Introduction to Biomedical Engineering: 2009 fall Midterm

November 18, 2009

Close book, 120 minutes (PM 1:10~PM 3:00)

Do **not** leave your answer along without any brief explanation except 3(3).

Equations for reference:

a. a. 1-D Fourier transform

$$X(\omega) = \int_{-\infty}^{+\infty} x(t) \cdot e^{-j\omega t} dt$$

$$x(\mathrm{t}) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} X(\omega) \cdot e^{j\omega t} d\omega$$

b. Discrete-time Fourier transform (DTFT)

$$X(\omega) = \sum_{n=-\infty}^{+\infty} x[n] \cdot e^{-j\omega n}$$

$$x[n] = \frac{1}{2\pi} \int_{2\pi} X(\omega) \cdot e^{j\omega n}$$

c. Nernst equation (of a permeable ion C)

$$E_C = v_i - v_o = \frac{kT}{qZ} \ln \frac{[C]_o}{[C]_i}$$

k (Boltzmann's constant): 1.38×10^{-23} Joule/K

T: Kelvin scale of absolute temperature (K)

Z: ionic valence

q(the magnitude of electron charge): 1.6×10^{-19} Coulomb

d. Goldman equation

$$E = \frac{kT}{q} \ln\left(\frac{P_K[K^+]_o + P_{Cl}[Cl^-]_i + P_{Na}[Na^+]_o}{P_K[K^+]_i + P_{Cl}[Cl^-]_o + P_{Na}[Na^+]_i} \right)$$

1. (Biopotentials, 18%) The following steady-state concentration and permeability are given for a membrane at 27℃. Note that A^+ is not permeable.

Ion	Cytoplasm (mM)	Extracellular (mM)	Ratio of Permeability
K^+	136	15	1.0
Na^+	19	155	0.019
Cl^-	78	112	0.381
A^+	64	12	--

   (1) Find the Nernst potential for Cl^-. (6%)

   (2) What is the resting potential of this membrane? (6%)

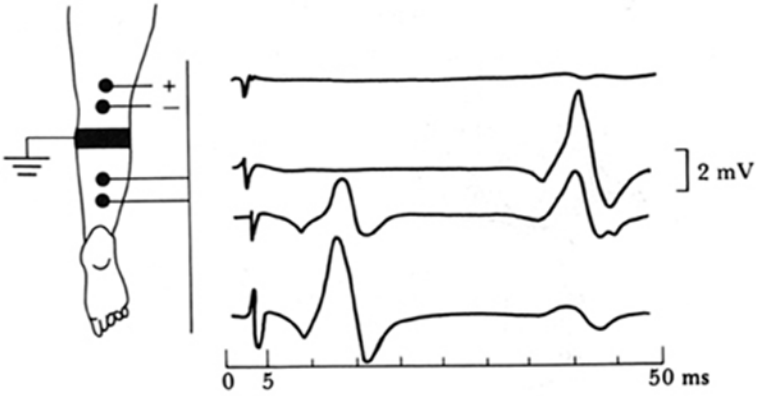
   (3) What is the direction of diffusion and drift for Cl^- ions? Explain why. (6%)

2. (Action potentials, 12%) The action potential is induced when the membrane potential increases beyond certain threshold.

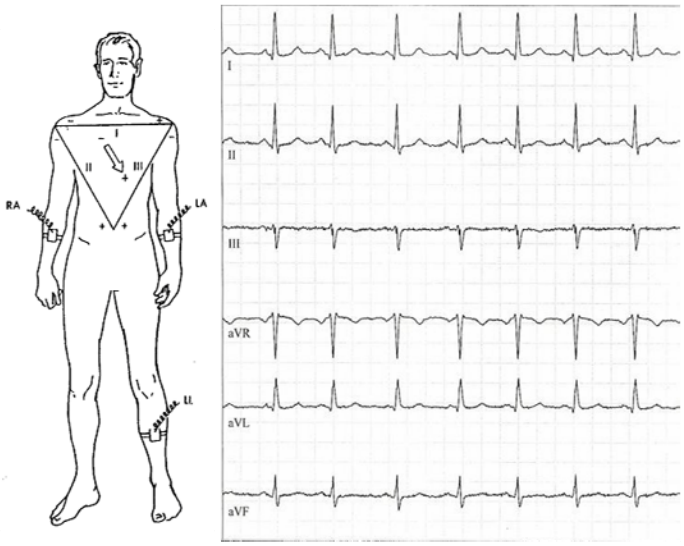
   (1) What kind of ion channel is highly activated during the beginning of depolarization? Also state the direction of the resulting current. (6%)

   (2) How does refractory period help the transmission of neural stimulus (神經刺激)? (6%)

