Out-of-balance Wheatstone Bridge

This is another article that might help you guide your students towards a successful Higher Investigation. The Wheatstone Bridge is not mentioned in the Higher Physics Course Specification. The potential divider is included, and the Wheatstone Bridge can be thought of as an application using two potential dividers. Investigating the voltage across the bridge when it is out of balance is straightforward and, if the correct setup is used, gives good results.

Theory – Balanced Wheatstone Bridge

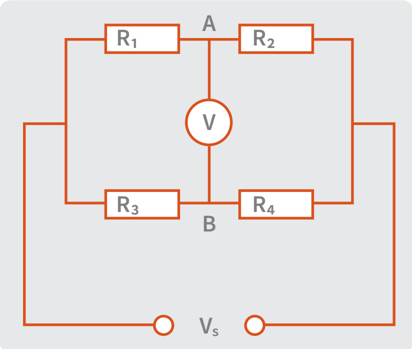

Figure 1 – Wheatstone Bridge circuit.

A Wheatstone Bridge (Figure 1) consists of two potential dividers. The voltages V_1 and V_3 across resistors R_1 and R_3 can be calculated as follows:

$$V_1 = \frac{R_1}{R_1 + R_2} V_s$$

$$V_3 = \frac{R_3}{R_3 + R_4} V_s$$

V_s is the supply voltage. When the voltmeter reads zero, $V_1 = V_3$. There is no potential difference V across the “bridge” AB and the bridge is said to be “balanced”. If we equate the above expressions for V_1 and V_3, we can show that, when there is no potential difference across AB,

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

A Wheatstone Bridge can be used to measure resistance, though this is no longer common practice. Suppose the resistances of R_3 and R_4 are known. R_1 is the unknown resistance and R_2 is a calibrated variable resistance.

R_2 is adjusted until V reads zero. The value of R_2 is noted. R_1 can then be found from:

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

Theory – Out-of-balance Wheatstone Bridge

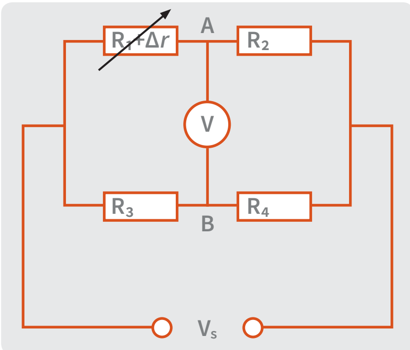

Figure 2 - Unbalanced Wheatstone Bridge.

If the bridge is initially balanced ($V = 0$ V) and R_1 has its resistance increased or decreased by Δr (Figure 2), the bridge will no longer be balanced. There will be a potential difference across the bridge and V will no longer read zero volts.

It can be shown that if Δr is small compared to R_1,

V is proportional to Δr.

Take the special case where R_3 and R_4 are equal and, when the bridge is balanced, R_1 and R_2 are also equal. You can have fun proving that, in this specific case, if R_1 changed by a resistance of Δr ohms:

$$V = \frac{\Delta r}{4R_1 + 2\Delta r} V_s$$

Note that Δr can be positive or negative. There is no need for anyone to know this formula. It is included to show that, in this case at least, V is proportional to Δr, provided that Δr is much smaller than R_1.

We address the question, “How much smaller is much smaller?” shortly. >>

Figure 3 - calibrated variable resistor.

Carrying out the investigation

We used the following apparatus:

- 3x 330 Ω resistors, 10% tolerance
- Calibrated variable resistor, range 0–9999 Ω in steps of 1 Ω. Such devices typically claim to be accurate to within 1%. See Figure 3.
- 5 V dc power supply - batteries could be used. The voltage is not critical, but if too small, the out-of-balance voltage will also be small.
- Voltmeter capable of reading to 0.1 mV

The Wheatstone Bridge was set up as shown previously. The variable resistor, set to 330 Ω, was placed in the R_1 position. This should have resulted in a balanced bridge, i.e. a zero reading on the voltmeter, but it did not, and adjusting the variable resistor could not restore balance. Its 1 Ω increments were too large. If this happens, there are two possible solutions, one of which might work and another which definitely will.

