POTENTIAL DIVIDERS

Potential Dividers is part of the **SEP 'Sensors' pack**

Published by the Gatsby Science Enhancement Programme,
London, 2006.

The Gatsby Charitable Foundation

Gatsby Science Enhancement Programme
Allington House (First Floor)
150 Victoria Street
London SW1E 5AE

Author: Chris Butlin
Editor: Miriam Chaplin
Designers: Pluma Design Ltd.
CD –ROM development and online: KDR Creative

Images provided by Chris Butlin, except where stated in text.
Diagrams for technical notes redrawn by MUTR, from originals by Chris Butlin.

SEP
Science Enhancement Programme

The Science Enhancement Programme (SEP) is part of Gatsby Technical Education Projects. It undertakes a range of activities concerned with the development of curriculum resources and with teacher education. For further information, visit www.sep.org.uk

CONTENTS

USING A POTENTIAL DIVIDER WITH A SENSOR

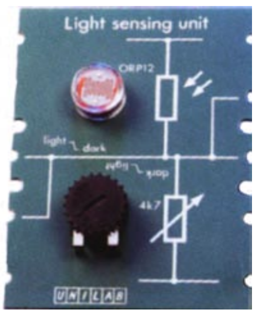
INTRODUCTION

With many sensors the potential divider set-up is a crucial element in producing a change of voltage output as the sensor's resistance changes. Whilst most students will be able to appreciate a little of its working by demonstrating the effect of a change of resistance on the voltage output from the universal potential divider, some might like to go into more detail and see mathematically why this occurs. Many may also like to see how the choice of the resistor to place in series with the sensor in the potential divider set-up is made.

ACTIVITIES

A simple demonstration, or student activity, could be shown in which a sensor at its highest resistance could be substituted for a 180kΩ resistor, and at its lowest resistance for a 68kΩ resistor. The universal potential divider could then be set up with one of its resistors switched in. With a voltmeter connected across the universal potential divider's resistor, the voltage outputs could be noted for the 180kΩ and the 68kΩ resistors (substitutes for a sensor). **The students' attention needs to be drawn to the difference between these two voltages – it should be as large as possible**. By repeating the noting of such voltages for different values of the universal potential divider's resistor, students will see how these affect this difference and will see that one value is better than the others. The activity Selecting the best value resistor to use with a sensor in a potential divider circuit deals with this either as a demonstration by the teacher or as a student task.

For the mathematically inclined, the notes Using a potential divider with a sensor can take students through the arguments to see why a particular value of potential divider resistor is best. They will need to know the expressions I = V/R and V= IR together with the fact that with two resistors in series with each other their resistance is the sum of the two. A problem may arise with the powers used in the notes and so you may need to substitute easier, though less realistic, values to work with.



Unilab Light sensing unit

If the students have been using the Unilab Alpha kits in either science or technology, you could draw their attention to its Light sensing unit (F5H27982), in which the LDR is connected in series with a 4.7kΩ variable resistor to make up a potential divider network.

As you will know, selection of the potential divider resistor is not so simply done when the sensor's resistance does not vary in a linear manner with whatever it is sensing. A compromise is then achieved bearing in mind the resolution required over its range. For example, you may wish to have a large number of values over a temperature range of say 0°C to 40°C, but a smaller number from 40°C to 100°C. The potential divider resistor would then be selected to produce a larger change of voltage output from 0°C to 40°C than from 40°C to 100°C.

One additional feature of the potential divider would be to show how connection of the multimeter/voltmeter across the lower two voltmeter sockets produces changes of voltage output **in the opposite sense** to those across the upper two voltmeter sockets. As the lower voltage output rises the upper falls and vice versa. Selection of which sockets to measure the voltage output across would normally be made so that it matched the direction of change of what the sensor was measuring e.g. if the temperature was rising then make the voltage output rise, too.

Typical results for 'Selecting the best value resistor to use with a sensor in a potential divider circuit':

Potential divider resistor value	Voltage output from potential divider with 68kΩ resistor in place of sensor /V	Voltage output from potential divider with 180kΩ resistor in place of sensor /V	Change of Voltage output from potential divider /V
4.7kΩ	0.38	0.15	0.23
10kΩ	0.79	0.32	0.47
20kΩ	1.39	0.61	0.78
47kΩ	2.48	1.24	1.24
100kΩ	3.58	2.08	1.50
470kΩ	5.17	4.00	1.17
1MΩ	5.52	4.60	0.92

