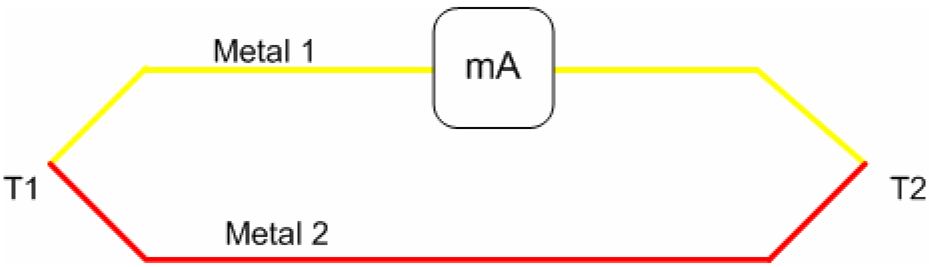
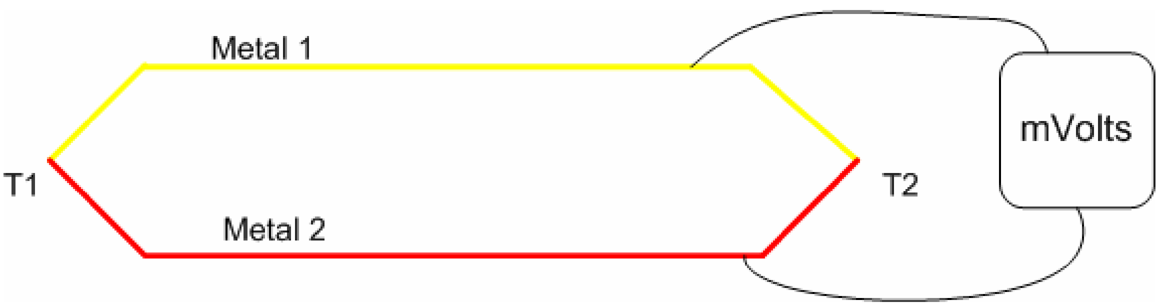
How Thermocouples Work

The simplest answer to how thermocouples work is that when you have two dissimilar wires twisted together as shown below and if temperature T1 is different that T2 then current will flow through the wires. This effect was discovered by T.J. Seebeck in 1831, and is often referred to as the Seebeck effect.



Seeback also discovered that the voltage potential that was generated was almost directly proportional to the difference in the two temperatures. That is if we connected a multimeter which was capable of measuring very low voltages across the two wires as shown below; then we could multiply the voltage by a constant and get the temperature difference between T1 and T2. This constant we use is called the Seeback coefficient and is based on the type of metals used for the wires.

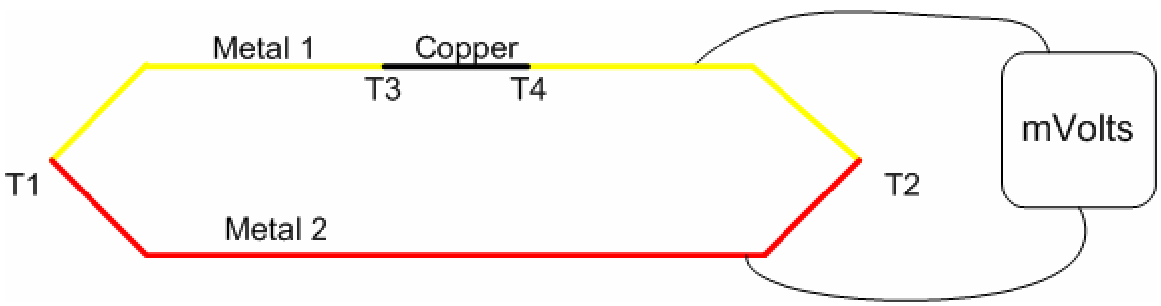


So lets assume that we are using a K type of thermocouple where the two metals are Chromega (yellow) and Alomega (red), for these two metals the Seebeck coefficient is about 51uV/°C.

