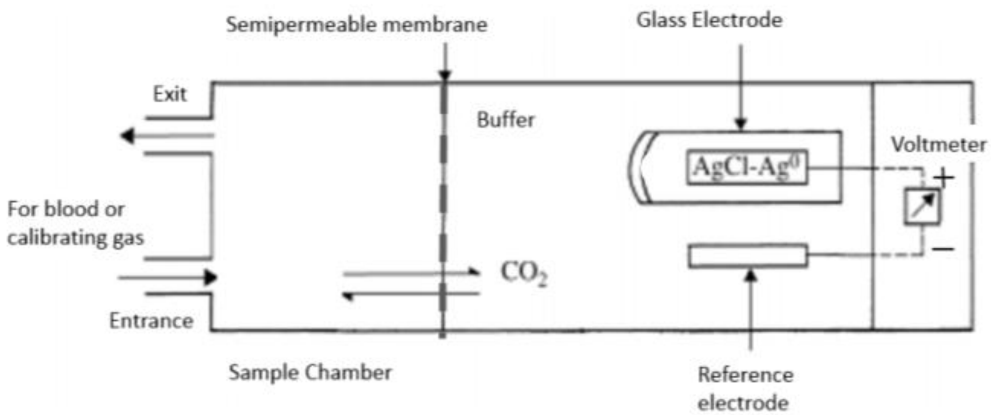
BENG 186B Winter 2025 HW #6
Due *Friday, March 14* at 11:59pm on Canvas (Gradescope)

Parts of the homework done collectively in-class (Friday, March 7) are indicated below with **[IC]**.

1. [**30 pts**] A Severinghaus electrode, shown below, is used to measure partial pressure of carbon dioxide (PCO_2) in a blood sample at room temperature. The internal solution of the glass electrode is 1 mmol/l of HCl. The voltage on the glass electrode relative to the reference electrode is measured with a voltmeter, reading -80 mV. The experiment is repeated for a calibration sample with known PCO_2 of 100 mmHg, now reading a voltage of -50 mV.



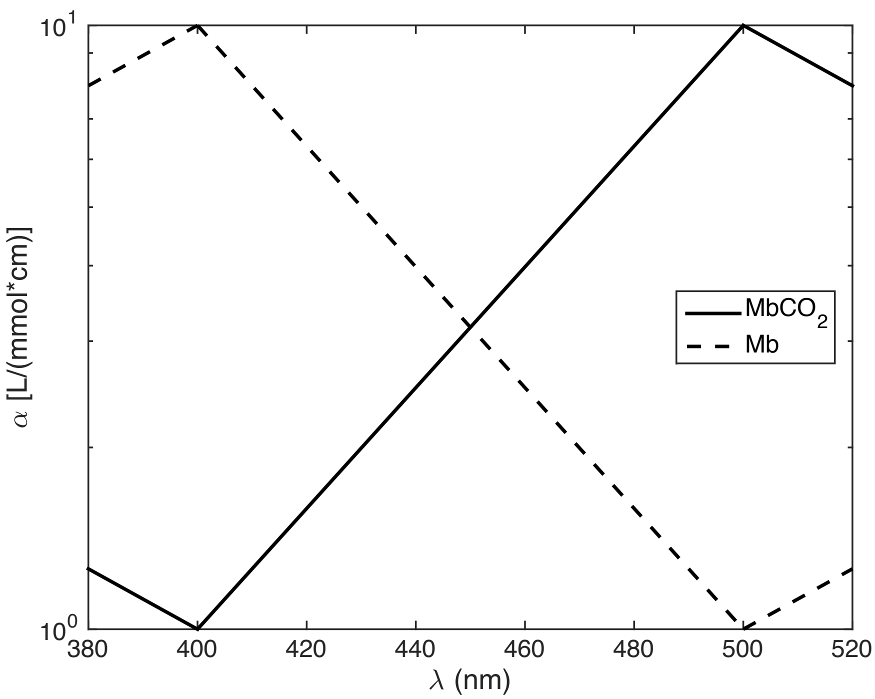
(a) **[IC]** [5 pts] What is the preferred type of reference electrode for this instrument? Explain your choice.

(b) [10 pts] Find the pH of the buffer solution surrounding the reference electrode, for the blood sample, and for the calibration sample.

