Name (Last, First): ______________________________

BENG 186B Winter 2013

Final

- This exam is closed book, closed note, calculators are OK.
- Circle and put your final answers in the space provided; show your work only on the pages provided. Include units.
- Do not attach separate sheets. If you need more space, use the back of the pages.
- Points for each problem are given in [brackets], 100 points total.

1	/10
2	/16
3	/10
4	/10
5	/15
6	/5+
7	/10
8	/10
9	/10
10	/4
Total	/100

Useful schematics and equations:

The Goldman-Hodgkin-Katz (GHK) equation:

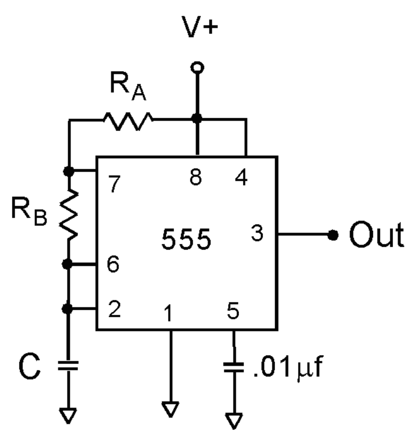
$$E = (60mV) \cdot \log_{10} \frac{P_K[K^+]_o + P_{Na}[Na^+]_o + P_{Cl}[Cl^-]_i}{P_K[K^+]_i + P_{Na}[Na^+]_i + P_{Cl}[Cl^-]_o}$$

Common mode gain and differential gain:

$$v_o = A_d\, v_d + A_c\, v_{cm}$$

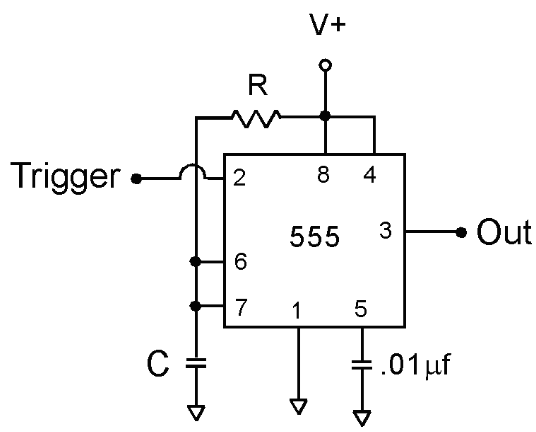
$$v_d = v_a - v_b$$

$$v_{cm} = (v_a + v_b) / 2$$



Oscillator

$T_{High} = 0.7\,(R_A + R_B)\,C$; $T_{Low} = 0.7\,R_B\,C$



One-shot

$T_{Pulse} = 1.1\,R\,C$

1. Circle the letter of the best (one and only one) answer for each. [10 pts; 1 pt each]

A) Precision of an instrument is:

a) Largest signal that it can measure without distortion.
b) Difference between its true output and its measured value.
c) Standard deviation of its measured output.
d) Smallest measurable increment in its output.
e) Ratio of signal amplitude over noise amplitude.

B) A second-order system with decaying oscillatory output in response to a step input is:

a) Overdamped.
b) Unstable.
c) Undamped.
d) Underdamped.
e) Critically damped.

C) Inertance in a hydraulic system is related to:

a) Fluid viscosity.
b) Compliance of the catheter.
c) Cross-sectional shape of the pipe.
d) Air bubbles.
e) Conservation of momentum.

D) For blood flow measurement by bolus injection of a fixed amount of contrast agent, a larger area under the measured concentration curve indicates:

a) Higher flow.
b) Lower flow.
c) No change in flow.
d) More flow delay.
e) No flow.

E) Choose the correct answer.

a) EOG signal can show up in EEG measurements.
b) ECG is commonly an invasive procedure.
c) ERG is used to measure eye movements.
d) ECoG measures electrical activity in the colon.
e) EMG measures the electrical activity of smooth muscle.

F) When positive electrical current passes through an Ag/AgCl electrode immersed in a KCl solution:

a) More AgCl deposits onto the electrode.
b) Some of the AgCl on the electrode dissolves into the solution.
c) Electrons leave the solution.
d) Electrons enter the solution.
e) None of the above.