So if T2 is at 0°C and T1 is at 100°C, then the yellow wire will have a voltage of 51*(100-0)uV or 5.1mV above the red wire. Now if T2 was at 20°C and T1 was still at 100°C then we would have 51*(100-20)uV or 4.08mV.

The point of this example is to show that thermocouples do not measure a temperature but rather they measure a temperature difference.

Next we investigate what happens if we broke one of our wires and wanted to splice it back together with some other wire. So for this example lets assume that our two metals are not copper and we want to splice the yellow wire with piece of copper as shown below:

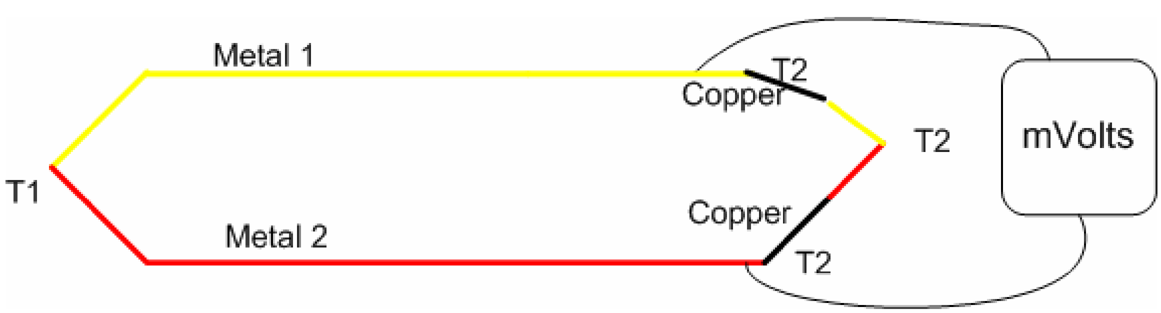


In this case the yellow wire and the copper create another thermocouple at T3 and T4. So basically we have to add this thermocouple effect into our equations. So the voltage that is generated by the copper wire would be Metal 1's and copper's Seebeck coefficient times the difference in temperature at T3 and T4.

Voltage= Seebeck * (T3 – T4)

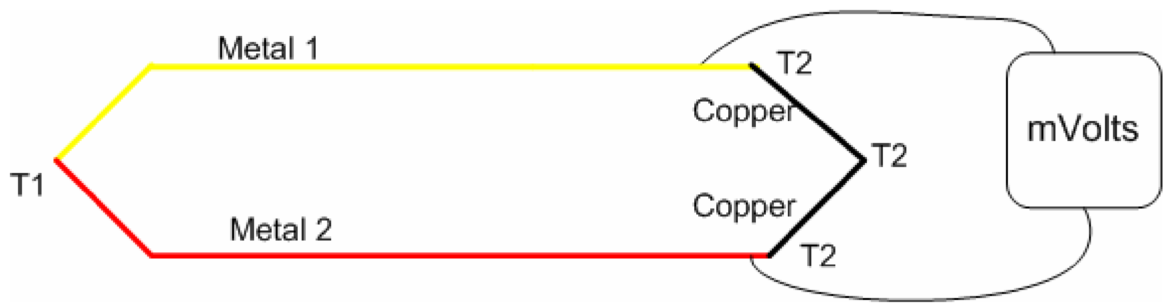
So basically if T3 is equal to T4 then the effect of adding the copper splice on our measurements would be zero. So we can generalize this a bit further to say that if we insert any metal splice in the wires, if both ends of the splice are at the same temperature it will not effect our measurements. When we have a splice with T3 and T4 at the same temperature it is often called an isothermal connection. In some application the splice is done on both wires at the same time, here again it is important to keep the splices at the same temperature as such people often use isothermal blocks, which are designed to keep splices at same temperatures.

