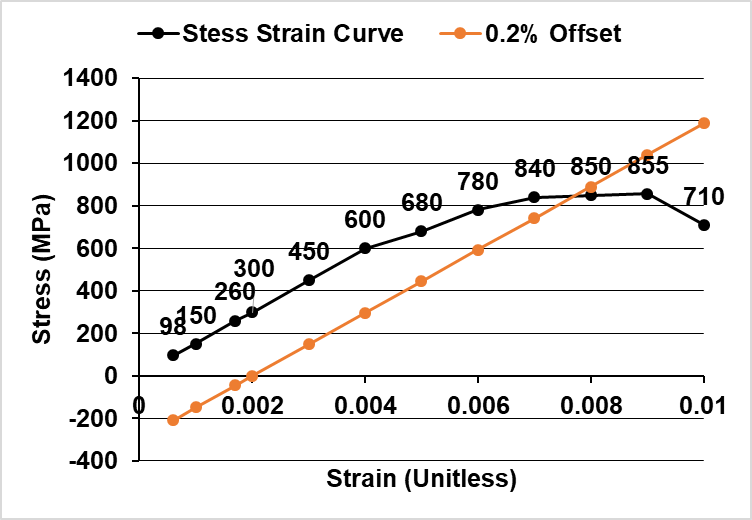
**(1 pt)** Correct intercept

**(1 pt)** Plotted correctly

**(1 pt)** Elastic region marked

**(1 pt)** Plastic deformation region marked

Note: mark if plot has incorrect units for strain (should be unitless), but don’t deduct points unless the values are wrong.



**Elastic**

**Plastic**

1. Determine the modulus of elasticity, yield strength, ultimate tensile strength, fracture strength, and ductility.

**10 points total**

**(2 pts) Modulus of Elasticity** (slope of linear region of stress-strain curve): **148.34 GPa**

Defined elastic region up to the point (0.40, 600), plastic region after

In Excel, found slope and intercept of the linear region to get y = mx + b

y = 148338.5 x + 5.572703

**(2 pts) Yield Strength** (intersection of stress-strain curve with 0.2% offset): **~847 MPa (845-850)**

0.2% offset is the line with the same slope which passes through (0.002, 0). Slope is 148338.5.

(y-y1)=148338.5(x-x1)

y=148338.5x-148338.5(0.002)+0

Therefore, the equation for 0.2% offset is y = 148338.5 x – 296.677

Plug the strain values from the table above into the offset equation and plot the resulting stress. Estimate the point of intersection from the graph.

**(2 pts) Ultimate Tensile Strength** (max on stress-strain curve): **855 MPa**

**(2 pts) Fracture Strength** (stress at which failure occurs): **710 MPa**

**(2 pts) Ductility** (strain at which failure occurs): **1%**

**-1 pt for wrong unit**

1. From your answers to parts a and b, decide whether this sample is likely based on a metal, ceramic or polymer. Justify your choice.

**5 points total**

**(3 pts)** Correct answer

**(2 pts)** Correct justification

Metal: Ductile with elastic AND plastic deformation (so it is not a ceramic), but high stress values (so it is not a polymer)

5. **(50 points)** Compare and contrast the following biomaterials in terms of 1) composition, 2) mechanical properties (E, yield strength, ductility, fracture toughness), and 3) biocompatibility. To do this, make a comparison table and be concise.

1. Ti-6Al-4V
2. Hydroxyapatite
3. Ultra high molecular weight polyethylene (UHMWPE)

**Answers (give credit for similar, or variants with explanations/sources cited):**

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Ti-6Al-4V** | **Hydroxyapatite** | **UHMWPE** |
| **Composition**  **(10 pts, 4 for alloy and, 2 for HA, 2 for UHMWPE, 2 for 45S5 bioactive glass)** | 88.3-90.8% Ti  5.5-6.5% Al  3.5-4.5% V  Trace:  0.05% N  0.08% C  0.13% O  (slides) | Ca10(PO4)6(OH)2  Nano-scale hexagonal platelets  Ca/P = 1.67  E  Not required, but correct:  Trace Elements (PPM):  Al 600  Cu 1  Fe 1000  Ge 100  Mg 2000  Mn 300  Na 3000  Pb 4  Si 500  Ti 30 | 1024px-Polyethylene_repeat_unit  With n>100,000  MW = 4 \* 106 g/mol  **(0.5 pt for structure, 1.5 pt for n OR molecular weight)** |
| **E**  **(8 pts, 2 per material)** | 110 GPa (slides)  116 GPa (Ratner) | 40-120 GPa  (9.2 GPa at body temp) | 0.69 GPa (Callister)  0.5-1.3 GPa (Ratner) |
| **Yield Strength**  **(8 pts, 2 per material)** | 877 MPa (Callister)  897-1034 MPa (Ratner) | Estimate with ultimate tensile strength  🡪 40-100 MPa | 21.4-27.6 MPa (Callister)  20-30 (Ratner) |
| **Ductility**  **(8 pts, 2 per material)** | 14% EL in 50 mm (Callister)  8% (Ratner) | 2-4%  0.2% or very low | 350-525% (Callister)  130-500% (Ratner) |
| **Fracture Toughness (8 pts, 2 per material)** | 100 MPa\*sqrt(m) | 1 MPa\*sqrt(m) | 1.72-5.16 MPa\*sqrt(m) |
| **Biocompatibility**  **(8 pts, 2 per material)** | Excellent for direct contact with tissue/bone, but can have poor surface wear properties if not treated (oxidized) or if in contact with another metal | Excellent for osteoinductive applications, but can lead to excessive exudate and accumulation of trace elements due to ceramic degradation | Biocompatible in joint surface applications, such as the lining of the acetabular cup, where UHMWPE can contact metals 🡪 Possible wear damage, inflammatory degradation products |

**Note: Ti-6Al-4V mechanical properties vary with heat treatment, and HA mechanical properties vary depending on formation temperature and porosity**