G) Choose the correct answer.

a) Arterial pressure is lower than venous pressure.
b) The sounds heard when the blood pressure cuff relaxes originate in the heart.
c) Electrostatic potential across a blood vessel in a magnetic field is proportional to blood velocity.
d) Tonometers measure frequency shift in reflected sound.
e) None of the above.

H) What is the purpose of DRL with a bioinstrumentation amplifier?

a) To increase the CMRR of the amplifier.
b) To reduce power consumption of the amplifier.
c) To increase input impedance of the amplifier.
d) To increase the grounding impedance of the body.
e) None of the above.

I) PO_2 is measured with:

a) A Clark electrode.
b) A Severinghaus electrode.
c) A pH electrode in a buffer of saturated $NaCO_3$.
d) Pulse oximetry.
e) None of the above.

J) A microshock is:

a) A minor electrical shock above the perception threshold, but below fatality levels.
b) An electrical shock caused by an optical fiber catheter.
c) An electrical shock where some part of the current passes through the heart.
d) An electrical shock where all current passes through the heart.
e) The minor effect on the human body of electrostatic discharge in improperly grounded bioinstrumentation.

2. Short answer, write your answer only in the space provided. [16 pts; 2 pts each]

(a) What is the relative accuracy (tolerance) of a stretchable resistor with strain gauge factor G = 2 and Young's modulus E = 10 kPa as it undergoes up to 100 Pa stress due to stretching?

(b) An operational amplifier (opamp) has a gain-bandwidth product of 10^6 Hz, and a DC open-loop gain of 10^4. What is the cut-off frequency of the open-loop opamp? What is the cut-off frequency of the closed-loop opamp connected as a non-inverting amplifier with unity gain (voltage buffer)?

(c) What is the difference between ENG and EMG?

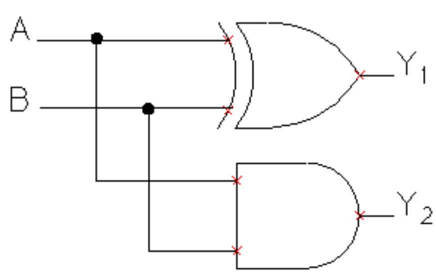
(d) Show a simplified circuit model of the electrode-skin impedance and identify key components in the model.

(e) Using Einthoven's triangle, express lead voltages III and aVL in terms of lead voltages I and II.

III =

aVL =

(f) Find the binary values of outputs Y1 and Y2 for all binary values of inputs A and B in the table below. What binary arithmetic does this circuit implement?

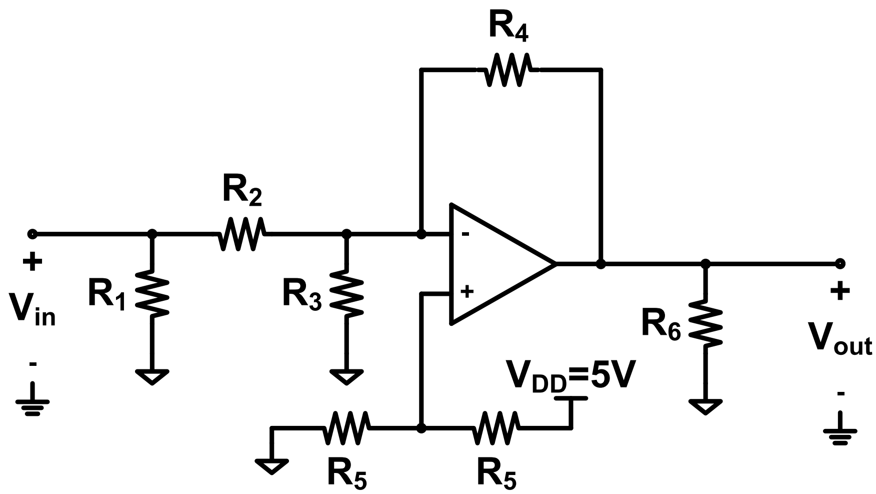


A	B	Y_1	Y_2
0	0		
0	1		
1	0		
1	1		

(g) What is the Doppler frequency shift for blood moving at velocity $v = 1$ m/s towards an ultrasonic transmitter and receiver of frequency $f = 1$ MHz and wave propagation speed $c = 10^3$ m/s?