To make our measurement system simpler we would like to be able to replace the junction at T2 with a different metal. To that extent look at the picture below:



Here we added two splices just before the junction at T2, here again since the splice junctions are at the same temperature there is no change in our measurement.

Well we can actually take this example a bit further and replace use copper at the junction for T2



Here what happens is that since the Metal 1 and copper joint is the same temperature as the Metal 2 and copper junction the effect of the copper is canceled out. Thus we do not actually have to use Metal 1 and Metal 2 for the metal at junction T2, instead we can use copper if the temperature of junction is the same.

So lets assume we want know what the temperature at T1 is and again we will assume that the thermocouple is K type with Seebeck coefficient of 51uV/°C. So we connect up the circuit as shown above and we measure 5.1mV. Looking at our equations above we find that:

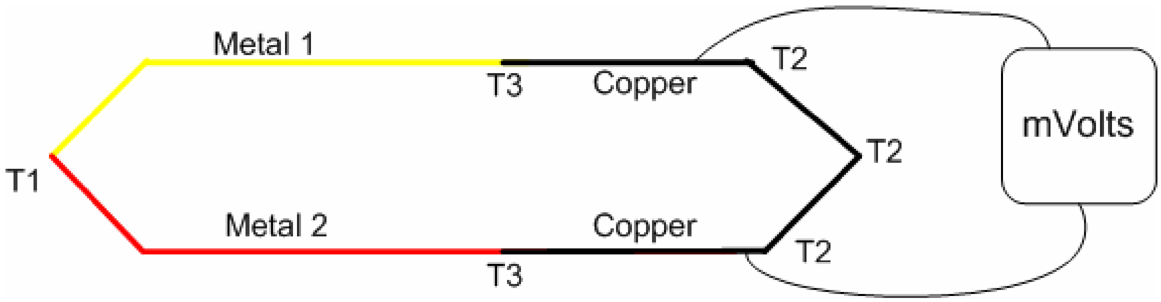
T1 = (Volts / Seebeck) - T2

T1 = (5.1mV / 51uV/°C) - T2
T1 = 100°C – T2

So we know our temperature difference is 100°C but until we need to know what T2, our reference temperature, is before we can measure T1. So what we could do is stick the wires at T2 in a glass of ice water, thus we would know the T2 would be 0°C. In fact this was the most common way to know T2 years ago and as such they often called the junction at T2 the ice reference point. However with the advent of highly accurate temperature measuring devices we can directly measure T2, instead of using ice.

At this point it is good to note that what usually happens is devices use a thermisitor or other semi conductor devices to measure T2, so why don't we use the same device to measure T1? Well the answer is simple, in that most thermisitors and semi conductor devices only can measure a small temperature range like (-20°C to 150°C) while a K thermocouple can go well over 500°C.

Well now that we know how the thermocouples work lets look at some common wiring problems with thermocouples. For example one guy decides that thermocouple wire is expensive so he uses copper wires to run from sensor to instrument like shown below:



Well as we have learned if T3 is the same temperature as T2 then he will not have a problem. However if T3 is in the cock pit of his airplane, which is about 20°C and T2 is on the back of the instrument which is 35°C then the net result is that his temperature measurements will read 15°C higher than expected.

Now some cheaper gauges actually do not measure the reference temperature (T2) instead they assume it will be a known level, say 20°C thus in this case T3 would be equal to T3 and the gauge will read correct. However if one morning the guy gets up and it is 0°C inside the cock pit, then T3 would be 0°C and the instrument is assuming the temperature is 20°C, thus all his readings will be 20°C higher than reality.

The net result is that if you do not know how your instrument measures the junction temperature it is best to use thermocouple wires all the way back to the instrument. Also if you want to have the most accurate reading possible make sure your instrument measure the reference junction temperature (T2). Then if you have to put splices in the thermocouple wires, make sure the two ends of the splice are at the same temperature.