1. **OPTIONAL: Power to Resist (from Spring 2018 midterm 2)**

Find the power dissipated by the voltage source in the circuit below. Be sure to use passive sign convention.
2. OPTIONAL: Amplifier with Multiple Inputs

In this problem we will use superposition and the Golden Rules to find the output of the following op amp circuit with multiple inputs:

![Op Amp Circuit Diagram]

(a) First, let’s turn off \( v_{s2} \). Use the **Golden Rules** to find \( v_{o1} \) for the circuit below.

![Op Amp Circuit Diagram]
(b) Now let’s turn off $v_{o1}$. Use the **Golden Rules** to find $v_{o2}$ for the circuit below.
(c) Use superposition to find the output voltage $v_o$ for the circuit shown below.
3. **OPTIONAL: PetBot Design (from Fall 2016 Final exam)**

In this problem you will design circuits to control PetBot, a simple robot designed to follow light. PetBot measures light using a photoresistor, which is a light-sensitive resistor. As it is exposed to more light, its resistance decreases. The diagram below shows the circuit symbol for a photoresistor.

![Diagram of photoresistor](image)

The basic layout of PetBot can be seen below. It is driven by one motor that will be modeled as a resistor. PetBot drives forward (towards the said light source) when a positive voltage is applied across the motor, and conversely a negative applied voltage drives PetBot backward (away from the light source). In this system the light sensor is mounted to the front of the robot, and the speed of PetBot is proportional to the applied voltage to the motor.

(a) **Speed control**

In our first circuit design, we will begin by making PetBot decrease speed as it drives towards light. Design a motor-driving circuit that outputs a decreasing positive motor voltage as PetBot drives toward the light source. The motor voltage should be at least 5 V when far away from the light. At this far away from the light source, the photoresistor value will be 10kΩ, and then drop towards 100Ω as it approaches the light.

In your design, you may use any number of resistors and op-amps. You also have access to voltage sources of 10V and $-10V$. **Based on your circuit, derive an expression for the motor voltage as a function of the circuit components that you used.**

**NOTE!** Since the motor is a resistor, the circuit design MUST have a buffer so that the applied voltage to the motor does not depend on its resistance.
(b) Distance control

When the PetBot stops at a distance of 1 m away from the light, the photo-resistor has a value 1 kΩ. We would like to have the PetBot drive away when closer than 1 m from the light (so for lower $R_p$), and drive towards the light when exceeding 1 m (so for greater $R_p$).

**Design a comparator circuit that outputs a positive motor voltage when the PetBot exceeds 1 m in distance from the flashlight (making the PetBot move toward it), and a negative voltage when PetBot is within 1 m of flashlight (making the PetBot back away from the flashlight).**

In your design, you may use any number of resistors along with the comparator. You also have access to voltage sources of 10 V and −10 V.
4. **OPTIONAL: Capacitive Charge Sharing (from Spring 2020 Midterm 2)**

Consider the circuit below with $C_1 = C_2 = 1 \mu F$ and two switches $\phi_1, \phi_2$. Suppose that initially the switch $\phi_1$ is closed and $\phi_2$ is open such that $C_1$ and $C_2$ are charged through the corresponding voltage sources $V_{s1} = 1 V$ and $V_{s2} = 2 V$.

\[ \begin{align*}
& \phi_1 & u_1 & \phi_2 & \phi_1 \\
& \underline{V_{s1}} & C_1 & C_2 & \underline{V_{s2}}
\end{align*} \]

(a) How much charge is on $C_1$ and $C_2$? How much energy is stored in each of the capacitors? What is the total stored energy?

(b) Now suppose that some time later, switch $\phi_1$ opens and switch $\phi_2$ closes. What is the value of voltage $u_1$ at steady state?
### Reference Circuits

#### Voltage Divider

![Voltage Divider Circuit](image1)

\[ V_{R2} = V_S \left( \frac{R_2}{R_1 + R_2} \right) \]

#### Inverting Amplifier

![Inverting Amplifier Circuit](image2)

\[ V_{out} = V_{in} \left( -\frac{R_f}{R_s} \right) \]

#### Noninverting Amplifier

![Noninverting Amplifier Circuit](image3)

\[ V_{out} = V_{in} \left( 1 + \frac{R_{top}}{R_{bottom}} \right) \]

#### Current Divider

![Current Divider Circuit](image4)

\[ I_1 = I_S \left( \frac{R_2}{R_1 + R_2} \right) \]

#### Inverting Amplifier with Reference

![Inverting Amplifier with Reference Circuit](image5)

\[ V_{out} = V_{in} \left( -\frac{R_f}{R_s} \right) + V_{REF} \left( \frac{R_f}{R_s} + 1 \right) \]

#### Noninverting Amplifier with Reference

![Noninverting Amplifier with Reference Circuit](image6)

\[ V_{out} = V_{in} \left( 1 + \frac{R_{top}}{R_{bottom}} \right) - V_{REF} \left( \frac{R_{top}}{R_{bottom}} \right) \]

#### Voltage Summer

![Voltage Summer Circuit](image7)

\[ V_{out} = V_1 \left( \frac{R_2}{R_1 + R_2} \right) + V_2 \left( \frac{R_1}{R_1 + R_2} \right) \]

#### Unity Gain Buffer

![Unity Gain Buffer Circuit](image8)

\[ V_{out} = V_{in} \]