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INSTRUCTOR'S SOLUTIONS MANUAL

BIOMATERIALS: THE INTERSECTION OF BIOLOGY AND MATERIALS SCIENCE

SECOND EDITION

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Biomaterials: The Intersection of Biology and Materials Science, 2nd ed.

Temenoff and Mikos

End of Chapter Problems Solutions Manual

(Note that only the text of the problems and solutions have been included in this solutions manual. For figures associated with particular problems, please see the appropriate chapter in the textbook.)

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Chapter 1

1.1 An artery is a flexible blood vessel that withstands various pressures regulates the flow of blood. A common application of biomaterials is in the fabrication of a vascular stent to prevent re-closure of arteries after angioplasty (removal of plaques that impede blood flow). In many of these products, metals are used and formed into a "chain link" type architecture.

(a) What specific bulk and surface material properties would be required for this application?

A variety of answers are acceptable as long as properly justified, particularly relating to the idea of flexibility (bulk mechanical property) and how the device interacts with blood (surface physical or chemical properties).

(b) Explain why this material type and architecture were chosen in terms of the properties you have listed above.

A variety of answers are acceptable as long as properly justified. An example: Metals can be easily formed into complex shapes like that shown here. The chain-link architecture allows for expansibility of the material without fracture, while providing sufficient strength to push against the side of the blood vessel.

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1.2 A current area of biomaterials research is in developing a tissue engineered bone replacement to be placed in large bone defects. In general, this approach involves seeding bone cells on a scaffolding material with the idea that this entire construct would be implanted into the site of injury to replace lost bone.

(a) Would a natural or synthetic material be best for the scaffold? Justify your answer in terms of the expected response of the body to your construct and why this material class may be better for this application.

Either natural or synthetic materials could be acceptable answers, as long as justified using concepts in 1.4.4.

(b) What FDA regulatory pathway would likely be involved in approval of this product?

This would likely be a combination product (device + biologic), so its main mechanism of action would have to be determined by the FDA and then that Center would take the lead in the regulatory process, with the other taking a secondary role.

1.3 Whether or not the biological response to a material is acceptable depends on the specific application (see definition of biocompatibility, Section 1.1). Assume a new material shows activation of the immune system *in vivo*. Discuss whether or not this result would be acceptable for the following applications and explain your reasoning:

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Variety of answers acceptable if well-justified. Most logical answers are found below.

(a) Stem of hip implant

Unacceptable since this could lead to long-term "rejection" of an implant that is designed to be permanently integrated into the body.

(b) Tissue engineered vascular graft

Unacceptable since this could lead to long-term "rejection" of an implant that is designed to be permanently integrated into the body.

(c) Carrier for vaccine delivery

Acceptable since a heightened immune response is desired overall - this could aid in making vaccine delivery more effective.

(d) Coating for implanted electrode

Unacceptable since this could lead to long-term "rejection" of an implant that is designed to be permanently integrated into the body. In addition, cellular response could reduce the ability of the electrode to transmit electrical signal to the surrounding tissue.

(e) Nanoparticle for cancer therapy

May be acceptable since a heightened immune response is one way to jump-start the body's defenses against cancer cells.

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1.4 Fluorine (F) is more electronegative than oxygen (O).

(a) If you replace O with F in a compound, which of the three major classes of primary bonds would it affect the most? Explain why you chose this class.

This would affect ionic bonding the most since ionic bonds occur only when atoms have large differences in electronegativity. Adding F would cause stronger bonding in many cases since it is more electronegative and thus there would be a larger attractive force with electropositive elements.

Another acceptable would be that this would affect covalent bonds, since electronegative elements are also found in covalent bonding. Adding F would cause more electron withdrawing from the elements it is bonded to, which would affect the attraction force, and also the polarity of the bond (see below).

(b) How would this replacement affect secondary bonding?

Replacement of O with F would cause more electron withdrawing from the elements F is bonded to, which cause the other elements to become more positive and thus the overall molecule to

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become more polar. This will allow for more polar bonds (such as hydrogen bonds) to be formed with neighboring molecules.

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Chapter 2

2.1. Using the diagram below, calculate the Miller indices for the following:
a) Plane AGDE (100)
b) Plane CDGH (001)
c) Plane AGCF (110)
d) Point C 0,1,1
e) Point G 1,0,1

Planes (hkl) (no commas)
Points h,k,l (no () and with commas)

2.2 Brass is an alloy of copper and zinc. Assume the weight percent composition of brass is 80% Cu and 20% Zn. Would you expect brass to be an interstitial solution or a substitutional solution? Justify your answer based on the Hume-Rothery rules.

Solvent = Copper
Atomic radius: 0.1278 nm,
Electronegativity: 1.9,
Face-centered cubic (FCC).

Solute = Zinc
Atomic radius: 0.1332 nm,
Electronegativity: 1.6,
Hexagonal close-packed (HCP).

