Name: ____ Date: _________________

Thermostat Circuit Worksheet

Part 1 — Build a thermostat from a circuit diagram

Use the circuit diagram in Figure 1 (below) to create a thermostat on your breadboard.

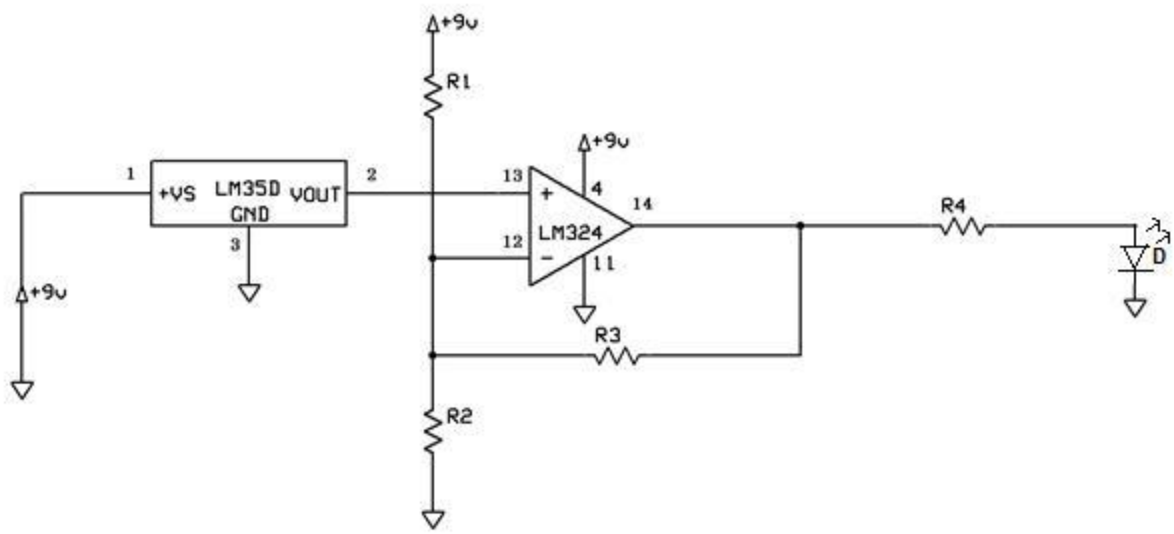

Figure 1: Circuit diagram for thermostat.

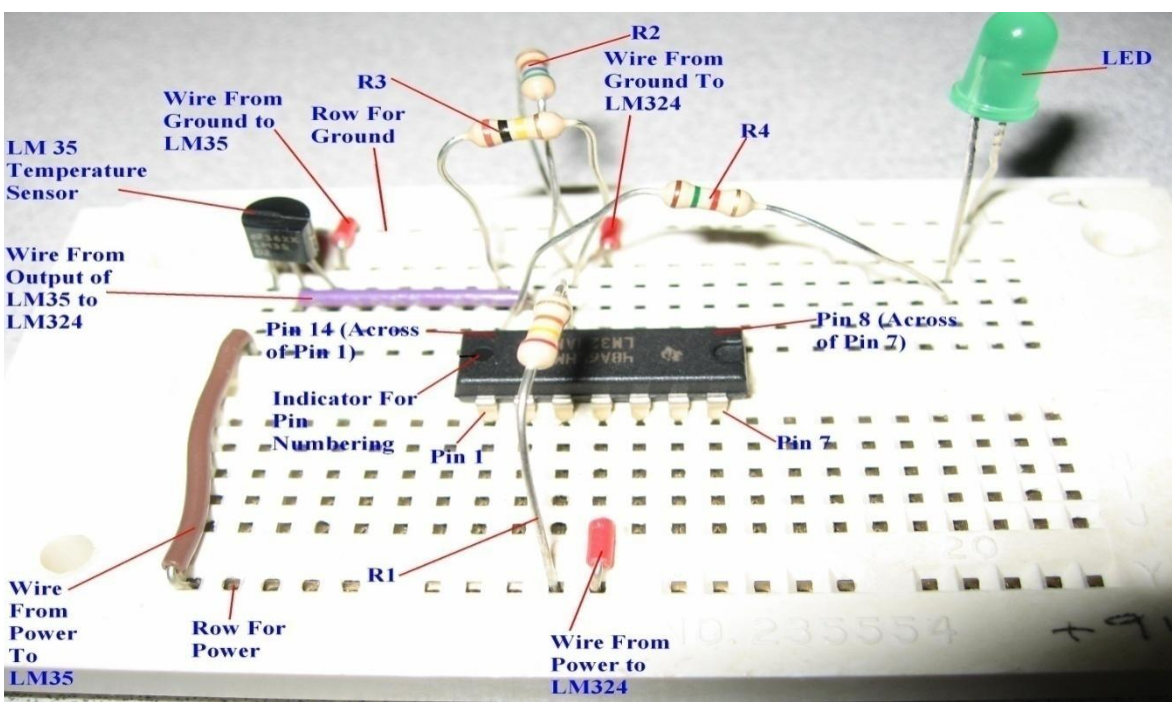

Figure 2. Finished circuit for thermostat.

Table 1 Circuit components in the circuit diagram.