You may be able to obtain balance by swapping the 330 Ω resistors around. They are made with a tolerance of 10%, i.e. they could be as much as 33 Ω above or below the nominal 330 Ω. If this does not work, one of the fixed resistors will have to be replaced by a rheostat that can be set at least as high as the given resistance of the fixed resistors. This is adjusted until the bridge is balanced. The value it is set to does not matter and it is not adjusted throughout the investigation.

It is, of course, not essential to use 330 Ω resistors. The value is "ballpark".

With the bridge balanced, R_1 was adjusted in steps of 1 Ω. We measured V with R_1 ranging from 320 Ω to 340 Ω, giving a range for Δ*r* of -10 Ω to 10 Ω.

Results are shown above in Figure 4.

Note that when we did the investigation, the results were not symmetrical. By this we mean that the magnitude of the value of V for Δ*r* = -10 Ω was not exactly the same as that for Δ*r* = +10 Ω, for example. This was not due to poor initial balancing - when we modelled an out-of-balance Wheatstone Bridge using a spreadsheet, we got the same result. However, you have to analyse the results quite closely to see a deviation from direct proportionality.

This proportionality, or near-proportionality, only holds if Δ*r* is much smaller than R_1. This is why we chose the values of fixed resistors to be around a few hundred ohms and incremented in 1 Ω steps . The graph in Figure 5 shows what happens if you increase Δ*r* by increments of 10 Ω.

Note that only positive increments of Δr were used in this stage. We see a clear departure from linearity at larger values of Δ*r*.

If you are thinking that using larger values for the fixed resistances but continuing to increment Δ*r* in steps of 1 Ω would give even better linearity, you would be correct. However, the trade-off is that V would be smaller, perhaps too small to measure accurately. The ratio Δ*r*:R_1 of 1:330 appears to be a good compromise.

Why bother?

Out-of-balance Wheatstone Bridges are very common in sensing and monitoring circuits. For example, one of the resistors could be a thermistor. Over a certain range of temperatures, V the out-of-balance voltage will be proportional to change in temperature.

Note on use of this article

When preparing these articles, we choose graph markers and gridline spacings for their clarity. We are aware that students using such markers and spacings might well be penalised in assignment write-ups for doing so. This material is not intended for student use though you are free to edit it to create something that could be useful to them. It is not intended as a second source of data either. <<

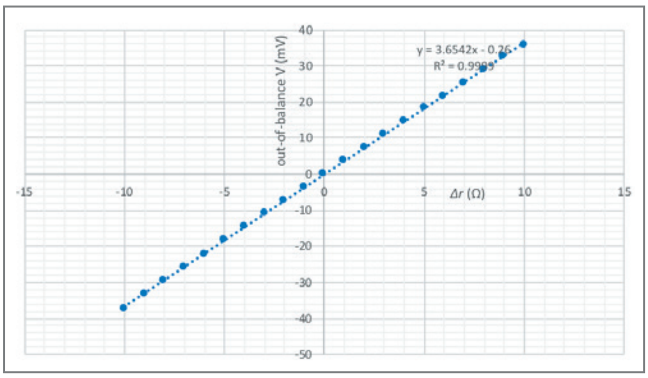

Figure 4 - Out-of-balance V versus Δr.

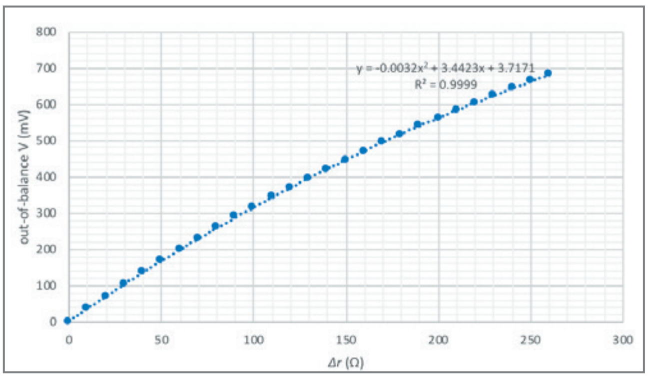

Figure 5 - Out-of-balance V versus Δr with larger Δr.