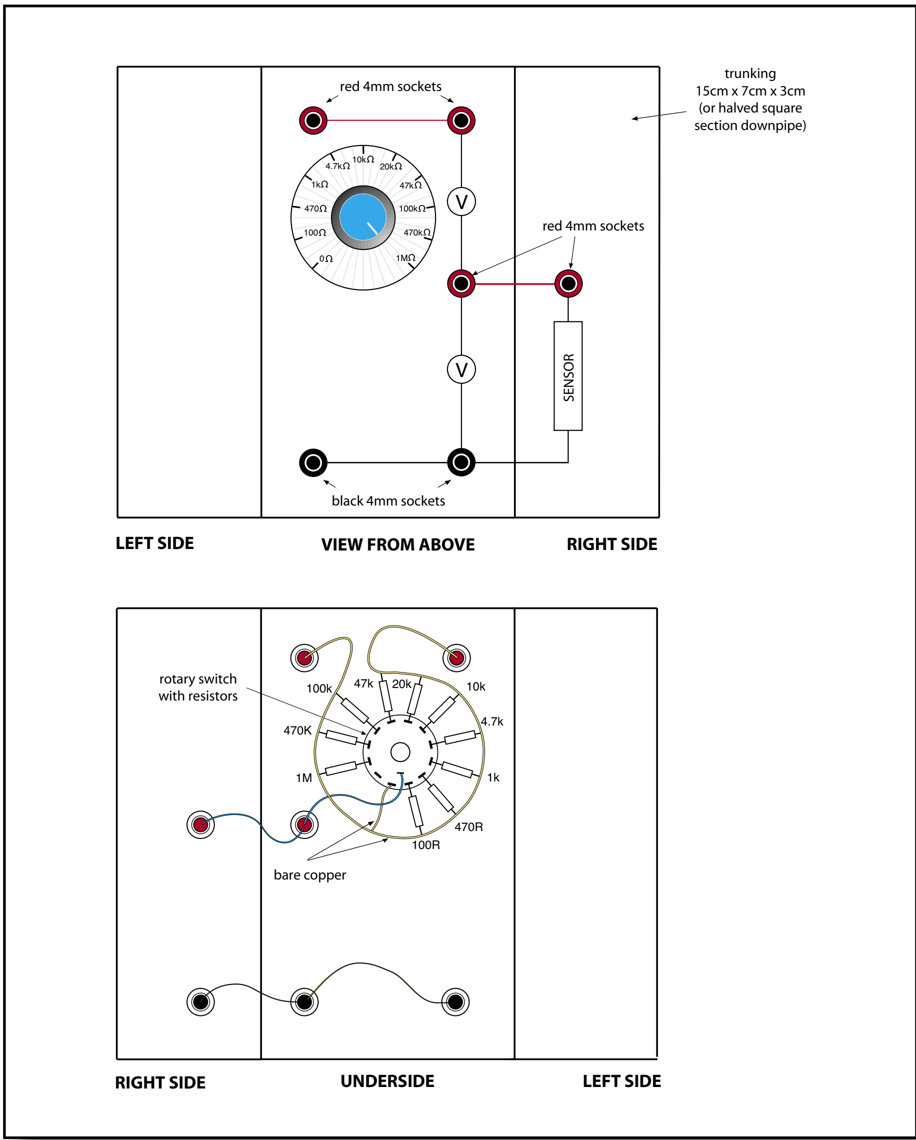
The results show that the 100kΩ produces the largest change in output voltage. This resistor would be the best one to use for a sensor with a resistance in the range 68kΩ to 180kΩ.

USING A POTENTIAL DIVIDER WITH A SENSOR: TECHNICAL NOTES

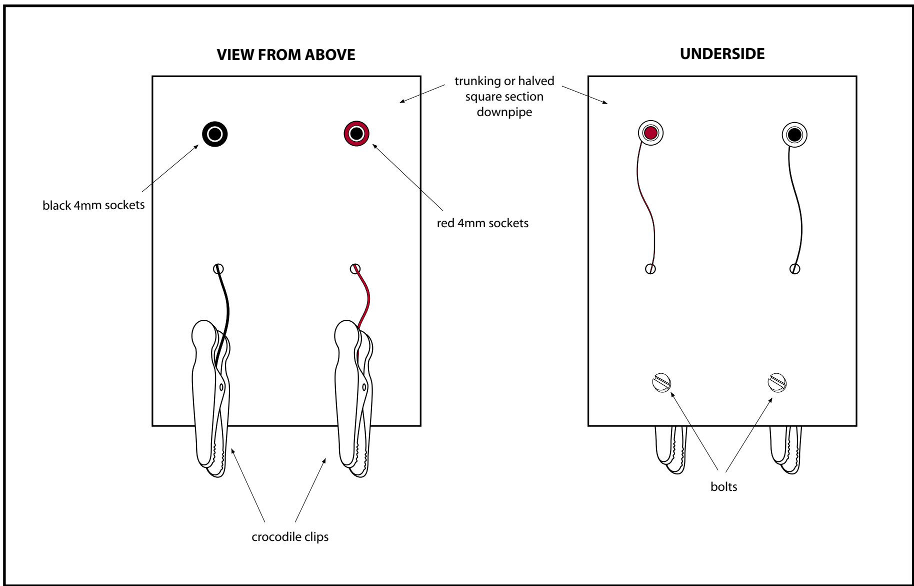
SELECTING THE BEST VALUE RESISTOR TO USE WITH A SENSOR IN A POTENTIAL DIVIDER CIRCUIT