(h) What is the use of adding a large resistance in series with the output of an opamp, when feeding back this output to the inverting input of the opamp through another resistor?

3. [10 pts]. Consider the following amplifier circuit with resistances $R_1 = 1\ k\Omega$, $R_2 = R_3 = 10\ k\Omega$, $R_4 = 1\ M\Omega$, $R_5 = 100\ k\Omega$, and $R_6 = 1\ k\Omega$. You may assume that the op-amp is ideal and not saturated.



(a) [6 pts] Find the output voltage V_{out} as a function of input voltage V_{in}.

Answer: V_{out} = ______________________

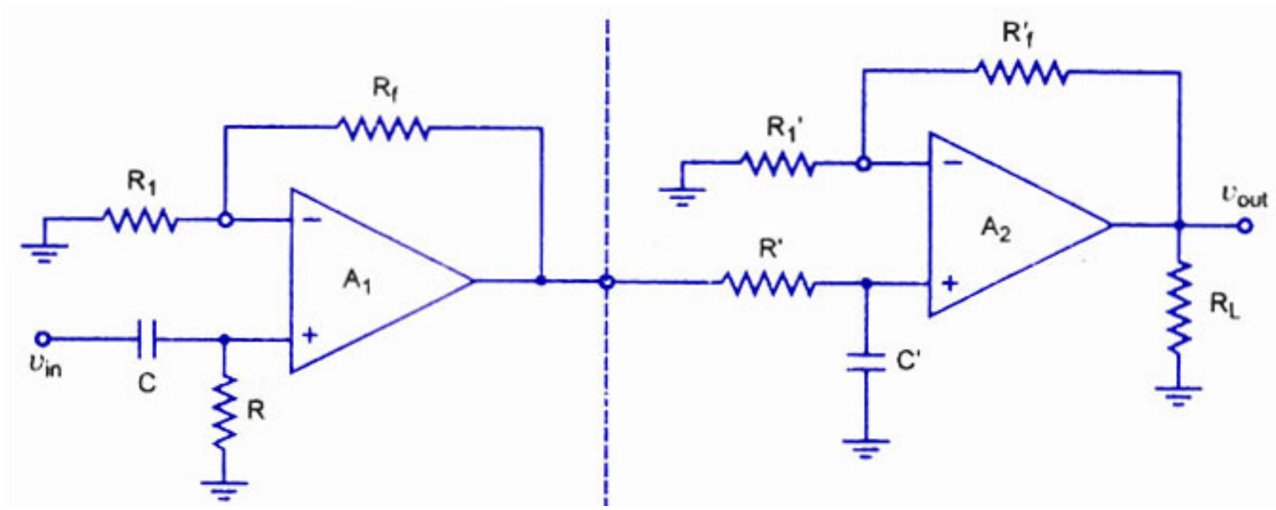
(b) [2 pts] Find the input impedance Z_{in}.

Answer: Z_{in} = ______________________

(c) [2 pts] Find the output impedance Z_{out}.

Answer: Z_{out} = ______________________

4. [10 pts]. A typical EMG bioamplifier circuit is given below. You may assume that the op-amps are ideal and not saturated.



(a) [5 pts] Find the transfer function $H(j\omega) = v_{out}(j\omega) / v_{in}(j\omega)$.

Answer: $H(j\omega) =$ ________________________________

(b) [5 pts] Find the maximum gain, low cutoff frequency, and high cutoff frequency of the filter response for $R_1 = R'_1 = 10$ kΩ, $R_f = R'_f = 1$ MΩ, R = 1 MΩ, R' = 10 kΩ, $R_L = 100$ kΩ, and C = C' = 100 nF. Sketch the Bode plot (log amplitude and phase as a function of log frequency). *Note*: $1 / 2\pi = 0.159\ldots$

Answers: A_{max} = ______________

f_{low} = ______________ (Hz)

f_{high} = ______________ (Hz)

(Bode plot on the next page.)

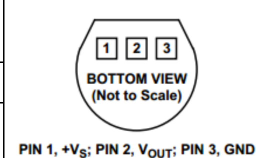
5. [15 pts] *Saccharomyces cerevisiae* is a species of yeast, which has been historically used to convert carbohydrates to carbon dioxide and alcohol. Looking to accelerate the brewing process of your favorite homemade beer, you create an incubator to optimize the fermentation process by maintaining the brewing temperature at its optimal value (see Table 1). For this, you have constructed the circuit shown in the figure below, which consists of a linear-output temperature sensor TMP36 (specifications in Table 2), an amplifier, and a comparator. This circuit is used to turn an electronic heater on and off by digitally controlling a solid-state relay (switch).

