Module 1, Lesson 4 - Potential dividers

Teacher

45 minutes

Purpose of this lesson

- Use and observe the behavior of potential divider circuits.
- Build potential divider circuits and measure voltages across resistors.
- Investigate how potential divider circuits can be used to change the output characteristics of a sensor.

**Notes for the teacher:*

- *This lesson does not use simultaneous equations and circuit analysis to derive a potential divider equation. If you want your students to analyze the circuits using Ohm's law, or practice solving simultaneous equations, then you should attempt the Module 1 Add-on Math Lesson first, before attempting Lesson 4 – Potential dividers.*
- *There are two* ***Assessment*** *sections with questions, one at the end of Part 1, and another at the end of Part 2. These exercises are presented separately to avoid confusion.*
- *Part 2 can be given as a homework exercise, in preparation for Lesson 5. Part 2 does not require any equipment or experiments, but simply asks students to use their knowledge and data to predict what will be observed in Lesson 5.*

Materials

Copy of the lesson	1 Beaker
1 Multimeter	Hot water
3 Resistors	Ice
3 Battery snaps	1 Thermometer
6 Alligator clips	1 Thermistor
Graph paper (or Excel)	

Background and Discussion

What is a potential divider or voltage divider?

In the previous lesson you saw that it was desirable to build a sensor whose output varied *positively* and *linearly* with temperature. *Resistance* of your thermistor does not vary positively or linearly with temperature (exponential decay), so it is not a good way to measure temperature. Instead, it is necessary to build a new circuit around the thermistor, from which we will be able to obtain a *voltage* reading which does vary *approximately* positively and linearly with temperature.

The circuit that we will use is called a “potential divider” or “voltage divider” circuit, fig. 1. The circuit contains two resistors – one is the thermistor which changes its resistance value with temperature, the other is a fixed 10kΩ resistor. In the voltage divider circuit, the battery voltage (9V) is “divided” between the two resistors in proportion to their relative sizes.

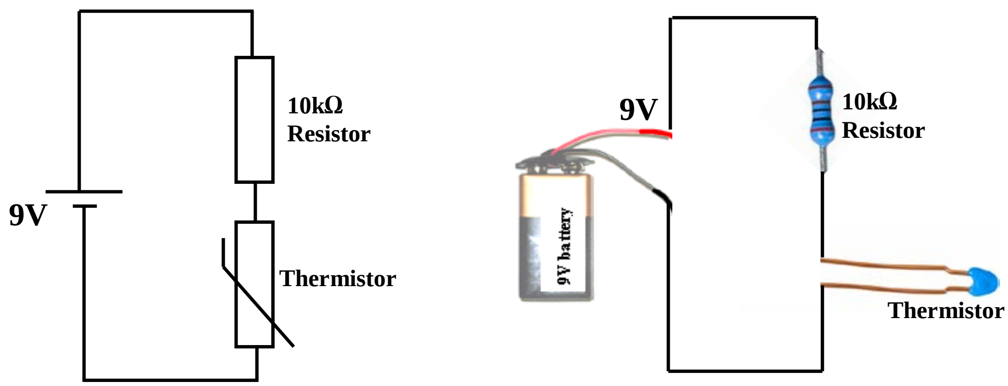


Fig. 1. Circuit diagram and setup for a voltage divider circuit.

*DO NOT BUILD THIS CIRCUIT YET – it is drawn here to help with discussion and understanding. You will build a circuit like this in the next lesson!

For example, if the thermistor also has a resistance of 10kΩ, both resistances are equal (as in fig 2a). Each resistor constitutes exactly half the total resistance. The voltage is divided equally – the resulting voltage across each resistance will be 4.5V, see fig. 2a. As another example, if the thermistor has resistance of only 5kΩ, then the thermistor forms only one third of the total resistance and the fixed 10kΩ resistor forms two thirds of the total resistance. Therefore the 10kΩ resistor will experience two thirds of the total voltage (6V) and the thermistor will experience one third of the total voltage (3V), see fig. 2b.

