University of California Berkeley
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LABORATORY 5 v1

OPERATIONAL AMPLIFIER

Integrated operational amplifiers—opamps for short—became widely available with the introduction of the µA709 designed by the legendary Bob Widlar in 1965. This part was rapidly superseded by the 741 which has better performance and is still in wide use. Today well over a hundred different versions of opamps are available. Opamps are arguably the most widely used analog circuit components.

The ideal opamp (Figure 1) produces an output that is the difference Vi+-Vi- of its inputs gained up by infinity. Practical opamps deviate from this ideal somewhat. For example, the gain of the opamp we are using in this lab is only about two million. In many applications these deviations from ideality do not introduce significant errors. Real operational amplifiers of course must be connected to a power supply which to reduce clutter is often now shown in the schematic diagram.

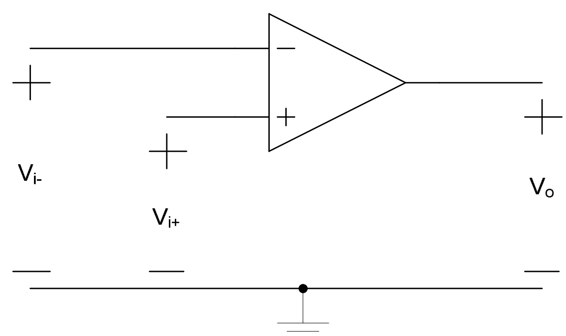


Figure 1 Ideal operational amplifier

Although an amplifier with infinite gain does not appear to be particularly useful, using only few extra components opamps can be configured to perform a very wide range of tasks and find almost universal application in interfacing sensors to other electronic circuits. In this laboratory we will focus on amplification and buffering, two tasks operational amplifiers excel at. We will also design the electronics for a pH (acidity) meter.

Before reading on please download the datasheet for the LMC6483. It contains a lot of information such as the supply voltage and temperature range over which the amplifier can be used. Like most datasheets this one also has a section on applications with many circuit suggestions. Datasheets are usually a very valuable source of information and I recommend that you make it a habit to check them out, at the minimum to get the connection diagram of the device.

LAB REPORT

Lab Session:

Name 1: SID:

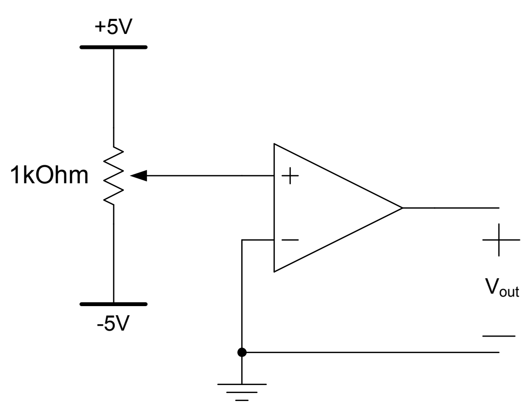
Name 2: SID:

In this laboratory we will be using the LMC6482 from National Instruments. An 8-pin package contains two identical operational amplifiers (check the datasheet for the pinout). You can use either opamp in these experiments. It's always a good idea to tie unused inputs to a known potential (e.g. ground) to avoid excessive power dissipation or other problems, but for this laboratory you probably will get by with just ignoring the unused part. We will power the operational amplifiers from ±5V (i.e. V^-=-5V and V^+=5V) in all experiments described in this laboratory and will not show the supply connections in schematics. Note that the operational amplifier has no dedicated terminal for ground.

1. Openloop Operation

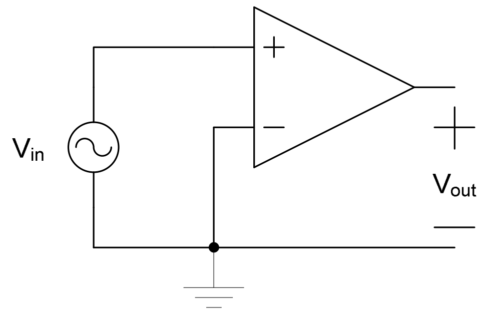
Let's first check that the operational amplifier is working and indeed has a very large gain. Set up the circuit below and adjust the potentiometer such that V_{out} = 0V. It's unlikely that you in fact will be able to do this because (explain):