Component	Part Number / Value
Power source	**9 Volt battery**
Temperature sensor	**LM35**
Operational amplifier	**LM324**
Resistor 1	**25 kΩ**
Resistor 2	**570 kΩ**
Resistor 3	**100 kΩ**
Resistor 4	**1.5 kΩ**
LED	**1.8V/20mA**

Part 2 — Circuit check

After building the circuit as shown in Figures 1 and 2, do a few quick checks to make sure that the circuit is properly assembled.

1. First, connect the battery terminals via wires to the breadboard power and ground rows.

   Look to see: Are any of the components smoking and/or getting extremely hot?

   > *If yes,* immediately disconnect the power by removing the power wire from the breadboard. After doing this, double-check the circuit diagram and your circuit to find out what needs to be fixed. *Tips:* Perhaps a wire or two are crossed, meaning they are going to the wrong place (for example, power when it should have been ground or terminal of an IC chip).

2. Next, use the multimeter to check the output of the temperature sensor. Since the temperature sensor should be at or about room temperature, the output should be reading about 210-230 mV, depending on the temperature in your room.

   Look to see: If the output is above 200 mV, check to make sure the LED is off.

   > *If the LED is on*, one or more of your resistances is incorrect or in the wrong place. Double-check the resistor placements and values found in Figure 1 and Table 1 respectively.

   Look to see: If the output is already below 200 mV, check to make sure the LED is on.

   > *If the LED is not on*, one or more of your resistances is incorrect or in the wrong place. Double-check the resistor placements and values found in Figure 1 and Table 1 respectively.

3. If all of these steps check out, there is a good chance your circuit is working properly!

Part 3 — Modeling the circuit (data recording)

1. After connecting the battery to the circuit, what is the measured value of the output voltage of the temperature sensor?
2. What temperature does this voltage equate to if the temperature sensor has an output of 10mV/°C?
3. Using a bag of ice to cool the sensor, what is the measured value of the output voltage as soon as the LED turns on?

4. What temperature does this voltage equate to?

5. Using heat from your fingers, what is the measured value of the output voltage as soon as the LED turns off?

6. What temperature does this voltage equate to?

Part 4 — Redesigning the circuit

After using this thermostat for a few weeks in a house, a few people have been complaining about the heater turning on too early and not staying on long enough. Using your values from the data recording section of the activity (Part 3), determine a new temperature range to use for the circuit that would allow the circuit to turn on later, and to stay on for longer.

1. What is your new temperature for when the LED should turn on?

2. What voltage does this equate to using the relationship given above between output voltage and temperature?

3. What is your new temperature for when the LED should turn off?

4. What voltage does this equate to?

The following equations and steps are used by engineers to determine the correct values for the resistors that are found in this type of circuit.

V_{A1}: Upper voltage limit (answer to question 4 above)

V_{A2}: Lower voltage limit (answer to question 2 above)

V_{CC}: Power source voltage (9V)

1. Determine ΔV_A (the hysteresis band) and n (proportionality constant) and record them in Table 2.

$$\Delta V_A = V_{A1} - V_{A2}$$
$$n = \frac{\Delta V_A}{V_{A2}}$$

2. Set R_3 to a large value, in our case we'll say 100 kΩ. Now determine R_1 and record these values in Table 2:

$$R_3 = 100\ k\Omega$$
$$R_1 = nR_3$$

3. Now determine R_2 and record its value in Table 2:

$$R_2 = \frac{\left(\frac{R_1 R_3}{R_1 + R_3}\right)}{\frac{V_{cc}}{V_{A1}} - 1}$$

(Notice that the numerator in this equation is also the equation for the equivalent resistance of R_1 in parallel with R_3) This equation is derived from analyzing the circuit using Kirchhoff's current and voltage laws and Ohm's Law.

4. The only resistance left is R_4. This resistance is, like R_3, set by us. We will keep R_4 the same value as found in the first circuit, Table 1. The exact reason for this will be investigated later. With these 4 resistor values you are now ready to redesign your circuit.

Table 2: Values for new circuit.

Resistor	Value
V_{A1}	
V_{A2}	
V_{CC}	**9V**
ΔV_A	
n	
R_1	
R_2	
R_3	**100 kΩ**
R_4	**1 kΩ**

Part 5 — Modeling the new circuit

1. With your new resistances in place, what is the measured output from the temperature sensor after connecting the battery? What temperature does this voltage equate to?

2. What is the measured value of the output voltage as soon as the LED turns on?

3. What temperature does this voltage equate to?

4. What is the measured value of the output voltage as soon as the LED turns off?

5. What temperature does this voltage equate to?

6. Do questions 3 and 5 match the temperature you chose as your new temperature range?

Part 6 — Analysis

1. This circuit uses the phenomenon called hysteresis, which can be observed in several branches of science, from biology to chemistry to economics. Hysteresis is a system that displays path-dependence, or memory. In other words, the output of the system depends on what has happened previously to the system. In what ways does this circuit fit this definition of hysteresis?

2. Which of the circuit components are used to introduce hysteresis into the system? (Hint: There are 4 of them.)

3. When the LED is off, is the output voltage, V_{out} , of the temperature sensor above zero or equal to zero? When the LED is on, is V_{out} above zero or equal to zero? Why?

4. Does your answer to Part 5, question 1 match closely with your answers to Part 3, questions 1 and 2? Why or why not?

5. Do your answers to Part 5, questions 2-5 match closely with your answers to Part 3, questions 3-6? Why or why not?

6. Knowing that a large current passing through the LED would burn out the LED, what role does R4 play in this circuit? Use a physical law to support your answer.