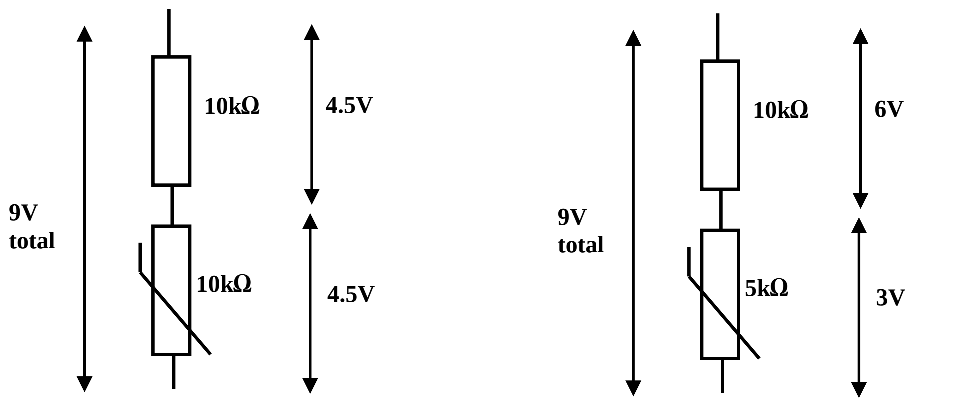


Fig. 2. A voltage divider divides the total voltage up between the two resistors in proportion to their resistances.

a) For two equal resistors, each resistor gets half the total voltage across it.
b) The 10kΩ resistor gets two thirds of the total voltage, whereas the 5kΩ gets one third of the total voltage across it.

Part 1 - Measuring voltages across resistors in a voltage divider circuit

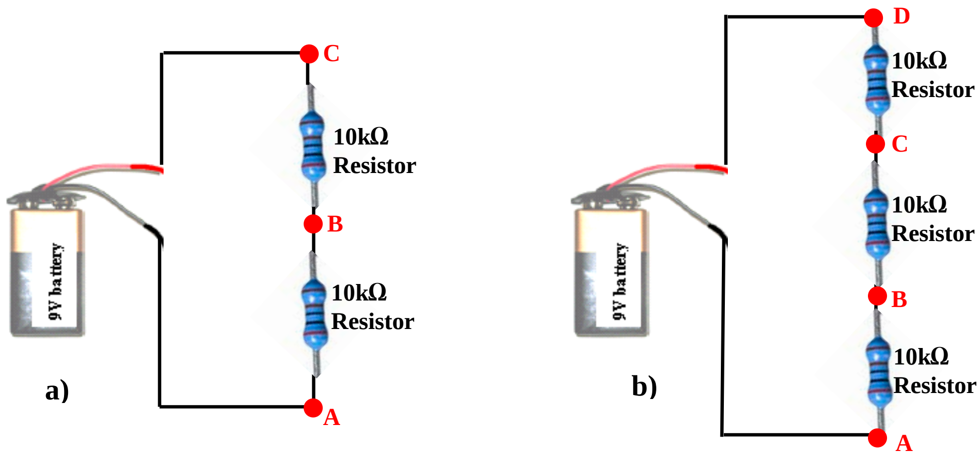


Fig. 3. a) Voltage divider circuit with 2 resistors.
b) Voltage divider circuit with 3 resistors.

1a) Build the circuit shown in fig 3a.

- Use your multimeter to measure the voltage between point A and point B.
- Use your multimeter to measure the voltage between point B and point C.
- Use your multimeter to measure the voltage between point A and point C.
- Record the measurements:

Answer – approximate values should be around:

V_{AtoB} = 4.5V V_{BtoC} = 4.5V V_{AtoC} = 9V

Note, these are estimated for a 9V battery. Students' measured values may differ slightly because their batteries may not be exactly 9V.

i) What is the resistance between points A and B, points B and C, and points A and C? NOTE: Disconnect the battery before measuring the resistances, otherwise the resistance in the other side of the circuit will affect the measurement. Write these down:

Answer:

R_{AtoB} = 10000 Ohms (or 10kΩ) R_{BtoC} = 10000 Ohms R_{AtoC} = 20000 Ohms

1b) Build the circuit shown in fig. 3b.