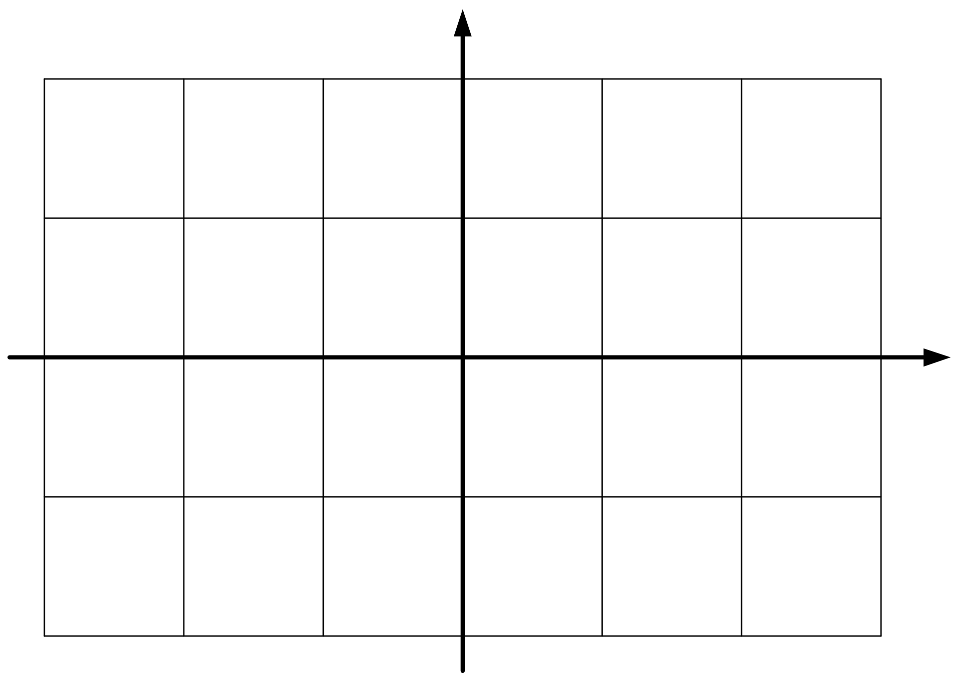
___ of 3 **P**



Draw the openloop V_{out} versus V_{in} characteristic of the operational amplifier.

- Draw the expected V_{out} versus V_{in} characteristics on the plot and copy the plot to your prelab
- Turn on the oscilloscope
- Change the scope to XY mode by pressing the Main/Delayed button followed by the XY soft key
- Set the function generator to sine wave output at 10 Hz with 100mV peak to peak amplitude
- Label the axes (variable, units, ticks) in the graph below and show the measured result in a different color than the expected result.





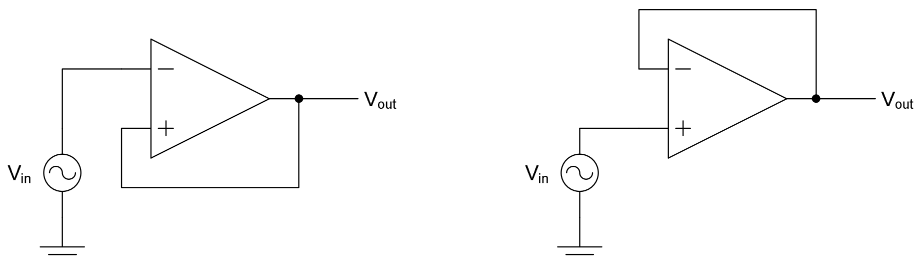
Expected characteristic: ____ of 3 **P**

Measured characteristic: ____ of 3 **M**

Explain discrepancies: ____ of 3 **M**

2. Positive and Negative Feedback

Most practical opamp circuits use feedback to set the gain to an accurate and reasonable (e.g. 10) value. This works very well – provided that the feedback is connected correctly. Here we compare opamps with positive and negative feedback.

