

Name _____

Advisor _____

Advisor e-mail _____

BIOENGINEERING
Ph.D. QUALIFYING EXAM
Nanotechnology

June 2006

Complete all questions.

Show all work.

Read the questions carefully, work neatly, and box your answer where appropriate.

Each problem is worth 25 points.

You have 4 hr to complete the exam.

Write your name on each page.

Question	Grade
<u>Bioinstrumentation</u>	<u>/25</u>
<u>Biomaterials</u>	<u>/25</u>
<u>Biomodeling</u>	<u>/25</u>
Concentration:	
<u>Nanotechnology</u>	<u>/25</u>
Total	/100

Bioinstrumentation

1. Design a system suitable for recording a biopotential signal with the following characteristics:

Bandwidth: 0.1 – 1000 Hz

Dynamic range: ± 100 mV

Assume that you have a 12-bit analog-to-digital converter with an input range of ± 10 V, and that you wish to digitally record the signal with the highest resolution possible.

- A. First, draw a *block diagram* that depicts each stage in your system, and gives the transfer function of each stage.

- B. What is the final calibration of your system, in Volts/Volt?

- C. What is the final resolution of your system, in Volts/bit?

Name _____

D. Draw the amplitude portion of the Bode plot describing your system (from the previous page). Plot the gain in decibels, and indicate the -3 dB pt(s).

E. Give a detailed circuit diagram for the system described on the previous page, showing all component values.

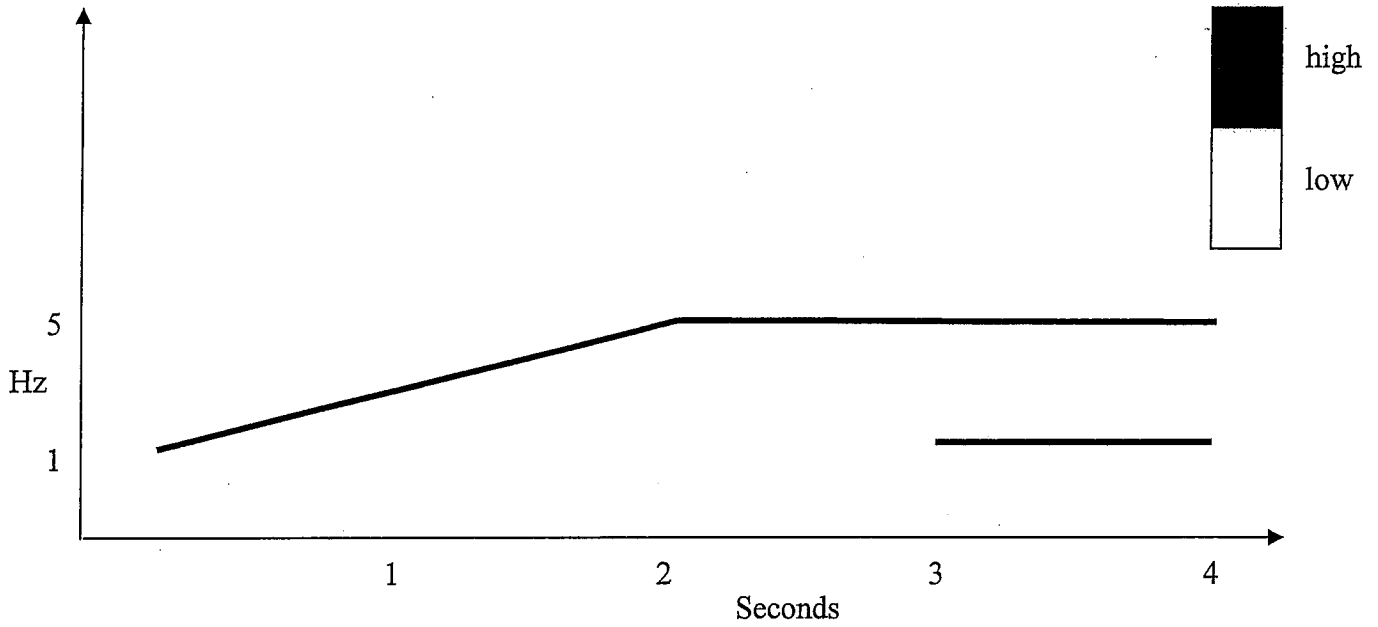
Name _____

- F. Assume that the biopotential signal above is a response to a sensory stimulus that has never been recorded before. You wish to characterize this novel signal so that you can report it in the journal *Nature*. How would you empirically determine the signal bandwidth? In particular, how would you distinguish the “unknown” signal from noise in the recording? (Be concise; think before you write.)

