Sensor Project

Introduction

In this project I am going to test and evaluate a thermistor. I am going to test the thermistor on how the resistance of this component changes under different temperatures. Thermistors are thermally sensitive resistors and have, according to type, a negative (NTC), or positive (PTC) resistance/temperature coefficient. A thermistor is a type of resistor whose resistance changes significantly when its temperature changes.

A negative temperature coefficient (ntc) thermistor has a resistance that decreases with increase of temperature. This is the most common type. This is the type of resistor that I shall be evaluating and will be using in my experiment.

A positive temperature coefficient (ptc) thermistor has a resistance that increases with increase of temperature. The resistance of a semiconductor generally decreases with increase of temperature. Semiconductors are therefore used to manufacture ntc thermistors.

When the temperature of a semiconductor is increased, the number of charge carriers increases as more valence electrons gain sufficient energy to break free from atoms to become conduction electrons. The number of charge carriers increases as the temperature is increased so the resistance of the semiconductor falls. Semiconductors are used to make a wide range of electronic devices including electronic chips, light emitting diodes and solid state lasers. Communications, commerce and entertainment have been revolutionised as a result of semiconductor devices. In electrical terms, materials are classed as either conductors or insulators or semiconductors.

Semiconductors are solid materials with conductivities in between the very high conductivity of metals and the very low conductivities of insulators. There are a variety of types of semiconductor, including metal oxides as well as elements like silicon and germanium. In insulators, essentially all the electrons are tightly bound to atoms or ions, and none are free to move under an external electric field. In effect, these materials do not conduct electricity at all. In metallic conductors, essentially all the atoms are ionised, providing free electrons, which move freely through the ions and can move under an external electric field. These conduction electrons 'glue' the ions together, and provide non-directional bonding which holds the material together. They become shared amongst all the atoms in the material instead of remaining attached to one atom.

Semiconductors differ from both insulators and metallic conductors. Only a small proportion of atoms are ionised, so that although there are conduction electrons they are relatively small in number and the material conducts, but not well. At higher temperatures, more atoms are ionised, and the conductivity rises. This is the picture for intrinsic semiconductors. Doping the semiconductor with atoms of other elements can increase the conductivity by increasing the number of mobile charge carriers. Doping of Group 4 elements such as silicon or germanium is done by adding about 1 in 1 million of atoms either from Group 5 or Group 3. In semi conducting group 4 elements such as silicon and germanium each atom has four outermost electrons in a shell that can hold eight electrons. Each atom shares an electron with a neighbouring atom to form a covalent bond. In this way, each atom is held in a lattice by four neighbouring atoms. Doping Group 4 elements with Group 5 elements produces n-type (negative type) semiconductor. The Group 5 atoms have five electrons in their outer shell, and use four of these to bond with Group 4 atoms, leaving one electron free to conduct. Doping Group 4 elements with Group 3 elements produces p-type (positive type) semiconductor. The Group 3 atoms have three electrons in their outer shell. One of the four possible bonds with neighbouring Group 4 atoms is incomplete. This vacancy behaves like a mobile positive hole, accepting an electron from a nearby atom. The electron fills one hole but leaves behind a new one. When a potential difference is applied, conduction by holes occurs as electrons hop from hole to hole, causing the holes to migrate to the negative end of the semiconductor. Extrinsic semiconductors are used in the manufacture of diodes, transistors, integrated circuits, hall effect devices as well thermistors. At constant temperature, the current through a semiconductor is in proportion to the potential difference so its resistance is constant. Thermal runaway can occur in semiconductor devices if the current causes a heating effect, which then reduces the resistance thus causing even more current and an even greater heating effect until the semiconductor becomes so hot that it becomes permanently damaged. A resistor in series with a semiconductor device may therefore be needed to prevent thermal runaway. The resistance of a metal and certain other materials increases with temperature. Barium titanate is a non-metal used in the manufacture of ptc thermistors as it has a much larger temperature coefficient of resistance than any metal or any other commonly available material.

PTC thermistors are used to prevent current surges in motor circuits and lighting circuits when such circuits are switched on. Increasing current increases the resistance of a ptc thermistor, which then serves to limit the increase of current. Thermistors are used in potential dividers and in Wheatstone bridge circuits to supply potential differences that vary with temperature to electronic control and measurement circuits. Manufactured from the oxides of the transition metals - manganese, cobalt, copper and nickel, NTC thermistors are temperature dependant semiconductor resistors. Operating over a range of -200°C to + 1000°C, they are supplied in glass bead, disc, chips and probe formats. NTCs should be chosen when a continuous change of resistance is required over a wide temperature range. They offer mechanical, thermal and electrical stability, together with a high degree of sensitivity. The excellent combination of price and performance has led to the extensive use of NTCs in applications such as temperature measurement and control, temperature compensation, surge suppression and fluid flow measurement. PTC thermistors are temperature dependent resistors manufactured from barium titanate and should be chosen when a drastic change in resistance is required at a specific temperature or current level. PTCs can operate in the following modes:

- Temperature sensing, switching at temperatures ranging from 60°C to 180°C, e.g. protection of windings in electric motors and transformers.
- Solid state fuse to protect against excess current levels, ranging from several mA to several A (25°C ambient) and continuous voltages up to 600V and higher, e.g. power supplies for a wide range of electrical equipment.
- Liquid level sensor.

The unique patented design Composite Thermistor contains 2 NTC and 1 PTC thermistors and has a resistance temperature characteristic similar to a single NTC but with a region of constant resistance. Designed for driving automotive coolant temperature gauges, the composite sensor resistance is virtually constant over a specified range, which results in a steady centre dial gauge reading during normal engine operation. Hot and cold zone sensitivity is retained, so that motorists are warned of abnormal conditions. With careful selection of the plateau region, the same type of device can be used in a wide variety of operation systems, so that the production economics are compatible with the requirements of our automotive customers.