Equipment:
6V battery
universal potential divider unit – see construction diagram
crocodile clip component holder – see construction diagram
connecting leads
plastic trunking
4 x 4mm black socket
5 x 4mm red socket
rotary switch 1 pole 12 way
collet knob
L C cap – blue
resistor M100R - 0.6W *
resistor G470R - 0.25W
resistor G1K - 0.25W
resistor G4K7 - 0.25W
resistor G10K - 0.25W
resistor G20K - 0.25W
resistor G47K - 0.25W
resistor G68K – 0.25W
resistor G100K - 0.25W
resistor G180K – 0.25W
resistor G470K - 0.25W
resistor G1M -0.25W
copper wire 18swg tinned
connecting wire black
connecting wire red
2 x crocodile clip

***Note:** the 100Ω resistor needs to be of higher power rating than the others.



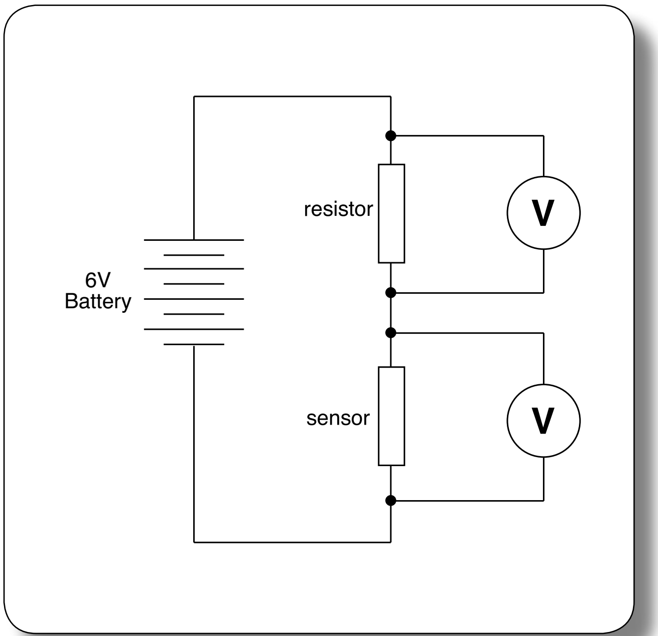
Universal potential divider unit construction



Crocodile clip component holder construction diagram

Using a Potential Divider with a Sensor

Many sensors change in resistance with whatever they are sensing: although we could measure the change in resistance, we usually use these with what is called a potential divider set up: this involves placing a resistor in series with the sensor, as shown:



A sensor and resistor set up in a potential divider circuit

Key ideas

- As the sensor's resistance changes, the voltage across it changes, and the voltage across the resistor changes, too. If the sensor's resistance increases, the voltage across it will increase while the voltage across the resistor will go down by the same amount.

- We could take the voltage change across either the sensor or the resistor: it is usually more helpful to use the arrangement which gives an increasing voltage as the quantity being sensed (light level, load, temperature) increases.

- The best choice of resistor to put in series with a sensor is one which gives the largest change in output voltage across the sensor or the resistor.

In reality the choice is often more complex, as many sensors do not change their resistance in a linear way. The choice of the series resistor is then a compromise to give the best **resolution** within a chosen section of the sensor's range. (The bigger the change in voltage output for a given change in whatever quantity is being sensed, the better the resolution).

Using a Potential Divider with a Sensor

Example A:
What happens to the voltage across the sensor and the resistor as the sensor's resistance changes?

If both the sensor and the resistor had resistances of 1 000 000Ω (1MΩ, a megohm) initially, then both the voltmeters would each read 3V with a 6V battery connected across them both. (We are assuming that the battery has an e.m.f. of exactly 6V and that it has no internal resistance. We are also assuming that the voltmeters have infinite resistance and so do not affect the current flow in the circuit) .