- Measure voltage between points A and B, then points B and C, then points C and D.
- Measure the voltage between points A and C, and then points B and D.
- Measure the voltage between point A and point D.
- Record the measurements:

Answer – approximate values should be around:

V_{AtoB} = 3V V_{BtoC} = 3V V_{CtoD} = 3V

V_{AtoC} = 6V V_{BtoD} = 6V V_{AtoD} = 9V

Again, values measured by students may be slightly less than this.

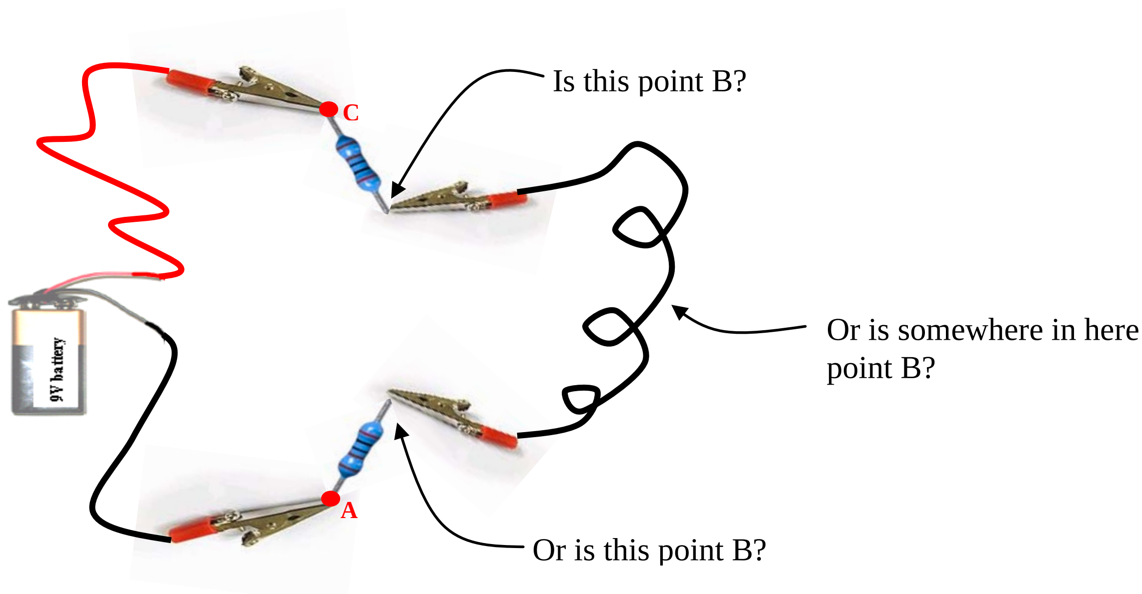
i) What is the resistance between points A and B, points A and C, and points A and D? Record the measurements:

Answers:

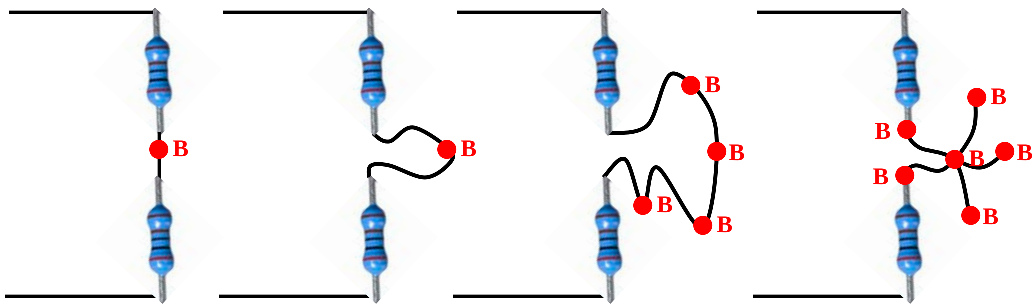
R_{AtoB} = 10000 Ohms (or 2kΩ) R_{AtoC} = 20000 Ohms R_{AtoD} = 30000 Ohms

**Note for the teacher:*

When building these circuits using alligator clips or similar, students sometimes become confused about which part of the "real" circuit 3a) constitutes point **B**. *They may think there are "two different point Bs". This highlights a significant and common misconception about electric circuits (often shared by college students), and this is a good opportunity to set students straight on a major electricity fundamental.*



The answer is that it doesn't matter. All of these points are electrically equivalent. They are all point B and will all measure the same voltage. We assume that the wires which connect components are perfect conductors with negligible resistance. Therefore it is only the components themselves that are important. The wires that connect them can be *of any shape and stretching or distorting wires has no electrical effect on the behavior of the circuit. **Any two points that are connected by a piece of wire are electrically identical**, even when the wire splits or bifurcates.*



All points B are electrically the same in this diagram. If students ask which is the "correct" point B, have them test each option and compare the results.