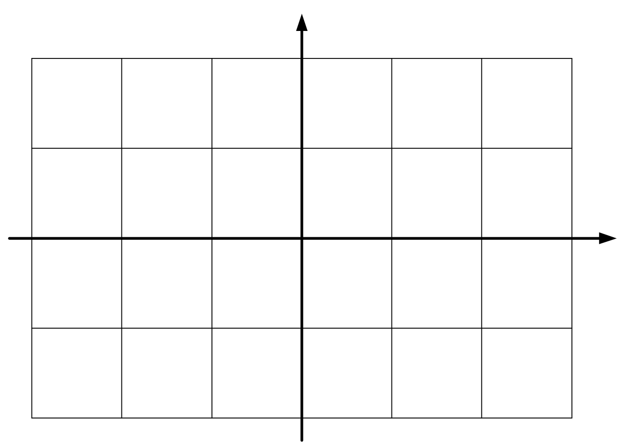


A B

Which of the two circuits, A or B, is configured for negative feedback?

Circuit with negative feedback: ______ ___ of 2 **P**

- Simulate and measure V_{out} versus V_{in} for the circuit with negative feedback
- Setup a DC sweep of the input V_{in} from -5V to +5V and plot the output as a function of input
- Attach your simulation plot to your prelab and copy to the plot below
- Build the negative feedback circuit and generate the XY plot just as you did in part 1
- Copy your measured results to the plot below
- Repeat all above with a positive feedback circuit
- Explain what's happening and summarize your result in the graph



Simulation: ___ of 3 **P**

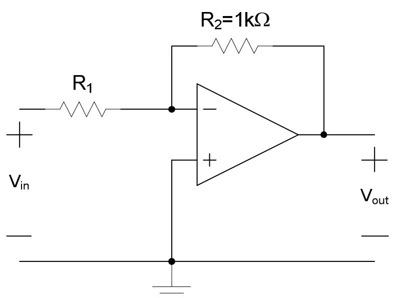
Measurement: ___ of 3 **M**

Explanation: ___ of 3 **M**

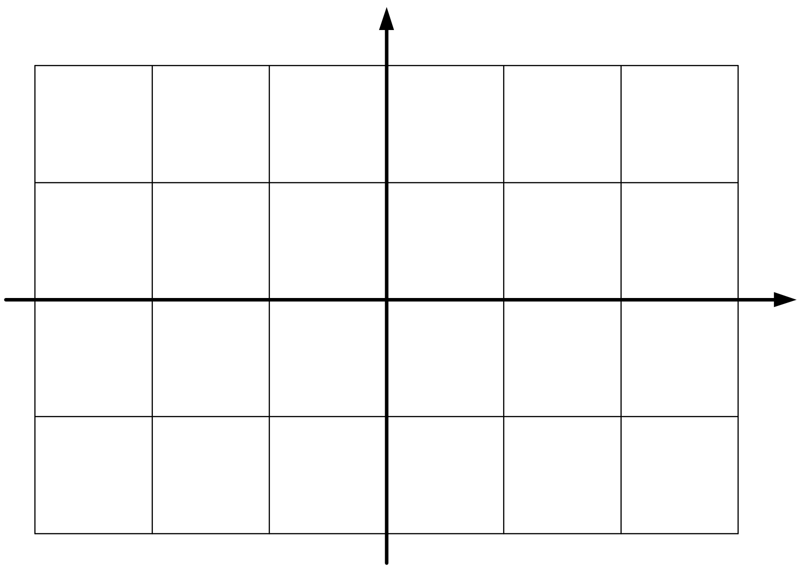
3. Voltage Gain

Now let's use the operational amplifier with feedback as shown below. What is the value of R_1 that results in a gain V_{out}/V_{in}= -10?

Value for R_1: ______ Ω ___ of 2 **P**



- Calculate the expected V_{in} to V_{out} relationship and plot below
- Measure the gain V_{in} to V_{out} relationship using the XY plot on the oscilloscope with a 1kHz, 1V peak to peak sine wave
- Include your measured result below
- Explain discrepancies.