However, if the sensor's resistance now falls to 0.5MΩ, then the voltmeter across it will read approximately 2V and that across the resistor approximately 4V:

Total voltage across sensor and resistor /V	Resistance of sensor/ MΩ	Resistance of resistor/ MΩ	Voltage across sensor /V	Voltage across resistor /V
6	1	1	3	3
6	0.5	1	2	4

We can look at this in terms of the resistance formula R=V/I and its rearranged versions I=V/R and V=IR:

(i) The current I flowing in the circuit will be given by the expression:

$$I = V_B/R_{Total}$$

Where V_B is the battery voltage and R_{Total} the resistance of the resistor and sensor added together.
If the resistor and sensor are each of resistance 1MΩ then, with a 6V battery across them both, then:

$$I = 6V/2M\Omega = 6/(2 \times 10^6) = 3 \times 10^{-6}A \text{ or } 3\mu A$$

To calculate the voltage V_S across the sensor we must rearrange the expression

$$I = V/R$$

to get $V_S = IR_S$, where R_S is the resistance of the sensor.
Substituting values for I and R_S gives

$$V_S = (3 \times 10^{-6}A) \times (1 \times 10^6) = \mathbf{3V}$$

The voltage across the resistor, V_R, is the same because it has the same resistance as the sensor.

Using a Potential Divider with a Sensor

(ii) If the sensor's resistance now falls to 0.5MΩ , while the resistance of the resistor is still 1MΩ, then the current flowing through the sensor and the resistor will be given by the expression:

$$I = V_B/R_{Total} = 6V/1.5M\Omega = 6/(1.5 \times 10^6) = 4 \times 10^{-6} \text{ A or } 4\mu A.$$

Therefore the voltage across the sensor is:

$$V_S = IR_S = (4 \times 10^{-6}) \times (0.5 \times 10^6) = 2V$$

and the voltage across the resistor is:

$$V_R = IR_R = (4 \times 10^{-6}) \times (1.0 \times 10^6) = 4V$$

Example B: How do we choose the best resistor to use with a sensor?

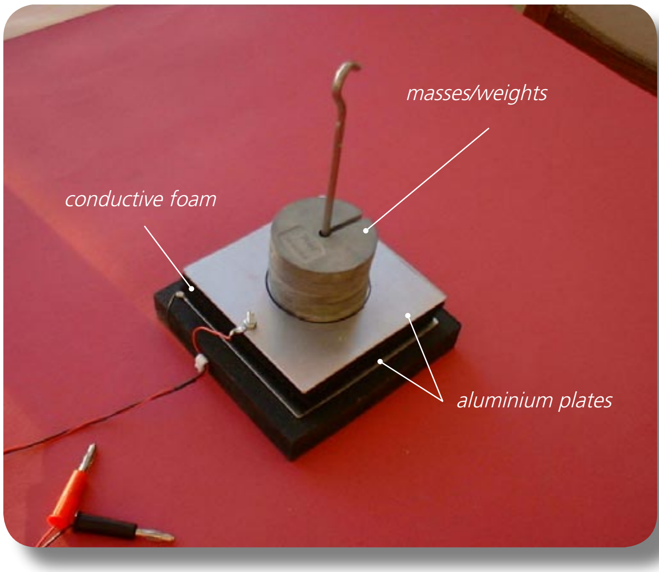
Suppose we need a temperature sensor to be used over the range 0°C to 100°C:

- If it is placed in series with a 47kΩ resistor, the voltage across this resistor changes from **1.0V to 2.0V.**
- However, when placed in series with a 180kΩ resistor, the voltage change is from **1.5V to 3.0V.**

The 180kΩ resistor would be a better choice as the change of voltage with it is 1.5V instead of just 1.0V.

Using a Potential Divider with a Sensor

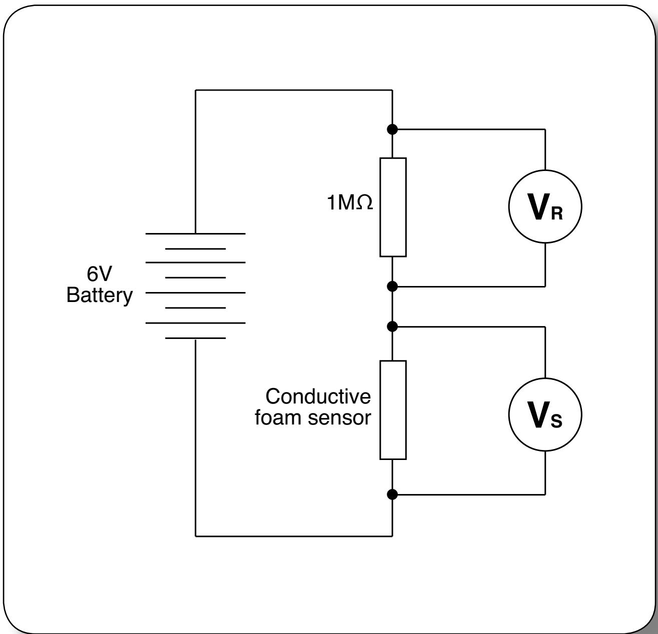
Example C:
How do we work out the change in voltage output if we know two values for the resistance of a sensor?



A conductive foam sensor

A conductive foam force sensor has a resistance of around **0.18MΩ** when no load has been placed on it, and about **0.07MΩ** with a load of 4.90N (mass of 500g) on it.