Assessment

1) Look at fig. 3a).

a) Calculate $R_{AtoB} \div R_{AtoC}$ and then calculate $V_{AtoB} \div V_{AtoC}$ using the voltages you measured for circuit 3a).

Answer: *both ratios should be 0.5*

b) Calculate $R_{BtoC} \div R_{AtoC}$ and then calculate $V_{BtoC} \div V_{AtoC}$ using the voltages you measured for circuit 3a).

Answer: *both ratios should be 0.5*

c) Do you notice any relationship between the resistances and the voltages? Explain.

Answer: *the proportion of the total voltage that is applied across each resistor, is equal to the proportion of the total resistance that is made up by that resistor.*

2) Look at fig. 3b)

a) Calculate $R_{AtoB} \div R_{AtoD}$ and then calculate $V_{AtoB} \div V_{AtoD}$ using the voltages you measured for circuit 3b).

Answer: both ratios should be 0.333 or $\frac{1}{3}$

b) Calculate $R_{AtoC} \div R_{AtoD}$ and then calculate $V_{AtoC} \div V_{AtoD}$ using the voltages you measured for circuit 3b).

Answer: both ratios should be 0.666 or $\frac{2}{3}$

c) Do you notice any relationship between the resistances and the voltages? Explain.

Answer: the proportion of the total voltage that is applied across each resistor, is equal to the proportion of the total resistance that is made up by that resistor.

Part 2 - Using your thermistor in a voltage divider circuit

You could ask students to complete Part 2 as homework, in preparation for the next lesson, because no equipment or experiments are needed in this section.

Look at the circuit shown in fig. 4. DO NOT BUILD THIS CIRCUIT YET – you will build something like this in the next lesson, but for now we will just think about how this circuit might behave. We will try to predict what results you will measure when you really do build this circuit in the next lesson.

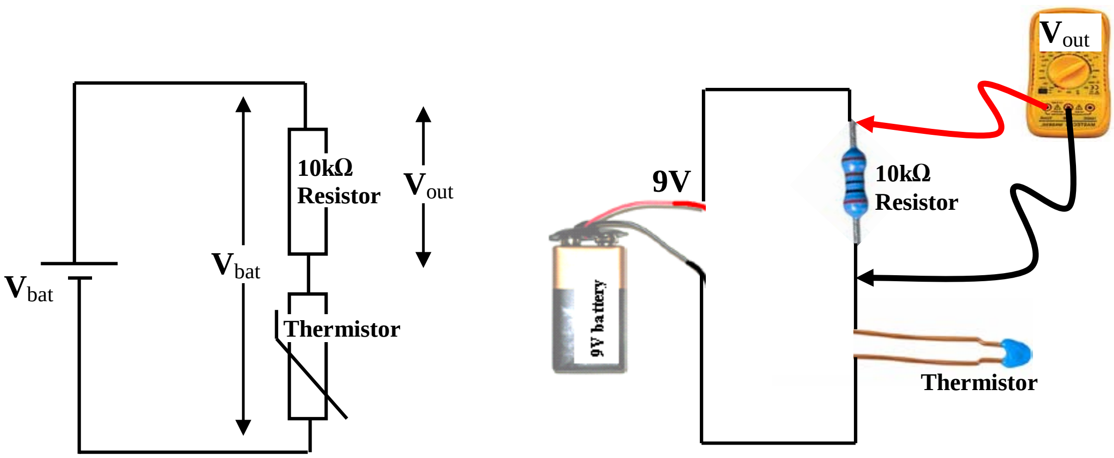


Fig. 4. Circuit diagram and setup for incorporating a thermistor into a voltage divider circuit. We will call the voltage across the 10kΩ resistor the "output voltage" and we can measure this output voltage with a multimeter.

