ENGINEERING TRIPOS PART IIA

Tuesday 23 April 2013 9.30 to 11

ENGINEERING TRIPOS PART IIA: Module 3G5

BIOMATERIALS

*Answer not more than **three** questions.*

All questions carry the same number of marks.

*The **approximate** percentage of marks allocated to each part of a question is indicated in the right margin.*

There are no attachments.

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS
Engineering Data Book
CUED approved calculator allowed

You may not start to read the questions printed on the subsequent pages of this question paper until instructed that you may do so by the Invigilator

Version: Final

1 (a) Write brief notes to explain the following:

(i) the difference between a cell, a tissue, and an organ;

(ii) cytotoxicity and biocompatibility;

(iii) the increase in medical device development in the 20^{th} century;

(iv) the classification of medical devices according to risk;

(v) the principles of bioethics;

(vi) the premise of tissue engineering.

[60%]

(b) Resorbable (erodible) polymers are commonly used in biomedical applications.

(i) Describe hydrolysis.

(ii) List the factors that influence a material's hydrolysis rate.

(iii) Explain the difference between bulk and surface erosion. What determines which form of hydrolysis will occur?

(iv) What are the key factors in the utilisation of erodible polymers in drug delivery devices? How are surface and bulk eroding materials used for drug delivery?

[40%]

2 (a) Explain why the human body is a hostile environment for implant materials. Describe the major mechanisms by which biological entities influence corrosion. [25%]

(b) A total joint implant undergoes both corrosion and wear, such that both metal ions and polyethylene wear particles are released. What are the biological implications in each case? [30%]

(c) Consider standard electrochemical cells of:

(i) Cobalt and Chromium;

(ii) Magnesium and Aluminium.

In each case, write the balanced reaction, compute the standard cell potential, using the reactions in Table 1, and indicate which is the anode and which is the cathode material. Which pair is more corrosive overall, and how does this influence materials selection for biomedical applications? What are some strategies for avoiding corrosion in these cases? [45%]

Reaction	Standard Electrode Potential
$Co^{2+} + 2e^- \rightarrow Co$	− 0.277 V
$Cr^{3+} + 3e^- \rightarrow Cr$	− 0.744 V
$Al^{3+} + 3e^- \rightarrow Al$	− 1.662 V
$Mg^{2+} + 2e^- \rightarrow Mg$	− 2.363 V

Table 1

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3 (a) Define polymeric materials and describe how they polymerize. [20%]

(b) A sample of polyethylene $(C_2H_4)_n$ has a mean molecular weight of 25,000 atomic mass units.

(i) Given a degree of polymerization of 750, a carbon-carbon bond angle of 109.5° and a carbon-carbon bond length of 0.154 nm, define and calculate the coiled length and extended length.

(ii) Every fourth hydrogen atom is replaced by a methyl group (CH_3). Draw the possible structures of this molecule in two dimensions, and label them by name.

(iii) The original $(C_2H_4)_n$ polymer is made into a co-polymer with an acrylate. Representing the two monomers as "A" and "B", draw and name possible co-polymer structures.

[30%]

(c) Given the data in Table 2, calculate the number average molecular weight, the weight average molecular weight, and the polydispersity index for a different sample of polyethylene. [20%]

Molecular weight range (g mol^{-1})	Number fraction x_i	Weight fraction w_i
8,000-16,000	0.05	0.02
16,000-24,000	0.16	0.10
24,000-32,000	0.24	0.20
32,000-40,000	0.28	0.30
40,000-48,000	0.20	0.27
48,000-56,000	0.07	0.11

Table 2

(d) Given two polymers, Z and Q, with density and crystallinity values as shown in Table 3, find the crystallinity of a specimen with a density of 2.26 g cm^{-3}. [30%]

Sample	Density (g cm^{-3})	Crystallinity (%)
Polymer Z	2.144	51.3
Polymer Q	2.215	74.2

Table 3

4 (a) List the materials commonly used in the components of the following three implants:

(i) hip implant;

(ii) endovascular stent;

(iii) endovascular stent graft.

Explain in each case the materials-selection criteria. For each implant, describe the types of medical conditions these implants are used to treat.

[40%]

(b) Referring to cell attachment and tissue formation, state whether orthopaedic implants and cardiovascular stents differ, explaining your reasoning. List the techniques typically employed to ensure that appropriate levels of cell attachment are achieved.

[15%]

(c) Explain briefly the difference between diffusive and martensitic phase transformations and how this difference is being exploited in self-expanding stents. For martensitic phase transformations, sketch the changes in the percentage of martensite formation as a function of temperature. Define all transformation temperatures.

[20%]

(d) Explain the steps for the deployment of superelastic and shape memory stents *in vivo*. State the conditions that must be satisfied in order for the superelastic and shape memory effects to be exploited in cardiovascular stents. In the case of a superelastic stent, sketch the hoop force as a function of the stent diameter.

[25%]

END OF PAPER