With a 1MΩ resistor:



Potential divider set up with sensor and 1MΩ resistor

Using a Potential Divider with a Sensor

The current I flowing through the sensor and resistor will be given by the expression:

$$I = V_B/R_{Total}$$

Where V_B is the battery voltage and R_{Total} is the resistance of the sensor and the resistor added together. When there is no load on the sensor this means:

$$I = 6V/(1M\Omega + 0.18M\Omega) = 6/(1.18 \times 10^6) = 5.08 \times 10^{-6}A \text{ or } 5.08\mu A$$

The voltage V_S across the sensor when there is no load will be given by the expression:

$$V_S = I \times R_{SE}$$

where R_{SE} is the resistance of the sensor when it has no load on it.
Substituting values for I and R_{SE} gives:

$$V_S = (5.08 \times 10^{-6}) \times (0.18 \times 10^6) = 0.91V$$

The voltage V_R across the resistor is given by the expression:

$$V_R = I \times R_R$$

where R_R is the resistance of the resistor in the potential divider circuit.
Substituting values for I and R_R gives

$$V_R = (5.08 \times 10^{-6}) \times (1.0 \times 10^6) = 5.08V$$

Now let's look at how things change when there is a load on the sensor.

The current I flowing through the sensor and resistor is given by the expression:

$$I = V_B/R_{Total}$$

Where V_B is the battery voltage and R_{Total} is the resistance of the sensor and the resistor added together.
Substituting values for V_B and R_{Total} gives:

$$I = 6V/(1M\Omega + 0.07M\Omega) = 6/(1.07 \times 10^6) = 5.60 \times 10^{-6}A \text{ or } 5.60\mu A$$

Using a Potential Divider with a Sensor

The voltage V_S across the sensor is given by the expression:

$$V_{SL} = I \times R_{SL}$$

where R_{SL} is the resistance of the sensor when it has a load on it.
Substituting values for I and R_{SL} gives:

$$V_S = (5.60 \times 10^{-6}) \times (0.07 \times 10^6) = 0.39V$$

The voltage V_R across the resistor is given by the expression:

$$V_R = I \times R_R$$

Where R_R is the resistance of the resistor in the potential divider circuit. So we have:

$$V_R = (5.60 \times 10^{-6}) \times (1.0 \times 10^6) = 5.60V$$

The **change** in **voltage across the sensor** as the load is added is (0.39V – 0.91V) or **–0.52V.**
The **change** in **voltage across the resistor** as the load is added is (5.60V – 5.08V) = **+0.52V.**
Note that the voltage across the sensor has decreased whilst the voltage across the resistor has increased by the same amount.

Using a Potential Divider with a Sensor

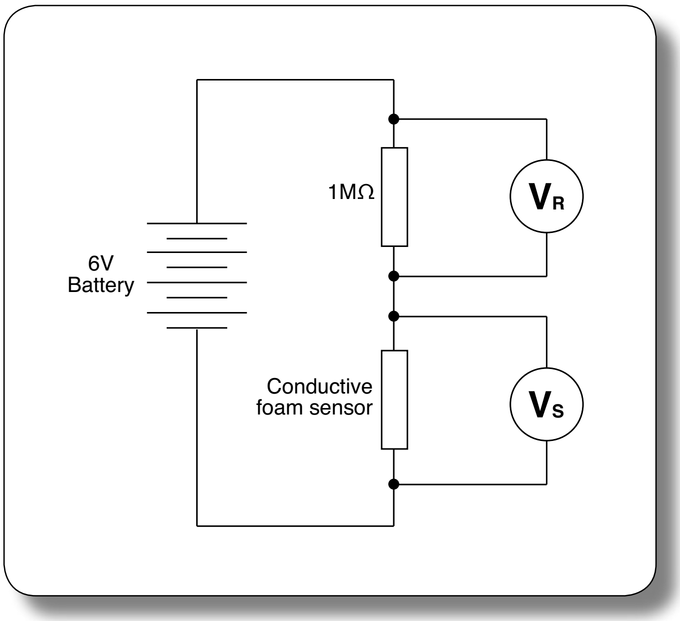
Questions

Q1. In Example A, why would it be of no use just to have the sensor connected across the battery and measure the voltage across it as its resistance changes? What would you expect to see happening, if anything? Explain.

The rest of the questions are all about the circuit used in Example C, and consider the effect of changing the resistance of the fixed resistor.

The conductive foam force sensor has a resistance of around **0.18MΩ** when no load has been placed on it, and about **0.07MΩ** with a load of 4.90N (mass 500g) on it.

Here is the original circuit with the 1MΩ resistor:



Potential divider set up with sensor and 1MΩ resistor

In the circuit with a 0.47MΩ (470kΩ) resistor:

Q2. Calculate the current I, when there is no load on the sensor.