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1. Atomic radii differ by less than 15% (~4%).
2. Electronegativities are similar (1.9 vs. 1.6).
3. Valence charges are similar (Cu^{+}/Cu^{2+} vs. Zn^{2+}).
4. Solution does not contain a large fraction of solute (20%).

Therefore, this should be a substitutional solution.

2.3 What is the difference in the definition of coordination number between metals and ceramics? Why are these two parameters different for the two classes of materials?

Coordination number in metals refers to the number of nearest neighbor atoms, since this parameter contributes to the overall stability of the structure, whereas coordination number in ceramics refers to the nearest neighbor ions of opposite charge, since this is what contributes to the stability of the crystal in ceramics.

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2.4 Why do point defects occur in groups in ceramics?

The defect cannot affect the overall electroneutrality of the material, so groups of defects must be formed so that both positive and negative charges are affected equally.

2.5 A polymer is made of the following fractional distribution. Calculate $\overline{M_n}$, $\overline{M_w}$, and PI for this polymer.

W_i	0.10	0.15	0.35	0.25	0.15
M_i (kg/mol)	100	200	300	400	500

						Sum (Σ)
W_i	0.1	0.15	0.35	0.25	0.15	1
M_i (kg/mol)	100	200	300	400	500	
$N_i = W_i / M_i$	0.001	0.00075	0.001167	0.000625	0.0003	0.003842
$x_i = N_i / \Sigma N_i$	0.260304	0.195228	0.303688	0.16269	0.078091	
$x_i * M_i$	26.03037	39.04555	91.10629	65.07592	39.04555	**260.3037**
$w_i = W_i / \Sigma W_i$	0.1	0.15	0.35	0.25	0.15	
$w_i * M_i$	10	30	105	100	75	**320**

$\overline{M_n}$ = $\Sigma(x_i * M_i)$ = 260.30 kg/mol

$\overline{M_w}$ = $\Sigma(w_i * M_i)$ = 320 kg/mol

PI = M_w / M_n = 1.23

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2.6. Using the data in Figure 2.35 and assuming first-order diffraction calculate the following: (Note that aluminum has a FCC structure.)

(a) the interplanar spacing for peaks corresponding to planes (111), (200), and (420).

First order diffraction: n=1

(111)

$2d \sin\theta = n\lambda$

$2d \sin 39° = 1.54$ Å

$d = 1.54$ Å $/(2*\sin 39°)$

$d = 1.22$ Å

(200)

$2d \sin\theta = n\lambda$

$2d \sin 43° = 1.54$ Å

$d = 1.54$ Å $/(2*\sin 43°)$

$d = 1.13$ Å

(420)

$2d \sin\theta = n\lambda$

$2d \sin 116° = 1.54$ Å

$d = 1.54$ Å $/(2*\sin 116°)$

$d = 0.86$ Å

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(b) the atomic radius for Al.

Using (111) plane:
$d(111) = a_0/ (1^2 + 1^2 + 1^2)^{0.5} = a_0/ (3)^{0.5}$

For FCC, $a_0 = 2r2^{0.5}$

$d(111) = 2r2^{0.5}/(3)^{0.5}$
$((3)^{0.5} * d(111))/ (2*2^{0.5}) = r$
$((3)^{0.5} * 1.22 \text{ Å})/ (2*2^{0.5}) = r$
$0.75 \text{ Å} = r$

2.7. Based on the results in Figure 2.47, is 5 seconds of UV light exposure sufficient to polymerize the poly(ethylene glycol) completely?

No. Peaks at 1635 cm^{-1} and 1410 cm^{-1} are still visible, indicating that unreacted poly(ethylene glycol) is still present, although these peaks disappear at longer time points.

2.8. In Figure 2.50, higher resonance frequencies are found to the left of the standard peak shown at 0.0 ppm (signal is shifted downfield from the standard). Given this information, provide a possible molecular explanation for the difference in location of the H signal from peak 4 vs the H signal in the solvent.

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Possible explanation: The H's in peak 4 are bound to C, which is bound to another C. However, in the solvent, the H is bound to a C bound to Cl, which is more electronegative than C. Therefore, the more electrons are withdrawn from the C in the solvent peak, which means the H's are less shielded and a higher resonance frequency (signal shifted downfield) is found for the solvent peak.

2.9. Acetone is preferred by some biomedical device manufacturers as a solvent for their polymers because it is considered by regulatory agencies to have fewer negative effects in the body than other organic solvents. Below is the mass spectrometry data and molecular structure of acetone. Acetone has the molecular formula of C_3H_6O and a molecular weight of 58.

(a) How are particles separated by mass in mass spectrometry?

Charged species are forced through a magnetic field, and lighter species are deflected more than heavier ones. Because of the geometry of the mass analyzer and the strength of the magnet, only ions with a certain mass are allowed to hit the detector, while all others strike the walls of the chamber. By altering the magnetic field in a controlled manner, the detector can record the amount of ions having various masses.

(b) What is the large peak at 43? Draw the molecular structure that accounts for this peak. Give a possible explanation why the peak at 43 is larger than the other peaks seen in the mass spectrum.

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