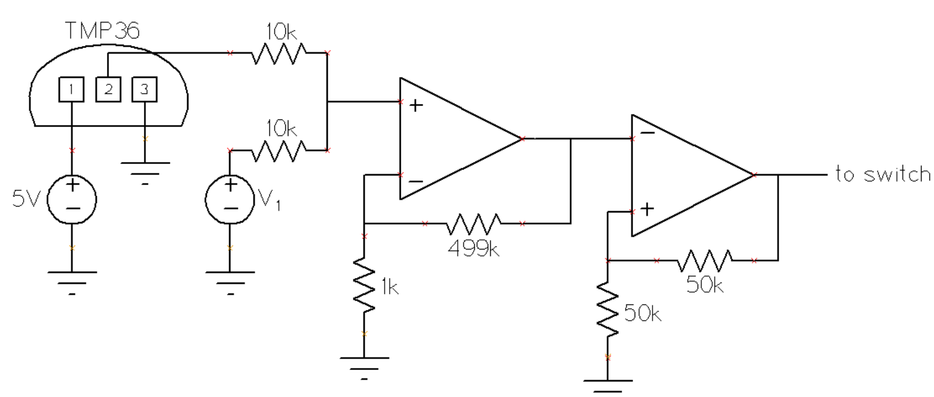
Table 1: Release of CO_2 (in grams) at 20, 25, 30, 35, and 40 °C.

Temperature (°C)	Mass CO_2 (g)	Averaged Mass CO_2 (g)
20	1.82 1.94	1.88 ± 0.06
25	2.91 2.75	2.83 ± 0.08
30	4.10 4.06	4.08 ± 0.02
35	5.17 4.97	5.12 ± 0.05
40	2.23 1.91	2.07 ± 0.16

Slaa, J., Gnode, M., & Else, H., "Yeast and fermentation: the optimal temperature", Journal of Organic Chemistry: Chem. Dut. Aspects 134, October, 2009.

Table 2: Specifications of TMP36.

Component	TMP36		
Description	Temperature sensor, which outputs an analog voltage (V_{out}) proportional to ambient temperature.		
Pin 1 (+Vs)	Source voltage	Between 2.7V and 5.5V	
Pin 2 (Vout)	Output voltage (linear with temperature)	0V at -50°C 1.75V at 125°C	
Pin 3 (GND)	Ground	Ground	



Temperature control circuit. All opamps are ideal and powered with –5V and +5V.

Using the data in Table 1, the datasheet specifications of the TMP36 in Table 2, and the following observations, answer the questions below.

Obs. 1: The output of the TMP36 is linear with the temperature (see Table 2).

Obs. 2: The opamps are ideal and operate between –5V and +5V.

Obs. 3: The output at +5V turns the heater on, while –5V turns it off.

a) [2 pts] What is the ideal brewing temperature?

Answer: T_{ideal} = ______________________

b) [3 pts] What are the outputs of the TMP36 at temperatures of –1°C and +1°C around the ideal temperature?

Answers: V_{below} = ______________________ (–1°C below T_{ideal})

V_{above} = ______________________ (+1°C above T_{ideal})

c) [10 pts] Select the ideal value of V_1 (a constant voltage between the –5V and +5V supplies) in the circuit in order to maintain the brewing temperature between –1°C and +1°C of the ideal temperature (as to avoid erratic switching of the heater).

Answer: $V_1 =$ ____________________

6. [5 pts] Design an implantable pacemaker circuit that outputs a periodic voltage pulse of duration 1 ms, period 1 s, and amplitude +3.6 V from ground. You can use 1.2 V buttoncell batteries, 555 timers, OP27 opamps, LM311 comparators, 10 nF capacitors, any size resistors, and any logic gates.

BONUS [+5 pts extra]: Design your circuit with short-circuit protection, with output impedance less than 1 Ω, but with maximum output current ±360 μA.

