Module 1, Lesson 5 – Building a linear temperature sensor

Teacher

45 minutes

Purpose of this lesson

- Combine a thermistor with a potential divider circuit to build a sensor whose output varies linearly and positively with temperature.
- Use a multimeter to measure the output voltages of a circuit.
- Calibrate the temperature sensor.
- Carry out an experiment to empirically evaluate the accuracy of the sensor.

Materials

Copy of the lesson
1 Multimeter
1 9V battery
1 Battery snap
1 Resistor
1 Thermistor
1 Beaker
Ice
Hot water
1 Thermometer
Graph paper (or Excel)
Hook up wire
1 Soldering iron
Solder
Liquid electrical tape

Part 1 - Building a linear temperature sensor

Build the circuit shown in fig. 1. (NOTE: It will be helpful to coat the soldered thermistor/wire union with liquid electrical tape) If you wish to use your sensor to measure temperatures at different depths in a river, you may want to use long leads (e.g. 15ft) to the thermistor, so that you can lower it into the water to significant depths. You could also mark one foot intervals on these leads with tape, so that you can tell what depth the thermistor is in the water.

**Note to teacher: if your students use their temperature sensors to measure environmental temperatures, e.g. in a river or pond, you may find it useful to tape the sensor and cables to a long pole or piece of pvc tubing with calibration markings to estimate depth. Alternatively your students may wish to attach a (small) weight to the end of the sensor cable, to help it hang vertically when dangled in the water. Marking 1ft intervals on the leads will help students estimate the depth of the temperature reading.*

Use the multi-meter to measure the voltage across the 10kΩ resistor (using the multi-meter as a *volt meter* as shown in the circuit diagram). This voltage will be the “output signal” of the sensor. We will convert this output signal into an equivalent temperature.