Q3. Calculate the voltage V_S across the sensor

Q4. Calculate the voltage V_R across the resistor

Using a Potential Divider with a Sensor

Q5. Calculate the current I flowing through the sensor and resistor when there is a load on the sensor

Q6. Calculate the voltage V_S across the sensor

Q7. Calculate the voltage V_R across the resistor

Q8. Calculate the change in voltage across the sensor as the load is added.

Q9. Calculate the change in voltage across the resistor as the load is added.

In the circuit with a 0.1 MΩ resistor:

Q10. Calculate the current I, when there is no load on the sensor.

Q11. Calculate the voltage V_S across the sensor

Q12. Calculate the voltage V_R across the resistor

Q13. Calculate the current I flowing through the sensor and resistor when there is a load on the sensor

Q14. Calculate the voltage V_S across the sensor

Q15. Calculate the voltage V_R across the resistor

Q16. Calculate the change in voltage across the sensor as the load is added.

Q17. Calculate the change in voltage across the resistor as the load is added.

Using a Potential Divider with a Sensor

In the circuit with a 0.047 MΩ resistor:

Q18. Calculate the current I, when there is no load on the sensor.

Q19. Calculate the voltage V_S across the sensor

Q20. Calculate the voltage V_R across the resistor

Q21. Calculate the current I flowing through the sensor and resistor when there is a load on the sensor

Q22. Calculate the voltage V_S across the sensor

Q23. Calculate the voltage V_R across the resistor

Q24. Calculate the change in voltage across the sensor as the load is added.

Q25. Calculate the change in voltage across the resistor as the load is added.

In the circuit with a 0.02 MΩ resistor:

Q26. Calculate the current I, when there is no load on the sensor.

Q27. Calculate the voltage V_S across the sensor

Q28. Calculate the voltage V_R across the resistor

Q29. Calculate the current I flowing through the sensor and resistor when there is a load on the sensor

Q30. Calculate the voltage V_S across the sensor

Using a Potential Divider with a Sensor

Q31. Calculate the voltage V_R across the resistor

Q32. Calculate the change in voltage across the sensor as the load is added.

Q33. Calculate the change in voltage across the resistor as the load is added.

Q34. Use the values you have calculated in questions 2-33 to complete the table.

Resistor value		**1.0MΩ**	**0.47MΩ**	**0.1MΩ**	**0.047MΩ**	**0.02MΩ**
Unloaded sensor	Current I /A	5.08 $\times 10^{-6}$				
	Voltage V_s / V	0.91				
	Voltage V_R / V	5.08				
Loaded sensor	Current I /A	5.60 $\times 10^{-6}$				
	Voltage V_s / V	0.39				
	Voltage V_R / V	5.60				
Change in voltage across sensor as it is loaded / V		-0.52				
Change in voltage across resistor as sensor is loaded / V		+0.52				

Using a Potential Divider with a Sensor

Answers

Q1. No change of voltage would be seen as the connection of the voltmeter is directly across the battery and so it would be the battery voltage (or e.m.f.) that would be noted, and that would not change. In reality there would be a small change due to the battery's internal resistance. As the sensor's resistance falls the current in the circuit would rise. A larger current flowing through this internal resistance would produce a voltage drop across it and so a smaller voltage would be noted across the battery.

Answers to calculations questions 2-34

in the circuit with a 0.47M Ω resistor:

Q2: I = 6V/(0.47MΩ + 0.18MΩ) = 6/(0.65 x 10^6) = **9.23 ×10^{-6}A or 9.23μA**

Q3. VS = (9.23 ×10^{-6}) × (0.18 x 10^6) = **1.66V**

Q4. VR = (9.23 ×10^{-6}) × (0.47 x 10^6) = **4.34V**

Q5. I = 6V/(0.47MΩ + 0.07MΩ) = 6/(0.54 x 10^6) = **11.1 ×10^{-6}A or 11.1μA**

Q6. VS = (11.1 ×10^{-6}) × (0.07 x 10^6) = **0.78V**

Q7. V_R = (11.1 ×10^{-6}) × (0.47 x 10^6) = **5.22V**

Q8. The change in voltage across the sensor as the load is added is (0.78V – 1.66V) or **–0.88V.**

Q9. The change in voltage across the resistor as the load is added is (5.22V – 4.34V) = **+0.88V.**

In the circuit with a 0.1M Ω resistor:

I = 6V/(0.1MΩ + 0.18MΩ) = 6/(0.28 x 10^6) = **21.43 ×10^{-6}A or 21.43μA**

V_S = (21.43 ×10^{-6}) × (0.18 x 10^6) = **3.86V**

V_R = (21.43 ×10^{-6}) × (0.1 x 10^6) = **2.14V**

I = 6V/(0.1MΩ + 0.07MΩ) = 6/(0.17 x 10^6) = **35.29 ×10^{-6}A or 35.29μA**

V_S = (35.29 ×10^{-6}) × (0.07 x 10^6) = **2.47V**

V_R = (35.29 ×10^{-6}) × (0.1 x 10^6) = **3.53V**

The change in voltage across the sensor as the load is added is (2.47V – 3.86V) or **–1.39V.**