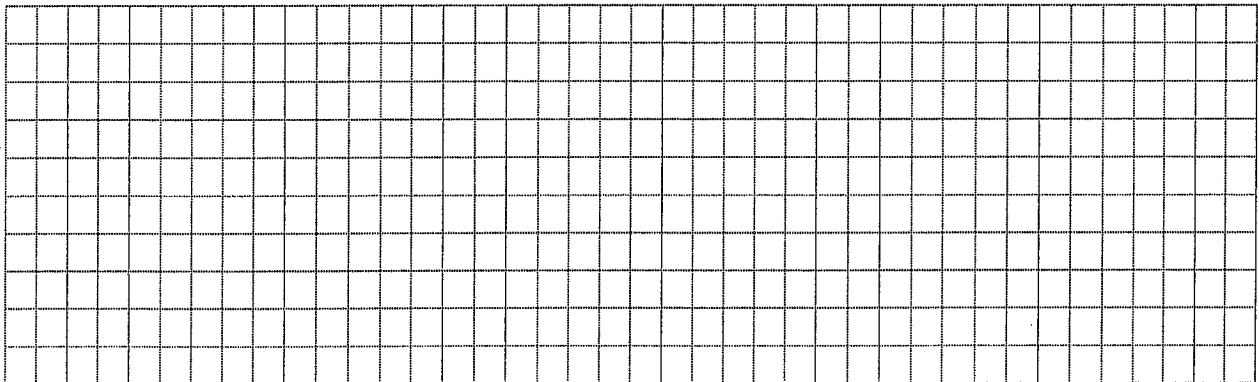
Name _____

2. A man is standing in a puddle, which grounds his feet. He reaches overhead to turn on a lamp, but the lamp is faulty and his hand touches a 120 V, 60 Hz AC voltage source. Draw a circuit diagram that describes the currents passing from the source to ground. Indicate the *physical origin* of all impedances in your circuit. State any assumptions, and be as quantitative as possible.

3. Consider the idealized spectrogram below



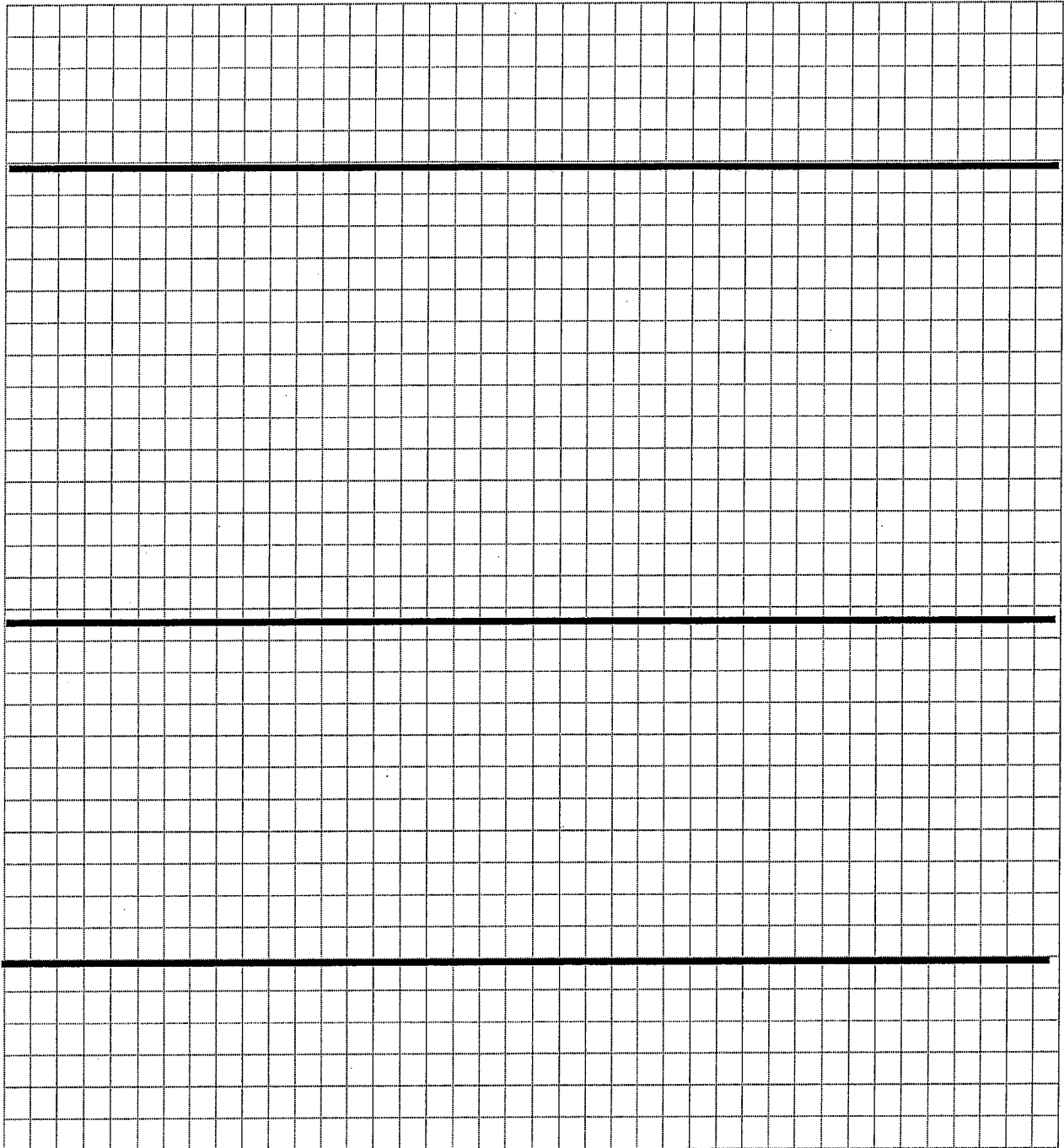
a. On the graph-pad below, draw a time-based voltage waveform from which this spectrogram could have been obtained. Label all axes.