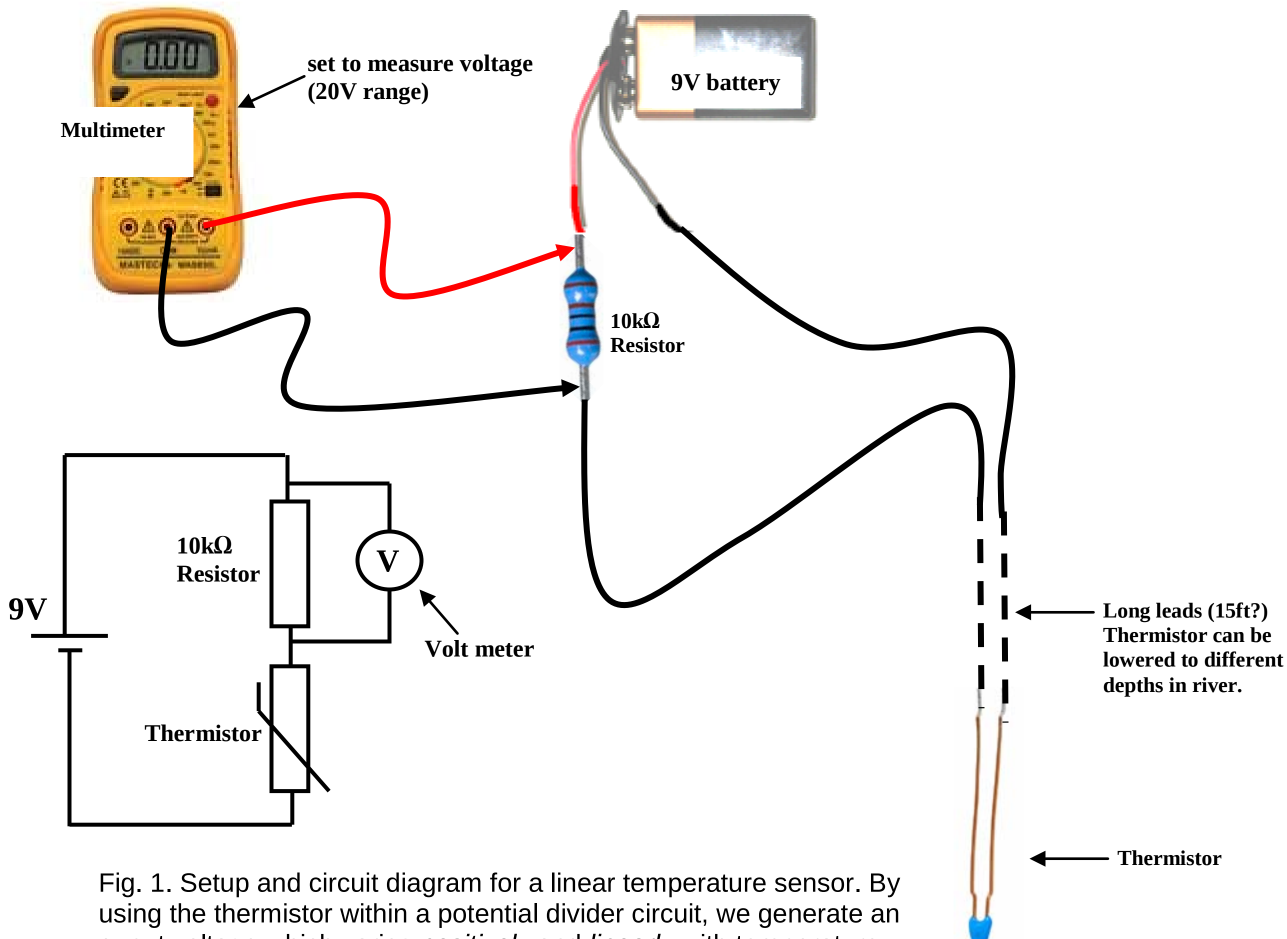


Fig. 1. Setup and circuit diagram for a linear temperature sensor. By using the thermistor within a potential divider circuit, we generate an ouput voltage which varies *positively* and *linearly* with temperature.

We could have just used the multimeter as an Ohm meter, as in lesson 3, to measure the resistance of the thermistor directly. We could then have used a graph or look up table (or perhaps a complicated