The change in voltage across the resistor as the load is added is (3.53V – 2.14V) = **+1.39V.**

With a 0.047MΩ (47kΩ) resistor:

I = 6V/(0.047MΩ + 0.18MΩ) = 6/(0.227 x 10^6) = **26.43 ×10^{-6}A or 26.43μA**

V_S = (26.43 ×10^{-6}) × (0.18 x 10^6) = **4.76V**

V_R = (26.43 ×10^{-6}) × (0.047 x 10^6) = **1.24V**

I = 6V/(0.047MΩ + 0.07MΩ) = 6/(0.117 x 10^6) = **51.28 ×10^{-6}A or 51.28μA**

V_S = (51.28 ×10^{-6}) × (0.07 x 10^6) = **3.59V**

V_R = (51.28 ×10^{-6}) × (0.047 x 10^6) = **2.41V**

The change in voltage across the sensor as the load is added is (3.59V – 4.76V) or **–1.17V.**

The change in voltage across the resistor as the load is added is (2.41V – 1.24V) = **+1.17V.**

Using a Potential Divider with a Sensor

With a 0.02MΩ (20kΩ) resistor:

I = 6V/(0.02MΩ + 0.18MΩ) = 6/(0.20 x 10^6) = **30.0 ×10^{-6}A or 30.0μA**

V_S = (30.0 ×10^{-6}) × (0.18 x 10^6) = **5.4V**

V_R = (30.0 ×10^{-6}) × (0.02 x 10^6) = **0.6V**

I = 6V/(0.02MΩ + 0.07MΩ) = 6/(0.09 x 10^6) = **66.67 ×10^{-6}A or 66.67μA**

V_S = (66.67 ×10^{-6}) × (0.07 x 10^6) = **4.67V**

V_R = (66.67 ×10^{-6}) × (0.02 x 10^6) = **1.33V**

The change in voltage across the sensor as the load is added is (4.67V – 5.4V) or **–0.73 V.**

The change in voltage across the resistor as the load is added is (1.33V – 0.6V) = **+0.73V.**

Q34.

Resistor value		**1.0MΩ**	**0.47MΩ**	**0.1MΩ**	**0.047MΩ**	**0.02MΩ**
Unloaded sensor	Current I /A	5.08 ×10^{-6}	9.23 ×10^{-6}	21.43 ×10-6	26.43 ×10^{-6}	30.0 ×10^{-6}
	Voltage Vs /V	0.91	1.66	3.66	4.76	5.4
	Voltage VR / V	5.08	4.34	2.14	1.24	0.6
Loaded sensor	Current I /A	5.60 ×10^{-6}	11.1 ×10^{-6}	35.29 ×10^{-6}	51.28 ×10^{-6}	66.67 ×10^{-6}
	Voltage Vs /V	0.39	0.78	2.47	3.59	4.67
	Voltage VR /V	5.60	5.22	3.53	2.41	1.33
Change in voltage across sensor as it is loaded /V		-0.52	-0.88	-1.39	-1.17	-0.73
Change in voltage across resistor as sensor is loaded /V		+0.52	+0.88	+1.39	+1.17	+0.73

The **0.1MΩ** resistor is the one to use here, because it gives the largest difference in voltage.

Activity: Selecting the best value resistor

Introduction

Many sensors that change in resistance with whatever they are sensing are often set up in a **potential divider circuit.** This places the sensor in series with a resistor and a battery. As the sensor's resistance changes, the voltage across it (and across a resistor in series with it) also changes.

- The problem is how to select the best value resistor to put in series with the sensor.
- The key to the solution is to select a resistor which gives the **largest change in voltage** across the range over which the sensor is used.