The voltage across the 10kΩ resistor is the "output voltage" of the voltage divider, labeled V_{out}. R_T is the resistance of the thermistor and V_{bat} is the battery voltage.

By analyzing the cicuit using Ohm's law, and remembering that the 10kΩ resistor has a resistance of 10000 Ohms, you can prove the following relationship:

$$V_{out} = \frac{10000\Omega}{R_T + 10000\Omega} \times V_{bat}$$ **(equation 1)**

This is a general way of writing down the relationship that you have already seen in part 1. The total battery voltage is divided between the resistors in proportion to their resistance.

**Note to teacher: if you want your students to derive equation 1, or to get practice in solving simultaneous equations, then see the Module 1 Add-on Math Lesson.*

Assessment

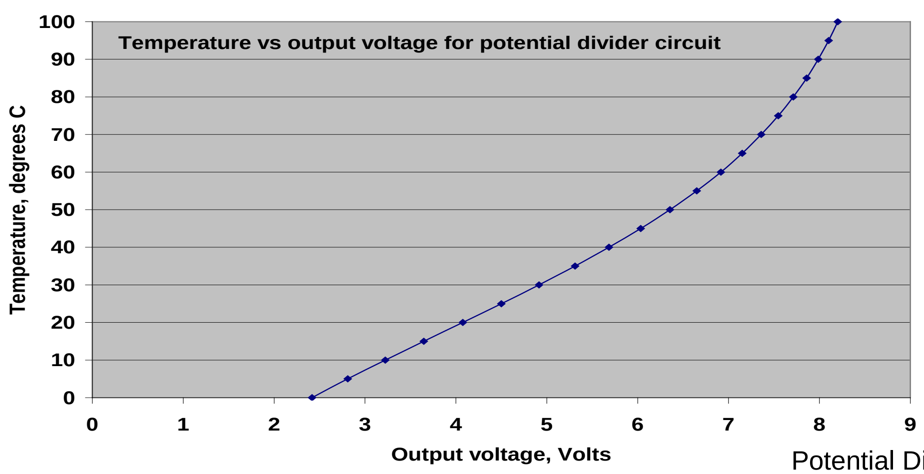
1) Look at your results for *Lesson 3 - Temperature vs. resistance characteristics of a thermistor*. Use the values that you recorded for the thermistor resistance, R_T (expressed in Ω), versus temperature, and record in the table below.

2) Combine these with equation 1 from above, to calculate what output voltage, V_{out}, you will expect to measure at different temperatures, for the circuit shown in figure 3. Assume the battery voltage, V_T, is exactly 9Volts.

3) Record these predictions in the table:

Temperature, ºC	0	10	20	30	40	50	60	70	80
Thermistor resistance, R_T (kΩ)	27.2	17.9	12.1	8.3	5.8	4.2	3.0	2.2	1.7
Convert from kΩ to Ω by multiplying by 1000									
Thermistor resistance, R_T (Ω)	27200	17900	12100	8300	5800	4200	3000	2200	1700
Output voltage, V_{out}	2.42	3.22	4.08	4.91	5.68	6.36	6.92	7.36	7.71

2) Plot these predictions on a graph of temperature versus V_{out}. Use the vertical (y) axis for temperature, and use the horizontal (x) axis for V_{out}.



3) What do you notice about the shape of the graph? Is this relationship (V_{out} versus temperature) more useful than the relationship you found in part 2 (R_T versus temperature)? If so, why?

Answer: again, this is not a linear relationship. However, over a useful range of environmental water temperatures (from 0ºC up to about 40ºC) the relationship very closely approximates a straight line. So, effectively we have now built a linear sensor in the 0-40ºC range. In this range, the sensor output signal varies positively and linearly with temperature.

4) When measuring the resistance of circuits, why is it important to disconnect the battery before measuring the resistances?

Answer: The resistance of the other side of the circuit (which consists of the battery and the other resistor) will affect the resistance measurement.

5) Could you use the battery voltage and the voltage across the resistor to calculate the voltage across the thermistor? Explain how.

Answer: The voltage across the resistor and the voltage across the thermistor must add up to the battery voltage. So subtracting the voltage across the resistor from the battery voltage would give the voltage across the thermistor.