7. [10pts] Find the resting potential of a membrane permeable to K^+, Na^+, and Cl^- considering that:

- The permeability of Na^+ is half of the permeability of K^+.
- The permeability of Cl^- is half of the permeability of Na^+.
- The concentration of K^+ is the same inside and outside.
- The outside concentration of Na^+ is four times the concentration of K^+, and the inside concentration of Na^+ is eight times smaller than K^+.
- The outside concentration of Cl^- is half that of Na^+, and the inside concentration of Cl^- is four times that of Na^+.

Answer: E_{resting} = ______________________________

8. [10 pts] The following table represents the absorptivity of two similar compounds in a substance as a function of wavelength.

Compound	**500nm**	**800nm**
A	3 l/mmol m	2 l/mmol m
B	1 l/mmol m	2 l/mmol m

You test a particular compound and find it to have equal absorbance of 0.1 at 500 nm and 800 nm wavelength, through 1 cm of tissue.

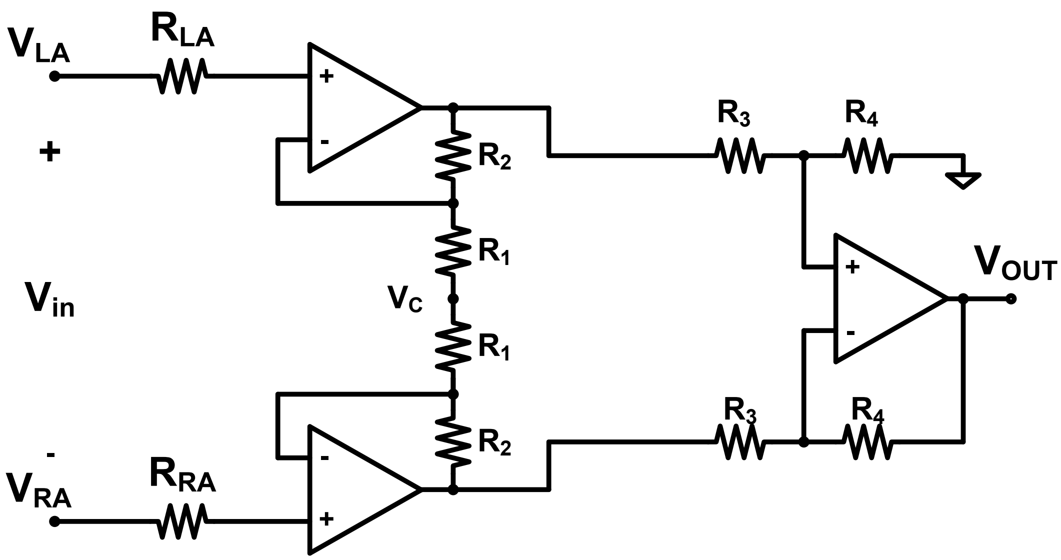
Beer's law of volume absorbance: $A(\lambda) = W\, L\, a(\lambda)$

a) [3 pts] What is the concentration of the combined substance?

b) [5 pts] What are the relative amounts of the two compounds?

c) [2 pts] What is the isosbestic wavelength for these two compounds?

9. [10 pts] Consider the bioinstrumentation amplifier shown below with circuit resistances $R_1 = R_3 = 1$ kΩ, $R_2 = R_4 = 100$ kΩ and with electrode-skin contact resistances $R_{LA} = 110$ kΩ and $R_{RA} = 90$ kΩ. The opamps are ideal except with input impedance $R_{in} = 200$ MΩ to ground on each of their inputs.



a) [8 pts] Find the differential gain A_d, common mode gain A_{cm}, and effective CMRR of the bioamplifier.

Answers: $A_d =$ ______________

$A_{cm} =$ ______________

$CMRR_{eff} =$ ______________

b) [2 pts] What would be the effect of shorting the V_c node to ground on the operation of the circuit?

10. [4 pts]

Wireless Non-contact ECG and EEG

a) [1 pt] What is required of a bioamplifier to acquire an ECG signal through a capacitive non-contact electrode?

b) [1 pt] Give one example of a convenient recording site for ECG routine measurements that does not rely on patient compliance.

Wireless and Global Health

a) [1 pt] What has historically been the greatest advance in public health?

b) [1 pt] Give one example of a wireless health engineering “solution” that does not solve a biomedical problem.