### Examination 2

(20 points)

1. A differential amplifier has a differential voltage gain of 100 and a common mode voltage gain of 2. It has a power supply of ±5 V.

   a. If an input voltage of 10 mV is connected between its positive-going and negative-going inputs, what will the output voltage be?

   
   \[
   \begin{align*}
   A_d &= 100 \\
   A_c &= 2 \\
   \frac{V_o}{V_i} &= 10 \text{mV} \\
   V_o &= 1 \text{V} \\
   V_o &= 1 \text{mV} \\
   \end{align*}
   \]

   b. If the positive-going and negative-going inputs are connected together and an input voltage of 10 mV is connected between these inputs and ground, what will the amplifier’s output be?

   
   \[
   \begin{align*}
   A_c &= \frac{V_o}{V_i} \\
   Z &= \frac{V_o}{10 \text{mV}} \\
   [V_o &= 20 \text{ mV}] \\
   \end{align*}
   \]

   c. What is the common-mode rejection ratio in decibels for this amplifier?

   
   \[
   CMRR = \frac{A_d}{A_c} = \frac{100}{2} = 50 \text{ dB}
   \]

   d. What is the maximum differential input voltage that this amplifier can amplify without introducing distortion in the output?

   
   \[
   \begin{align*}
   V_{i, \text{max}} &= \frac{V_{cc}}{A} = \frac{\pm 5 \text{V}}{100} \\
   V_{i, \text{max}} &= 50 \text{ mV} \\
   \end{align*}
   \]
(20 Points)

2. Multiple Choice. Choose the one best response for each question and write its letter in the space at the right of the problem. Only answer 10 of the 11 problems, and indicate which you do not want graded by writing “omit” in the space on the right. If all 11 questions are answered, number 11 will not be graded.

1. The value of the half-cell potential for an electrode is determined by
   a. The current across the electrode-electrolytic solution interface
   b. The chemical reactions occurring at the electrode-electrolytic interface
   c. The concentration gradients of ions in solution located beyond the electrode-electrolytic solution interface
   d. The biopotentials being measured by the electrode
   e. The input resistance of the amplifier connected to the electrode

   1. b

2. The percentage of hemoglobin in blood that is oxygenated can be clinically determined by
   a. Weighing it.
   b. Electrochemically measuring the partial pressure of oxygen in the blood.
   c. Counting the number of red blood cells in a particular volume of blood.
   d. Measuring the partial pressure of carbon dioxide in the blood.
   e. Comparing the transmitted light at an infrared and a visible red wavelength.

   2. e

3. The direct method of measuring blood pressure involves
   a. Invading the body
   b. The use of a cuff
   c. Measuring oscillations in pressure
   d. Korotkoff sounds
   e. Occlusion of an artery during a portion of the cardiac cycle

   3. a

4. The presence of a small air bubble in the fluid in a catheter coupled to a pressure transducer for directly measuring blood pressure will change the characteristics of the system by
   a. Reducing the damping and increasing the resonant frequency
   b. Reducing the damping and reducing the resonant frequency
   c. Increasing the damping and increasing the resonant frequency
   d. Increasing the damping and reducing the resonant frequency
   e. The bubble will have no effect on the system

   4. b
5. A temperature sensor in which the primary output is a voltage that is a function of temperature is a
   
   a. thermistor
   b. thermocouple
   c. resistance temperature device (RTD)
   d. fiber optic thermal sensor
   e. differential temperature sensor

6. The fact that blood contains ions is an essential concept for which of the following types of flowmeters:
   
   a. Electromagnetic
   b. Doppler ultrasound
   c. Thermal dilution
   d. Thermal conductivity
   e. Differential pressure
   f. All of the above
   g. None of the above

7. The frequency response of an operational amplifier circuit is broadened (increased) by

   a. Increasing the gain of the operational amplifier circuit
   b. Reducing the gain of the operational amplifier circuit
   c. Connecting the input signal to the negative going input of the operational amplifier
   d. Increasing the power supply voltage of the operational amplifier
   e. Reducing the power supply voltage of the operational amplifier
   f. Increasing the input resistance of the circuit

8. The ultrasound method of measuring blood flow is based on

   a. Korotkoff sounds
   b. Indwelling fluid-filled arterial catheter with an external strain gauge pressure sensor
   c. Sphygmomanometer cuff with an ultra sensitive microphone
   d. The Doppler effect
   e. Electromagnetic induction
9. Two strain gauge bridge pressure sensors are identical with the exception that one has a diaphragm that has twice the diameter of the diaphragm of the other one. In what other way is the first pressure sensor different from the second (smaller) one?
   
   a. Less sensitive to motion artifact
   b. Lower sensitivity to pressure changes
   c. Greater sensitivity to pressure changes
   d. Smaller compliance when connected to a fluid-filled catheter
   e. There should be no difference in characteristics between the two pressure sensors

10. Microelectrodes are frequently used to measure

   a. The half-cell potential of a biopotential electrode
   b. Very small currents of the order of microamperes
   c. Electric charge on proteins
   d. Contraction force of individual muscle cells
   e. The potential across a cell membrane