4. Using C, L and R components, create an electric circuit with second order response characteristics.
 - a. Draw and label a circuit diagram with components arranged to provide a second-order system with low-pass characteristics.
 - b. Derive an expression (in terms of R, C and L) for the transfer function of this circuit.
 - c. Choose/determine appropriate component values if the undamped natural frequency of this system is 485 rad/sec and the system is critically damped.
 - d. Determine the magnitude and phase of the transfer function for an 85 Hz sinusoidal signal input.
 - e. Consider the signal you drew in Problem 3 as the input to your circuit. Draw the likely output.

5. Cardiac Mechanics in a Normal Human Heart

- a. On the first line of the graph below sketch both a left and right typical ventricular pressure trace for two successive cardiac cycles.
 - b. On the second line, draw the associated ECG trace
 - c. On the third line, draw the likely heart sounds heard with a stethoscope
- In all cases be sure to label and value both axes!***



Name _____

- d. For TWO of the signals above (a and b, OR a and c, OR b and c):
 - i. Thoroughly discuss the transducer used in the measurement. Include the source of the signal, the method of transduction, how the transducer is placed etc.
 - ii. For those SAME TWO signals, state and justify the low and/or high-frequency cut-offs you would use for signal conditioning the output of the transducer.

Name _____

3. You plan to use an implant made out of material X. Your co-worker, Mr. Slow says that if you do this material X will cause neighboring cells to be lysed by the membrane attack complex.
 - i. What is the membrane attack complex?

- ii. Do you believe your co-worker? Explain why or why not.

Name _____

4. Dr. Glass needs to insert a rod in the body. He needs it to be soft while it is being inserted and needs it to be hard 1 hour after it is inserted. NITINOL is not an option for this. What type of material should he use, metal, polymer or ceramic? Explain the material property that will make this possible and how it will work in this case. (Hint: encrypted in this question is a helpful hint.)

Name _____

5. Design an **in vitro** experiment to determine if material Y is biocompatible. You must use a standard biocompatibility test. Explain your experimental design in **great** detail. Include sections on: A) how you will know from your results if material Y is biocompatible or not, B) the advantages of the method you chose and C) the disadvantages of your method.

3. Derive a relation between b , \hat{b} , and the sample size n .

Nanobiotechnology

1. (a) Explain how the formula,

$$h\nu_{n,m} = E_{\text{gap}} + (n^2\hbar^2)/(8m_e^*a^2) + (m^2\hbar^2)/(8m_h^*a^2)$$

may be used to determine the photoluminescent spectrum from a semiconductor quantum dot of diameter a . n is the principal quantum number for the conduction band states, m is the principal quantum number for the valence band states, E_{gap} is the bandgap of the semiconductor, m_e^* is the effective mass of the electrons in the conduction band, and m_h^* is the effective mass of the holes in the valence band.

As part of your discussion, indicate what quantities are denoted by $\nu_{n,m}$ and h .

- (b) What are two approximations used in deriving the formula of part 1(a)?

Name _____

2. (a) Give two examples of peptides that may be (i) bound to CdS quantum dots through thiol linkages and (ii) bound to integrins associated with various cells (fibroblast, fibrosarcoma cells, neural, etc.).

(b) How may quantum dots functionalized with such peptides be used as biotags?

3. Discuss one potential use of carbon nanotubes in bioengineering.

Name _____

4. Assume that you have at your disposal CdSe/ZnS quantum dots with several different photoluminescent (PL) spectra (different colors). Assume that you have at your disposal PbSe quantum dots with different photoluminescent (PL) spectra each at a different wavelength in the infrared portion of the spectrum. Assume that you have at your disposal GaN quantum dots with PL spectra in the ultraviolet portion of the spectrum. Further assume that you know how to functionalize any of these quantum dots with any peptides or antibodies you desire. Using these quantum dots and biomolecules, design experiments using quantum-dot biotags to study a cellular process or function of your choice. (You do not have to use all of the previously-described quantum dots; one is enough but you may use more.)

Name _____

5. The fabrication of (a) colloidal quantum dots, (b) carbon nanotubes, and (c) self-assembled monolayers of molecules all illustrate techniques of nanofabrication. Pick one of these [(a), (b), or (c)] and describe its fabrication