formula) to convert resistance readings into temperature measurements.

The reason for building this new circuit is that its output varies *linearly* and *positively* with temperature. By understanding the math for an equation of a straight line (y=mx+b) a simple formula can be derived that will convert sensor outputs (voltages) into temperature measurements.

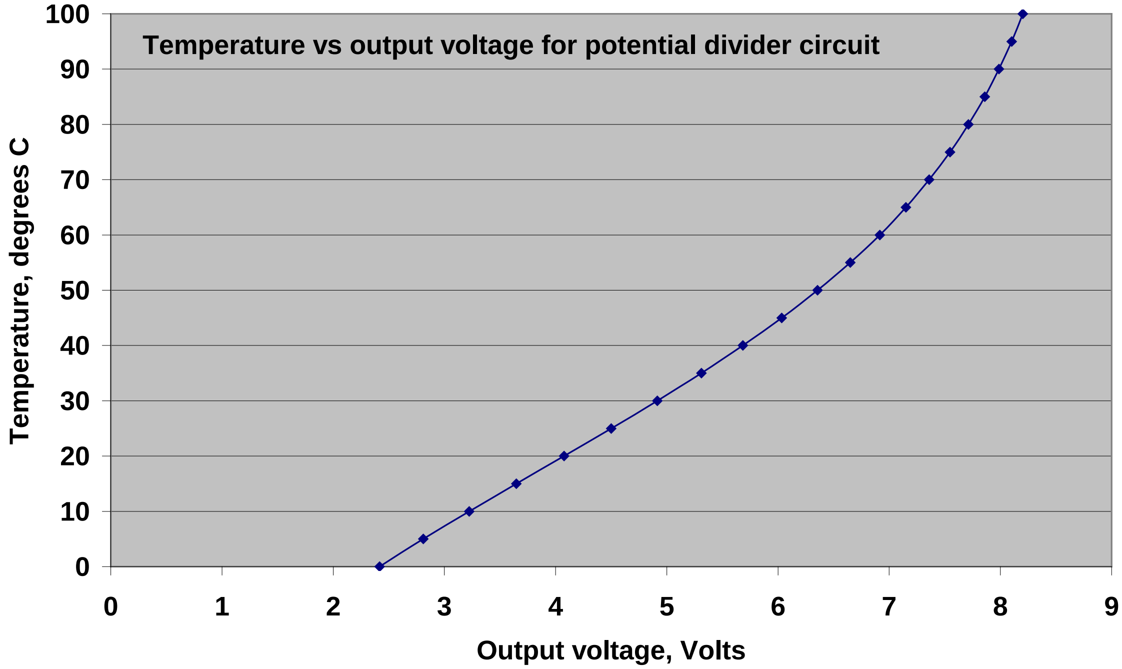
Part 2 - Calibrating your linear temperature sensor