11. Which of the following light sensors is the most sensitive to low light intensities?

   a. Photodetector tube
   b. Photomultiplier tube
   c. Photodiode
   d. Phototransistor
   e. Photo-LED
   f. Photo-operational amplifier
3. A thermocouple is used to measure the temperature of a steam sterilizer in the central supply unit of a large medical center. The thermocouple has a Seebeck coefficient of 50 μV/°C, and the total resistance of its two wires is 10 Ohms. It is directly connected to a microammeter that has an internal resistance of 40 Ohms. The meter is used to indicate the temperature of the sterilizer which should be maintained at 120 °C. The room temperature where the microammeter is located is 25 °C.

a. What would be the open circuit voltage of the thermocouple?

\[ V = \alpha (T_2 - T_1) \]
\[ = \frac{50 \text{ mV}}{\text{°C}} (120 - 25) \text{°C} \]
\[ = 0.00475 \text{ V} \]
\[ = 4750 \text{ μV} \]

b. How much current will flow in the ammeter when the sterilizer is at 120 °C?

\[ R_{\text{total}} = 10 + 40 = 50 \text{ Ω} \]
\[ V = IR \]
\[ I = \frac{V}{R} \]
\[ I = \frac{0.00475}{50} = 0.000095 \text{ A} \]
\[ = 95 \text{ μA} \]

c. If the length of the thermocouple wire is doubled, how will this change the open circuit voltage and the meter reading?

If the length was increased the total resistance of the two wires would increase which would increase the total resistance. This would decrease the current flowing through the ammeter. The voltage wouldn't change since it's not dependent on resistance.
4. Choose one and only one of the following questions. If both are answered, only the first will be graded:

a. Describe the pulse oximeter.

Pulse oximeter measures change in volume of blood based on cardiac activity. With each pulsating motion created by the cardiac system, the volume in the arteries changes, and the pulse oximeter picks this up. This method is easy to use and requires infrequent calibration for measurements. Downsides include this is only applicable for tissue that light can be transmitted through and venous pulsations can affect the data received. This method allows for the amount of oxygenated hemoglobin to be determined like blood oximetry.

b. Describe oscillometric measurement of blood pressure.
3. A pair of electrodes is to be used to measure a biopotential. Both electrodes are placed on a patient in positions appropriate for the measurement of the biopotential. Each electrode has a polarization resistance of 10,000 Ω and a polarization capacitance of 2 μF. The series resistance due to the electrode-tissue interface is 500 Ω, and the half-cell potential is of each electrode is 300 mV. The amplifier used with the electrode pair has an input resistance of 80,000 Ω. The biopotential being measured has both high and low frequency components.

a. Draw an equivalent circuit for this instrumentation showing the connection together of all components: the electrodes, the signal voltage from the patient, and amplifier input. Be sure to label each component with its value or function. There is no need to simplify the circuit here.

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\[
\begin{align*}
E_{nc} & \quad E_{nc} \quad E_{nc} \quad E_{nc} \quad E_{nc} \quad E_{nc} \\
\text{Cp} & \quad \text{Rf} & \quad \text{Cf} & \quad \text{Rf} & \quad \text{Cf} & \quad \text{Rf} \\
E_{nc} & \quad E_{nc} \quad E_{nc} \quad E_{nc} \quad E_{nc} \quad E_{nc} \\
\end{align*}
\]
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\[R_s = 500 \, \Omega\]
\[E_{nc} = 300 \, \text{mV}\]
\[R_i = 80\, k\, \Omega\]

b. Does the amplifier circuit see a different input voltage at high and low frequencies when the signal voltage from the patient i.e. the biopotential remains unchanged at these frequencies? Explain your answer and if there are amplifier input voltage differences between high and low frequencies, calculate the different voltages that will be seen at the amplifier input at high and at low frequencies as a function of the biopotential voltage, \(E_b\). Here you might want to simplify the circuit.

4. At high frequencies, there is a lower voltage due to the amplitude of the biopotential voltage. This is partially because at high frequencies the capacitor acts as an open circuit.

\[
\text{Input at high frequencies: } V_H = \frac{E_b}{n}
\]

\[
\text{Input at low frequencies: } V_L = \frac{E_b}{n} + \frac{E_{nc}}{n}
\]

c. Is this a good amplifier to use with these electrodes based upon the information given? Give your reasons for your answer based only on the information in this problem and your answers to parts a and b.

2. It is good which is good, however since \(R_p\) is great, this will cause a greater difference between the voltage seen at high and low frequencies (since it is what creates the
(15 points)
6. A semiconductor blood pressure sensor has a sensitivity of 5 $\mu$V/(mm Hg)(volt of bridge excitation). The reading from a patient’s blood pressure measured using a catheter and external sensor had a maximum value of 3.75 mV and a minimum value of 2.5 mV when the sensor’s bridge is powered by a 5 volt source?

   a. What was the patient’s blood pressure

   $$3.75 \text{ mV} = \left( \frac{5 \text{ mV}}{\text{mm Hg}} \right) \times \text{mm Hg} \quad \underline{150 \text{ mm Hg}} \quad \text{systolic}$$

   $$2.5 \text{ mV} = \left( \frac{5 \text{ mV}}{\text{mm Hg}} \right) \times \text{mm Hg} \quad \underline{100 \text{ mm Hg}} \quad \text{diastolic}$$

   blood pressure = \underline{150 \text{ mm Hg}} \quad \underline{100 \text{ mm Hg}}$$

   b. How might this change if the same semiconductor pressure sensor chip was located on the catheter tip?

   The blood pressure would be lower because it would not be subjected to the disturbances and other factors that it comes in contact with once it is outside of the catheter. At the catheter tip the pressure sensor chip should receive the most accurate reading possible.