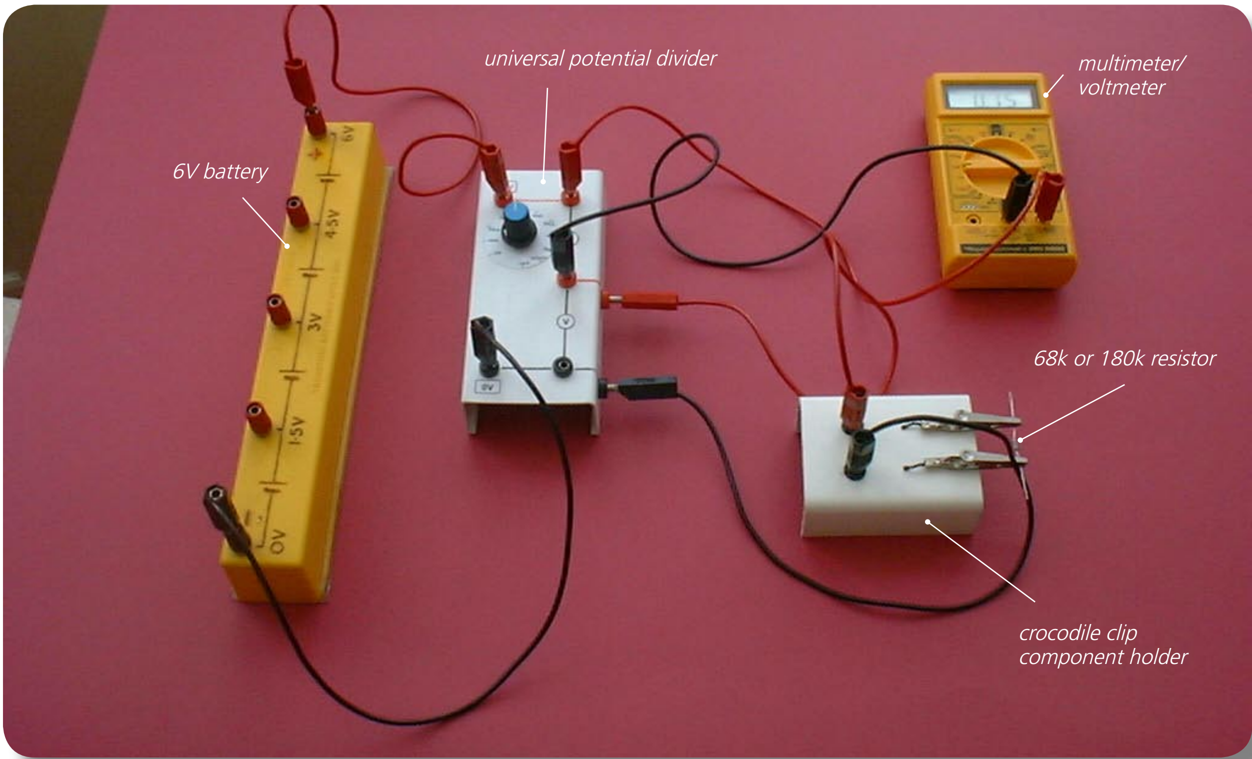
For example, suppose we need a temperature sensor to be used over the range 0°C to 100°C:
- If it is placed in series with a 47kΩ resistor, the voltage across this resistor changes from 1.0V to 2.0V.
- However, when placed in series with a 180kΩ resistor, the voltage change is from 1.5V to 3.0V.

The 180kΩ resistor would be a better choice as the change of voltage with it is 1.5V instead of just 1.0V.

In reality the choice is often more complex, as many sensors do not change their resistance in a linear way. The choice of the series resistor is then a compromise to give the best **resolution** within a chosen section of the sensor's range. (The bigger the change in voltage output for a given change in whatever quantity is being sensed, the better the resolution).

Activity: Selecting the best value resistor

Procedure



Potential divider circuit: test circuit

- Set the universal potential divider unit's resistor to **4.7kΩ.**
- Connect the 6V battery so that its +6V socket is connected to the red +6V socket of the potential divider unit and its 0V socket to the black 0V socket of the potential divider unit.
- Connect a crocodile clip component holder so that its sockets are connected to the black and red **Sensor** sockets on the side of the potential divider unit.
- Clip a **68kΩ resistor** (to represent a sensor's minimum resistance) into the crocodile clip component holder.
- Finally, connect a voltmeter (or a multimeter on its voltage range) to the upper pair of red output voltage sockets on the potential divider unit.

- Record the voltmeter reading for each potential divider resistor value from 4.7kΩ to 1MΩ in the second column of your results table.

- Replace the 68kΩ resistor in the crocodile clip component holder by a **180kΩ** resistor (to represent the sensor's maximum resistance).
- Record the voltmeter reading for each potential divider resistor value from 4.7kΩ to 1MΩ in the third column of your results table.
- Fill in the values for the change in voltage output in the fourth column of the table.
  (Column 4 value = column 2 value – column 3 value).

Activity: Selecting the best value resistor

Results

Potential divider resistor value	Voltage output from potential divider with 68kΩ resistor in place of sensor /V	Voltage output from potential divider with 180kΩ resistor in place of sensor /V	Change of Voltage output from potential divider /V
4.7kΩ			
10kΩ			
20kΩ			
47kΩ			
100kΩ			
470kΩ			
1MΩ			

Questions

Which potential divider resistor value produced the largest change in output voltage?

Which potential divider resistor is likely to be the most suitable to use if the sensor's minimum resistance over the range in use is 68kΩ and its maximum resistance over this same range is 180kΩ?