Composite Thermistors can be custom-designed to match the electrical and thermal characteristics of gauges and probe housings.

Thermistors are used in temperature sensors and digital thermometers in systems when the resistance needs to drop drastically under a small amount of temperature change. An example of a system when a thermistor is needed is in incubators, when the temperature needs to be controlled and the temperature needs to be kept totally constant. If the temperature inside begins to decreases then the resistance will increase, therefore the cooling system will stop producing cold air so much. If the temperature begins to increase then the thermistor's resistance will decrease, therefore the cooling system will work more, thus keeping the temperature inside the system constant. Another context in which thermistors are needed is inside mobile phones. The components inside the phone, which are all needed to make the phone work, will only work at a certain temperature. If the temperature of the phone gets too high some of the components may break. Mobile phones have a system using a thermistor, when the temperature of the phone gets too high the thermistors resistance decreases allowing the system to work. The mobile phone automatically shuts down and switches off, allowing all the components to cool down. This stops the owner needing to get the phone repaired.

Method

Initially the method I intended to use involved a cell, a voltmeter, and ammeter and the thermistor. I would have then calculated the resistance using R=V/I. However after further research I found out that the thermistor could possibly burn itself out. This would result in the thermistor not working properly and my results would be inaccurate. The circuit I was going to use can be seen below.

Instead of using this method I decided to use a multimeter attached directly to the thermistor. The basis of my experiment is to find out what the resistance of the thermistor is at different temperatures. I change the temperature of the thermistor I will put the thermistor in a beaker of water and to lower the temperature I will add ice, to increase the temperature I will heat the water using a Bunsen burner. I will use a thermometer to tell me when to check the resistance. The temperatures I will take my readings at are 5,10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, and 80˚C. I will start by cooling the water with the ice and then heat the water to 80˚C, I will then also record the resistance when the thermistor is cooling afterwards and add ice again at the end so that I will be able to check my first recordings were accurate. The resistance should be the same each time the thermistor is at a certain temperature. However a potential human error is if I take the recording at the correct time.

Diagram

Apparatus list

Apparatus	Reason
Thermistor	To find out how the resistance of the thermistor changes as the temperature increases.
Multimeter	The source of power of the circuit, so that the thermistor works and also to find the resistance of the thermistor.
Bunsen burner	To heat the water the thermistor will be in.
Ice	To decrease the temperature of the water that the thermistor will be in.
Thermometer	To know when to take the resistance reading.
Beaker of water	To provide an environment where the temperature change can take place so the thermistor’s resistance can change.
Tripod and gauze	For the beaker to be heated on.

Results

Heating

Temperature (˚C)	Resistance (kΩ)
5	1.025
10	0.742
15	0.630
20	0.511
25	0.398
30	0.333
35	0.287
40	0.254
45	0.205
50	0.170
55	0.148
60	0.133
65	0.111
70	0.098
75	0.088
80	0.078

Cooling

Temperature (˚C)	Resistance (kΩ)
80	0.078
75	0.086
70	0.098
65	0.112
60	0.131
55	0.148
50	0.170
45	0.206
40	0.254
35	0.286
30	0.333
25	0.398
20	0.511
15	0.631
10	0.741
5	1.025

Conclusion

As you can see from the results, as expected the resistance produced by the thermistor decreases drastically as the temperature increases. This is because the semiconductor material of the thermistor becomes more conductive as the temperature increases. This is because some of the electrons of the semiconductor are able to cross from the valance band to the conductance band as I explained earlier. The sensor performed very well because no anomalous results were found, the resistance at different temperatures was very similar both times I took a set of readings, when the temperature was increasing and when the temperature was decreasing. The sensor performed as expected and produced very accurate and precise results.

To be a good sensor system it should possess high resolution, appropriate output for a given input, rapid response time, small unsystematic fluctuations in results, and a small systematic error.

The resolution of a sensor is the smallest change it can detect in the quantity it is measuring. With my sensor, on the multimeter, the second decimal place fluctuated, indicating that changes of that magnitude are only just resolved. The resolution is related to the precision with which the measurement can be made.

The sensitivity of a measuring system is the ratio of change of output to change of input. The sensitivity of my thermistor is measured in kΩ. Sometimes it is necessary to reduce the sensitivity so that the measuring instrument can deal with larger changes of input. This is why I decided to take my readings in kΩ instead of Ω.

The response time is the time a sensor takes to respond to a change in input. Changes which occur more rapidly than this will usually be averaged out. In any monitoring of a process, such as my experiment, the response time of the thermistor must be short enough to detect important changes as they occur. My thermistor was successful in doing so therefore the response time of my thermistor was very good.

The input signal may fluctuate or the sensor itself may generate noise. Small unsystematic variations are present in all experimental data. Their size limits the precision with which a measurement can be made. Taking an average over repeated measurements can improve the final result, as long as the conditions can be kept the same. This is why I took recordings when the thermistor was in an environment when the temperature was increasing and then decreasing, this gave me two sets of recordings which allowed me to check my results were correct.

Systematic error is very hard to detect, because detecting it means making another, even better, measurement. Systematic errors include zero error, and error due to disturbing influences, for example temperature. My experiment controlled the temperature and therefore this will not have been a factor.

Therefore I can conclude that my thermistor performed fairly well, this is because the results followed a pattern, my thermistor performed successfully because the response time was good, there was an unsystematic error when the multimeter reading was fluctuating and therefore I can conclude that my readings were fairly accurate.