2a) Using the above circuit, measure the output voltage (voltage across the 10kΩ resistor) while exposing the thermistor to a range of different temperatures. Place the thermistor in a cup of hot water. Measure the temperature with a thermometer and at the same time read the output voltage from the multi-meter. Now reduce the temperature by adding a little cold water and stirring/mixing well. Repeat over a range of temperatures, eventually adding ice to get down to 0°C. Record results in the table below (or similar) and then on a graph with temperature on the vertical axis (y-axis) and output voltage on the horizontal axis (x-axis).

Temperature, ºC	0	10	20	30	40	50	60	70	80
Output voltage, V_{out}	2.42	3.22	4.08	4.91	5.68	6.36	6.92	7.36	7.71

Answer: table shows results estimated for a 9V battery. Student voltages may be slightly smaller.

Your graph should look similar to the one in lesson 4.



2b) Is your graph exactly the same as the one you predicted in lesson 4? If not, can you suggest some reasons to explain any differences?

Answer: one reason for differences may be that, in lesson 4, part 2, you assumed that your battery was exactly 9V. In practice it may be rather less – around 8V.

2c) Over what range of temperatures is it reasonable to approximate your graph as being a straight line? Is this a useful range if you want to use your sensor to measure the temperature of the Hudson River?

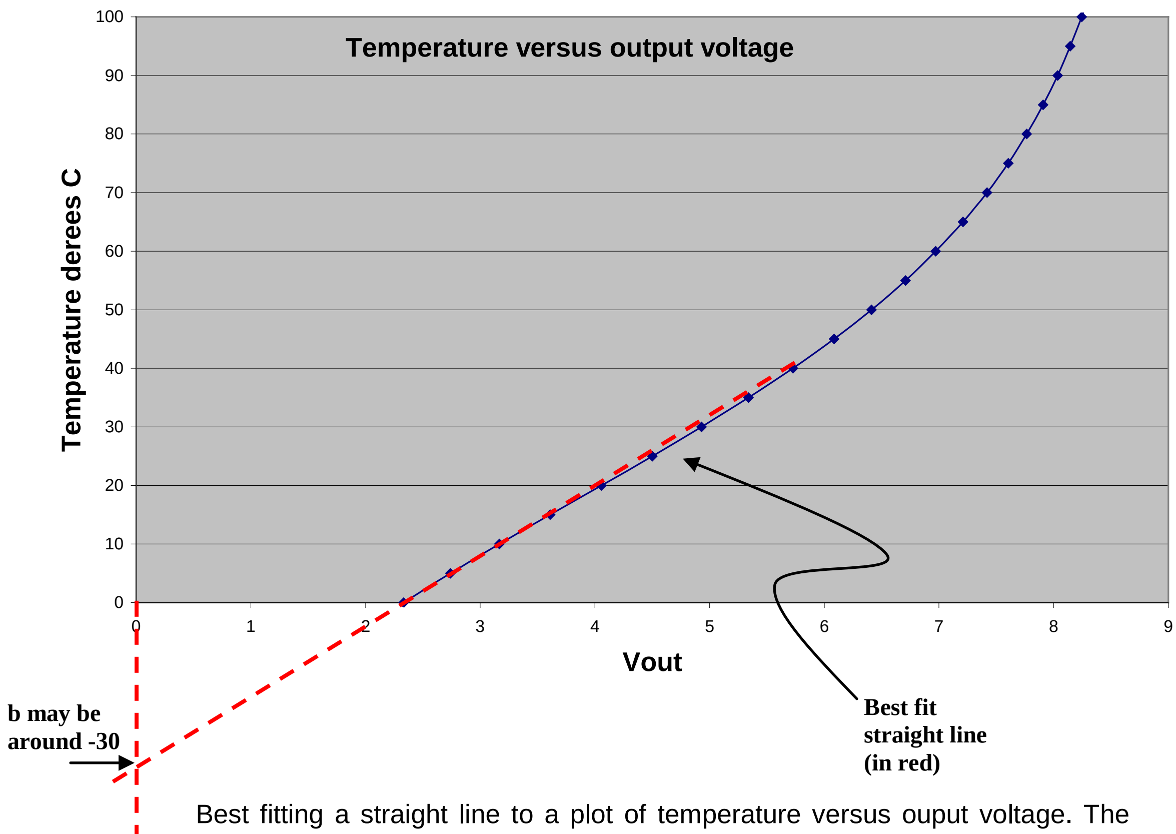
Answer: you should see good linear behavior from 0°C up to about 40°C. Yes, this is a good range of temperatures for measuring the river. It can't get colder than zero without freezing (in practice some salinity may enable slightly lower temperatures than zero Celsius), and it won't get hotter than 40°C (body temperature).

2d) Using a ruler, best fit a straight line to your graph over the range of values that you think can be reasonably approximate by a straight line (probably 0°C up to about 40°C).

2e) Derive the equation of this straight line using the formula y=mx+b. In this case your Y axis represents temperature, and X axis represents the sensor output voltage, V_{out}. Hence the equation of the straight line becomes:

$$\text{Temperature} = m \times V_{out} + b \qquad \textbf{equation 1}$$

Where m is the gradient and b is the height at which the line crosses the y axis. Note that b may be a negative number, i.e. the straight line may intersect the Y axis at a number below zero, see fig. 2. You can find b graphically by extrapolating the axes and your straight line as shown in red in the figure.



Best fitting a straight line to a plot of temperature versus ouput voltage. The straight line can be extrapolated to find its intercept with the Y axis (the value b). Note that b may be negative, typically taking values around -30.

Calculating the values of m and b is really the process of **calibration**. You have now found a simple formula which relates any sensor output, V_{out}, to Temperature (the quantity you want to measure). Now you can use your sensor system and your equation 1 to measure new unknown temperatures in the environment.

2f) How accurate do you think your sensor system is? Design and carry out an experiment to estimate the typical errors that will be associated with your sensor measurements.

Answers might include using the sensor with the straight line fit to measure the temperature of some water, and comparing this with the values given by a thermometer. Place the thermistor in a beaker of water with a thermometer. Read the sensor output voltage off the multimeter and simultaneously measure the water temperature with the thermometer. Now insert the voltage value into the straight line equation, with values of m and b as previously calculated, to calculate temperature. How well does this agree with the value that you read off the thermometer. Repeat this several times with water at several different temperatures. Ideally discuss the concept of root-mean-square with students and have them calculate an rms error. If this is beyond the mathematical capabilities of the students, they could calculate the average of the magnitudes of all the errors.

NOTE: You may elect to have your students use graphing calculators in this lesson.