3. (Biomedical signals, 20%)
   (1) In the figure of H-reflex experiment below, the four traces show potentials evoked by stimulation of the posterior tibial nerve with pulses of increasing magnitude. Assume the distance from the recording electrodes to stimulating electrodes is 30 cm, from the stimulating electrodes to the spinal cord is 40 cm. Calculate nerve conduction velocity using the H reflex. (8%)



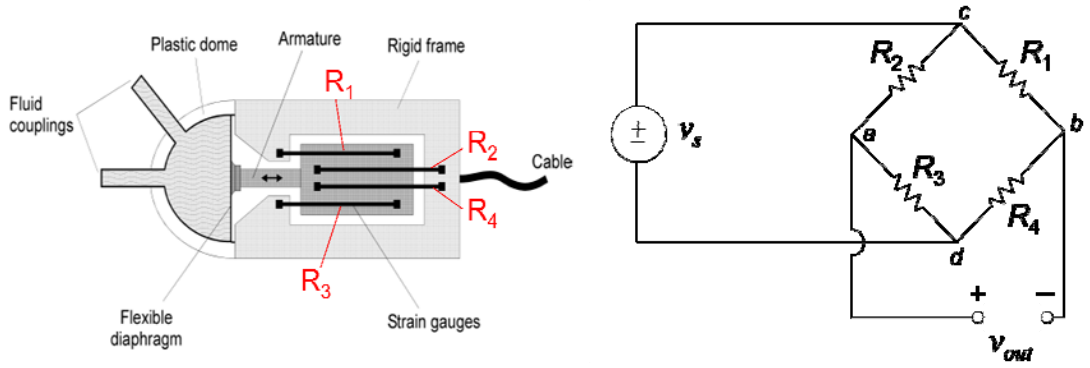
   (2) Given the demonstration of Einthoven's triangle and six recording traces of limb leads as below, explain why Lead II and aVR (augmented vector right) shows almost in opposite polarity? (6%)



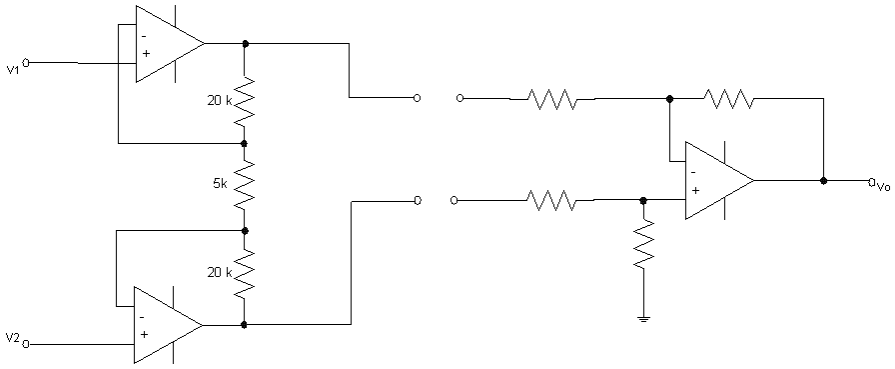
   (3) Where does the signal source of EEG **mainly** come from? (6%, 全對才給分)
   (a) white matter（白質） (b) gray matter（灰質） (c) Schwann cells (d) Pyramidal cells (e) volume currents produced by postsynaptic potentials (f) action potential induced currents inside axons

4. (Biosensors, 20%) The structure of a strain-gage pressure sensor and its corresponding equivalent circuit are illustrated as below.
   (1) The equivalent circuit is also known as Wheatstone bridge. What is the null condition of the output voltage (v_{out})? (Hint: The relationship between v_{out} and v_s has to be known first.) (6%)
   (2) Explain how pressure of fluid can be measured by this instrument. (6%)
   (3) Assume all the registers in the diagram has an initial value of R_0. Given that the variation of

pressure leads to an increase of R_1 and R_3 by 5% and a decrease of R_2 and R_4 by 5%, calculate v_{out} if v_s = 5V. (8%)



5. (Amplifier, 16%) The figure below shows a differential amplifier consisting of two stages. Stage 2 has a known CMRR of 500.
   (1) Calculate the CMRR of the first stage. Then calculate the total CMRR (both stages combined). (10%)
   (2) Why can this differential amplifier reject large 60-Hz common-mode signals that usually exist on the body? (6%)



Stage 1 *Stage 2*

6. (Signal processing, 14%)
   (1) An ECG signal has been sampled at 400 Hz. What is the highest frequency of interest in the original ECG signal? (6%)
   (2) The spectrums of two continuous signals, $x_1(t)$ and $x_2(t)$, are shown in magnitude as below. Find the Nyquist rate in Hz (minimal sampling frequency without aliasing) for $x(t) = x_1(t)* x_2(t)$. (8%)