Simulation: ___ of 3 **P**

Measurement: ___ of 3 **M**

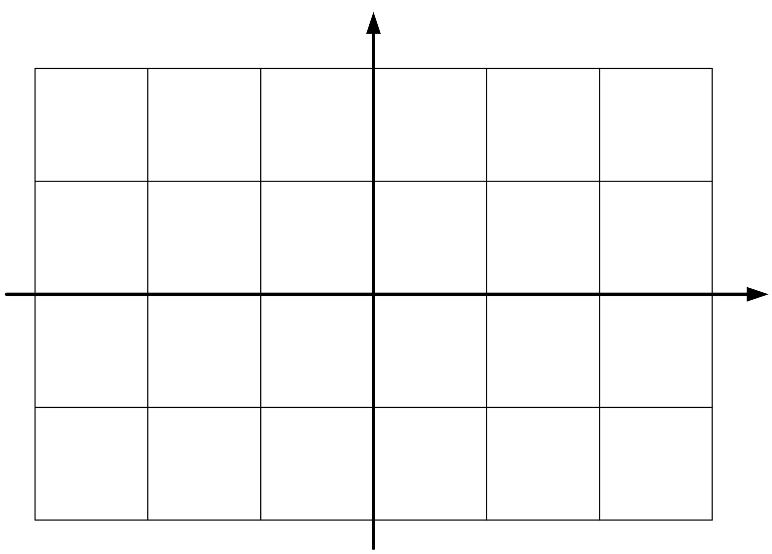
Discrepancies: ___ of 3 **M**

4. Buffers

In the previous experiment you had to take the 50Ω output resistance of the function generator into account to get the correct gain. This is possible when the output impedance is known. However, often the output impedance of a source (often a sensor) is not known and may even vary from part to part or with temperature. The problem with the inverting amplifier configuration is its finite input resistance, R_1. Non-inverting gain stages have infinite (or nearly infinite) input resistance. Since no current is flowing, the value of the source resistance does not matter for the gain. Build and measure the IO characteristics of a non-inverting amplifier for R_s=0Ω, 1kΩ, and 100kΩ. Set V_{out}/V_{in}=11 choose the smaller of the gain setting resistors to be equal to 1kΩ. Calculate the correct value of the other resistor.

Circuit diagram for a non-inverting amplifier. Label the resistors (including Rs, the series output resistance of the sensor):

Diagram ___ of 5 **P**



Measurement (3 traces): ___ of 5 **M**

5. Electronic Interface for a pH Sensor

In this part you will design the electronic circuits for a pH sensor. The pH is an important for characterizing acidity. You can read up on it e.g. on the Wiki (http://en.wikipedia.org/wiki/PH).

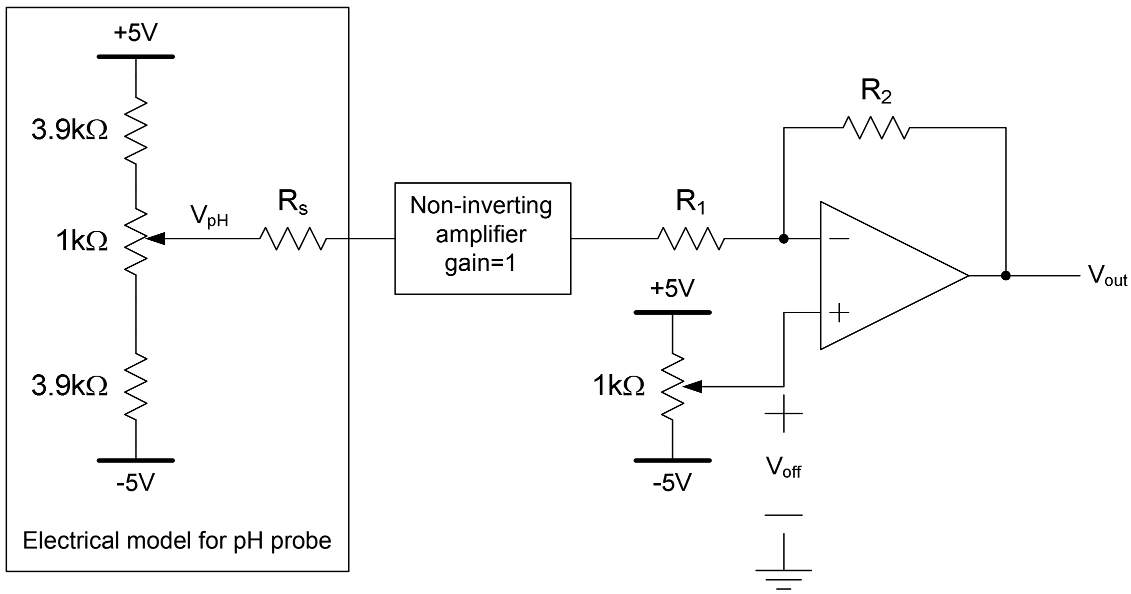
The pH of a fluid is measured with an electrode and produces a voltage according to the following equation (standard Ag/AgCl pH probe at 25°C):

$$V_{pH} = -(pH - 7) \times 59.16 \frac{mV}{pH}$$

The table below gives a few examples for *pH* and electrode voltage V_{pH}:

pH	V_{pH}	V_{out}
0	414.12mV	0V
4	177.48mV	1V
7	0V	1.75V
14	-414.12mV	3.5V

One of the challenges is that the output resistance of pH electrodes is very high and variable, typically in the range of R_s = 50MΩ … 500MΩ. You are to design an amplifier that produces $V_{out}=pH/4$ from V_{pH}. The diagram below shows the conceptual circuit:



To develop our circuit we will not actually work with acids and electrodes but instead simulate the behavior with a circuit that has the same electrical behavior. The amplifier consist of a non-inverting stage with gain one followed by an inverting amplifier.

- First derive an expression for V_{out} as a function of R_1, R_2, V_{off} and V_{pH}

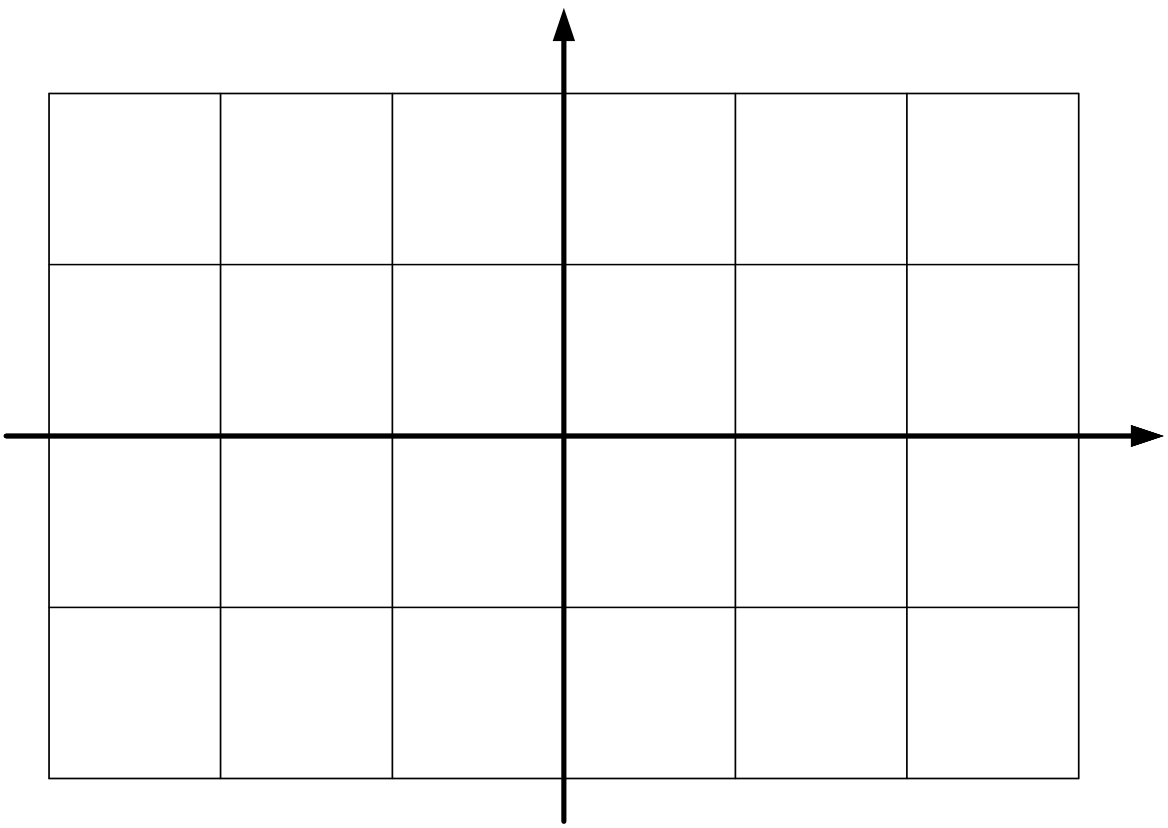
- Find appropriate values for these components such that for V_{out}= pH/4 from the electrode voltage V_{pH}. Chose R_1=1k. You can solve for R_2 and V_{off} by plugging in some of the values of V_{pH} and V_{out} as given in the table above
- You may have to combine several resistors or add a potentiometer in series with R1 to get a sufficiently accurate value for the gain
- Verify your circuit with the simulator with R_s=100kΩ and 1MΩ
- Test your circuit with R_s=100kΩ and 1MΩ
- Plot V_{out} versus V_{pH} in the range V_{out} =0 … 3.5V.