(c) [10 pts] Find PCO_2 for the blood sample.

(d) [5 pts] The flow rate of the blood sample through the chamber is now increased. Would you expect the voltmeter reader to increase, decrease, or stay the same? Explain.

2. [**20 pts**] A protein called Martian blood protein (Mb) has been identified in Martian blood. Mb binds CO_2, and the CO_2 saturation of Mb in Martian blood is of interest to researchers. Unsaturated Mb absorbs violet light and allows green light to pass, while saturated Mb ($MbCO_2$) absorbs green light and allows violet light to pass. The absorption spectra of Mb and $MbCO_2$ are shown below. Note the logarithmic scale on the y axis!



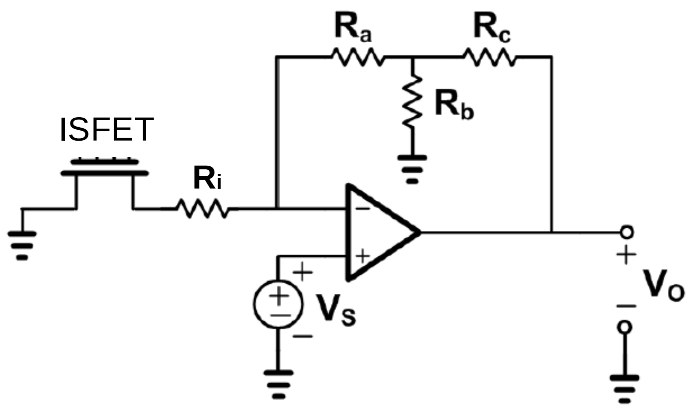
(a) **[IC]** [5 pts] What is the isosbestic wavelength λ_i for Mb? What is the absorptivity α_i at this wavelength?

(b) [15 pts] If you were designing a Martian carbon-dioximeter with 2 light sources, what wavelengths, λ_1 and λ_2, would you pick for your light sources? Find an expression for CO_2 saturation (SCO_2) in terms of the absorbances at your chosen wavelengths, $A(\lambda_1)$ and $A(\lambda_2)$.

3. [**20 pts**] Consider a wearable sensor that uses ISFETs (ion-sensitive field effect transistors) for monitoring electrolytes in sweat to alert and prevent dehydration during physical exercise. The sensor is mounted on the user's arm, with the ISFET gate in contact with the skin. The ISFET interfaces with an active circuit shown below to measure the concentration of targeted ions S^+ in the sweat. $V_S = 100$ mV, $R_i = 100\ \Omega$, $R_a = 1\ \mathrm{M}\Omega$, $R_b = 1\ \mathrm{k}\Omega$, and $R_c = 1\ \mathrm{M}\Omega$. The conductance g_{ds} of the ISFET is approximately proportional to the ion concentration:

$$g_{ds} = \frac{W}{L}\,\mu\,k\,[S^+]$$

with width $W = 100\ \mu$m, length $L = 10\ \mu$m, electron mobility $\mu = 0.1$ m^2/Vs, and charge-coupling factor $k = 0.1$ CL/m^{2}mol.



(a) [10 pts] Derive V_o as a function of the target ion concentration $[S^+]$, and write the sensitivity of the sensor. What is the smallest concentration that you can detect if the output V_0 is quantized with 1 mV LSB resolution?

(b) **[IC]** [10 pts] What purpose does R_i serve in protecting the health of the user and the circuit from accidential electrical shorting of the ISFET? Explain.

4. **Design Problem [30 pts]:** Design a pulse oximeter system using a 1.2 V battery, a single red LED, a single infrared LED, and a single photodiode that is equally sensitive to red and infrared light. The red and infrared LEDs need to be activated at 1 kHz pulse rate in alternating fashion (0.5 ms red followed by 0.5 ms infrared, repeated at 1 kHz rate). Your system should output two voltage signals, one directly proportional to incident red light intensity and the other directly proportional to incident infrared light intensity on the same photodiode. You may use as many resistors, capacitors, opamps, timers, switches, and gates as you need. Protect your circuit from accidental shorting of the voltage output so that no more than 100 μA may be drawn from the output.
Hint: In the reverse bias mode, a photodiode outputs a current that is linearly proportional to light intensity.