**DIODES and TEMPERATURE**

Student ABC345 Word Count = 1751

**Introduction**

Diodes are semiconductive electric components. The fundamental property of a diode is that it only conducts electric current to one direction. A diode has two electrodes called the anode and the cathode. When the cathode is negative potential relative to the anode by an amount larger than the forward threshold voltage, the diode will conduct current. However, if the cathode is positive, at the same voltage or not negative enough relative to the anode to break the threshold voltage, the diode will not conduct current (Margareth 2015). Diodes are used for a range of things, for example, to rectify alternative currents, limit the range of a signal and protect other electronic components. They are also used in temperature measurement devices due to their forward voltage dependence on the temperature (Texas Instruments 2018), which is the aspect I got particularly interested about.

**The aim of this experiment is to determine a precise relationship between temperature and the threshold voltage of a silicone diode (1N4007).**

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| A close-up of a cable  Description automatically generated with low confidence | Vishay: **Diode 1N4007**  https://3.bp.blogspot.com/-1DMQy53Z0nk/V-3pel3XPAI/AAAAAAAAAY0/8-VwfBaOVMINcMuu9PbF3AgXsuZBuaDrwCLcB/s1600/IMAGEN+PAG.1+DE+1N4007.jpg |

**Research Question**

**How does the temperature affect the forward threshold voltage of a silicone diode?**

**Hypothesis**

The threshold voltage is expected to have a negative linear correlation with the temperature, as a linear correlation would make the diode useful in temperature measurement due to its consistency. The threshold voltage is expected to drop as the temperature increases, hence the negative correlation. I wish to confirm the negative linear function like the one explained by A.M. Abd El-Maksood (2017).

**Variables**

**Independent variable:** The **temperature** of the diode (°C). A digital thermometer is used to measure the temperature of the of the oil where the diode is placed. First measurement is done at room temperature, after which the measurements are done in intervals of 20°C starting from 40°C.

**Dependent variable:** The **threshold voltage** of a diode (V). The threshold voltage was found by altering the voltage in the circuit and finding a value when there were no changes between the input voltage and the voltage going through the diode.

**Controlled variables:** *Current* in the circuit is controlled with a resistor to minimize the heating of the diode itself.

**Materials:** Table #1

* 1N4007 silicon diode with normal threshold voltage of 0,7 V at room temperature.
* Beaker
* Canola oil to be heated and diode inserted.
* DC voltage supply and voltmeter
* Laboratory burner and trivet to heat oil quickly
* Resistor at 10 ohms, switch, for on and off
* Digital thermometer with metals sensor used to measure oil at high temperatures.

**Method Step One**

Figure #1 Circuit Design (CircuitLab, https://www.circuitlab.com/)

Diagram

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The circuit was designed so that the voltmeter shows the voltage in the circuit when the switch is open, and therefore the change in potential energy can be seen when the switch is closed.

**Method Step Two**

1. After setting up the circuit, the diode and the thermometer were put in the oil.
2. The oil was heated up to the desired temperature (in case of first datapoint no heating is required as it is measured in room temperature, in this case 22,8 °C).
3. The voltage source was turned on starting from 1,00 V.
4. The switch was pressed to see the voltage drop.
5. Voltage source was adjusted to the value shown after the drop, and then the switch was pressed again.
6. This was repeated until there was no change in the voltage when the switch was pressed, and the value was written down.
7. Steps 2-6 were repeated for temperatures 40°C, 60°C, 80°C,100 °C, l 20°C, 140°C and 160°C respectively.

The experiment had eight different data points and three trials in total. Three trials were found sufficient, as the spread of the collected data was small.

**Risk assessment**

During the experiment the following safety risks were considered:

**Hot oil:** Might cause splatters at the higher temperatures, keeps the beaker hot for longer time.

***Resolution*:**Goggles were worn in case of oil splatters and a jacket was worn to avoid staining the clothes. The beaker was left to cool down after the experiment and it was not touched during the experiment to avoid bums.

**Fire and the laboratory burner:** As fire and gas involved, I must be careful.

***Resolution:***The usage of the burner was revised to minimize the possibility for an accident. The burner was securely shut in between the trials and immediately after the experiment was done.

**Electric circuits:** A possibility to be electrocution.

***Resolution:*** Always have the voltage source shut when manipulating the circuit.

**Raw Data:** Table #2

Temperature and measured threshold voltage

Table

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The first data point is 22,8 °C because I wanted to start my measurement with the room temperature to see if the threshold voltage acquired would match the estimated threshold voltage of a silicon diode. The threshold voltage of the silicone diode being approximately 0,7 V we can see that the result acquired corresponds to the theoretical value with a reasonable error.