Although real pH electrodes have higher R_s, we use these smaller values in the laboratory since it is difficult to get reliable results on with higher valued resistors on solderless breadboards. An actual design would be fabricated on a printed circuit board to avoid these problems. We will work with printed circuit boards in later laboratories.

Calculated value for R_1: ______ kΩ ___ of 2 **P**

Calculated value for R_2: ______ kΩ ___ of 2 **P**

Calculated value for V_{off}: ______ V ___ of 2 **P**



Simulated V_{out} vs V_{pH}: ____ of 10 **P**

Measured V_{out} vs V_{pH}: ____ of 10 **M**

SUGGESTIONS AND FEEDBACK

Time for completing prelab:

Time for completing lab:

Please explain difficulties you had and suggestions for improving this laboratory. Be specific, e.g. refer to paragraphs or figures in the write-up. Explain what experiments should be added, modified (how?), or dropped.

PRELAB SUMMARY

Lab Session:

Name 1: SID:

Name 2: SID:

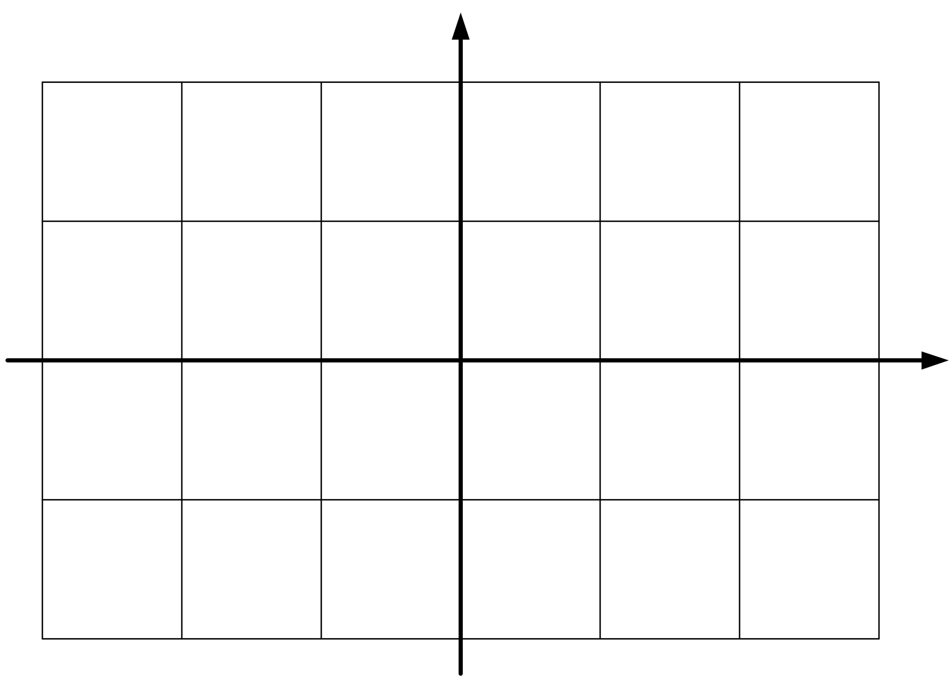
Summarize your prelab (P) results here and turn this in at the beginning of the lab session.

1. Openloop Operation

Explain why it is unlikely that you in fact will be able to make $V_{out} = 0V$

___ of 3 P

Expected openloop characteristics



___ of 3 P

2. Positive and Negative Feedback

Circuit with negative feedback: ______ ___ of 2 P

Simulation: (Please attach) ___ of 3 P

3. Voltage Gain

Value for R_1: ______ Ω ___ of 2 P

Simulation: (Please attach) ___ of 3 P

4. Buffers

Circuit Diagram ___ of 5 P

5. Electronic Interface for a pH Sensor

Calculated value for R_1: ______ kΩ ___ of 2 **P**

Calculated value for R_2: ______ kΩ ___ of 2 **P**

Calculated value for V_{off}: ______ V ___ of 2 **P**

Simulated V_{out} vs V_{pH}: ___ of 10 **P**