**Analysis**

From this data the average threshold voltage (Vave) for each temperature can be calculated. The uncertainty of this average (ΔVave) is taken by subtracting the minimum voltage from the maximum voltage and dividing that by two.

Sample calculation for Table #3.

Vave = (0,65 + 0,65 + 0,64) / 3 ≈ 0,65 V ΔVave = (0,65 – 0,64) / 2 = 0,005 V ≈ 0,01 V

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| After these calculations it was noted that the voltmeter used for the measurement already had an error of  ± 0,01 V and therefore that value must be the smallest possible error despite the calculated result being smaller. This way each data point ended up having the same error and hence it has only been marked once on the top row of Table 3.  The error used for the temperature is ±1 °C. Although the accuracy of the thermometer used was ± 0,1 °C, a higher error value had to be used because keeping the temperature exact during the experiment proved to be difficult. This was especially true with higher temperatures, as the temperature started to decrease quickly. | Data Table 3:  Average threshold voltage at each temperature  Table  Description automatically generated |

Graph #1.

The data from Table #3 is plotted (using LoggerPro by Vernier) on the graph of **threshold voltage against the temperature:**

Chart, line chart

Description automatically generated

From Graph #1 we can see that a descending straight line can be fitted through the datapoints, showing a negative linear correlation as predicted in the hypothesis. From the gradient (k) of the graph we can acquire the temperature coefficient for the diode. The change factor in this case being voltage resulting in the units of volts per degree. From the graph we can get the gradient by choosing two points that the line of best fit passes through, such as (50;0,6) and (150;0,4). With this, the gradient can be found as follows:

k = (0,4–0.6 V) / (150 – 50 °C) = –0,002 V / °C = –2 mV / °C

The acquired value for the temperature coefficient corresponds to the approximate value given for silicon diodes (Patil n.d.). The line of best fit is linear, so the gradient (m) and *y*-intercept (b) are needed to find the equation of the line. As we already have both values calculated by LoggerPro, all we do is to substitute the values for the equation:

*y*= *m x* + *v* becomes. Vx = –0,002 T + 0,7029

Because there is a linear relationship between the temperature and the forward voltage drop, the temperature of the diode can be tracked easily through the changes in the threshold voltage. This is the property that makes diodes useful as temperature measurement devices.

**Conclusion and evaluation**

After the data has been collected and processed, it can be concluded that the initial hypothesis is supported by the results of the experiment. From the raw data presented on Table #1 it can be observed that the threshold voltage of the diode decreases as the temperature increases, therefore confirming the hypothesis of having a negative correlation between the variables. Normally, the temperature coefficient relates resistance to temperature but for this study I defined the coefficient as a voltage and temperature function.

After calculating the average threshold voltage from the three trials, it was plotted against temperature to Graph #1, from which we can clearly see that the line of best fit is a straight line. The slope of the line, which represents the temperature coefficient of the diode, shows the change of threshold voltage per degree. This was shown to be –2,7 mV / °C which corresponds to the approximate value given for silicon diodes (Patil n.d. and A.M. Abd El-Maksood).

The precision of the obtained data is quite high, as from the three trials each threshold voltage stayed within 0,02 V. However, it must be noted that the change of the threshold voltage with a temperature difference of 40 °C was quite small, and therefore the error becomes relatively significant, as the lower limit of the error bar is often approximately at a same point where the lower error bar of the next datapoint is located. Due to the consistency of the data, the linear fit for the datapoints could still be drawn successfully. The acquired temperature coefficient and its correspondence to a theoretical value further suggest that the data presented in Table #2, Table #3 and Graph #1 has been both accurate and precise.

The **random error** that could have affected the precision of the experiment is the reaction time. As the oil reaches the wanted temperature, the switch must be pressed in order to see the voltage drop. Furthermore, the voltage must be readjusted after the temperature has been reached, and this means that especially in the higher temperatures the oil had already started to cool down.

The possible **systematic errors** in this experiment include the internal resistance of the diode, that can cause the diode to heat up more than the oil's temperature suggests. This is possible even though the 100-ohm resistor was put in place to minimize the error caused by the internal resistance. However, as the error bars were placed at ± °C, it is likely that this systematic error falls within the error bars.

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