Faculty of Science
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Laboratory Report Cover Page

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Appendices

Introduction

A diode is a semiconductor device employed as a unidirectional electrical current regulator. In this laboratory experiment, we intend to subject a diode to various temperature environments: room temperature, ice water submersion, and hot water. The goal is to monitor the voltage across the diode while adjusting the supplied current (sourced from an external power supply) and recording temperature variations. These recorded measurements are critical data points for determining two significant parameters: the Boltzmann constant and the reverse saturation current. This investigation holds the promise of enhancing our comprehension of the diode equation.

Theory

A semiconductor diode is a device which only allows a current to flow in one direction; it cannot flow in any other direction. A semiconductor diode is synthesized by combining a p-type doped semiconductor to an n-type doped semiconductor. The junction between the semiconductors are called a 'p-n junction'.

Figure 1.0: P-N Junction

If the semiconductor diode is connected to a voltage source, the current that flows through the junction depends on the polarity of the applied voltage. The diode will be known as 'forward biased' if a large current flows through the diode. If the current flows through the diode in the opposite direction, almost no current will flow through, which we would call a 'reverse bias'. When a p-n junction is formed, electrons from the n-type material's conduction band diffuse to the p-side, where they interact with holes in the valence band.

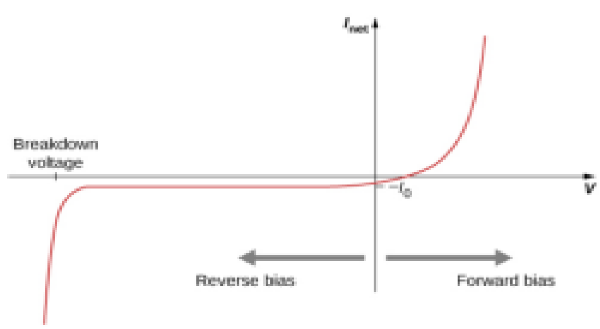


Figure 3.0: Forward and Reverse Bias Graph

A pn semiconductor junction has a current-voltage relationship described by the following equation:

$$I = I_0[exp(\frac{V}{Vt}) - 1]$$

Where I is the current flowing through the device and V is the voltage applied across the junction. The value I_0 is the reverse saturation current which is the maximum current which can flow through the junction in a reverse biased. Though the I_0 value is very small usually in μA. The value V is the thermal voltage which can be defined by the following equation:

$$V_t = \frac{K_B T}{|q|}$$

Where K_B is Boltzmann's constant, T is the temperature in kelvins and $|q|$ is the absolute value of charge on charge carriers.

We have the diode constant equation of $I = I_0[exp(\frac{V}{Vt}) - 1]$. In a reverse biases, the constant is nearly equal to the I_0 value where the I_0 value is near the range of μA which is very small compared to a forward bias current (in a mA range). People usually speak of the diode as no current in a reverse bias.

Since diodes function like a one-way-value, transistors are also like one-way-values that can be opened and closed in order to control current. A junction transistor is made up of three parts: an n-type semiconductor, commonly known as the emitter; a thin p-type semiconductor, known as the base; and another n-type semiconductor, known as the collector. The following diagram displayed a transistor setup using a power supply.

Procedure

In this experimental setup, we employed a silicon bipolar junction transistor, a dual multimeter, a 200mA current source, a thermometer, an insulated cup, ice cubes, and hot water as the necessary materials. To ensure proper configuration, the n-p-n junction comprising the base, collector, and emitter was wired in accordance with the provided schematic, and the transistor's diode-like behaviour was confirmed through lead reversal. Subsequently, room temperature was recorded using a thermometer, and voltage readings were taken at incremental increments of 2^n in the supplied current, with 'n' representing the number of data points up to a maximum of 200mA. These steps were then repeated for the diode submerged in both hot and ice water, facilitating a comprehensive examination of the diode's response to temperature fluctuations.

Results and Calculations

Room Temp: 26.166 ± 0.0005 ℃ = 299.316 K

Current (mA)	Voltage (V)
20.0 ± 0.05 mA	0.572 ± 0.0005 V
40.0 ± 0.05 mA	0.595 ± 0.0005 V
60.0 ± 0.05 mA	0.610 ± 0.0005 V
80.0 ± 0.05 mA	0.621 ± 0.0005 V
100.0 ± 0.05 mA	0.629 ± 0.0005 V
120.0 ± 0.05 mA	0.636 ± 0.0005 V
140.0 ± 0.05 mA	0.642 ± 0.0005 V
160.0 ± 0.05 mA	0.647 ± 0.0005 V
180.0 ± 0.05 mA	0.652 ± 0.0005 V
197.6 ± 0.05 mA	0.654 ± 0.0005 V

Table 1.0: Table of Diode Current and Measured Voltage at Room Temperature

Boiling water: 86.218 ± 0.0005 ℃ = 359.368 K

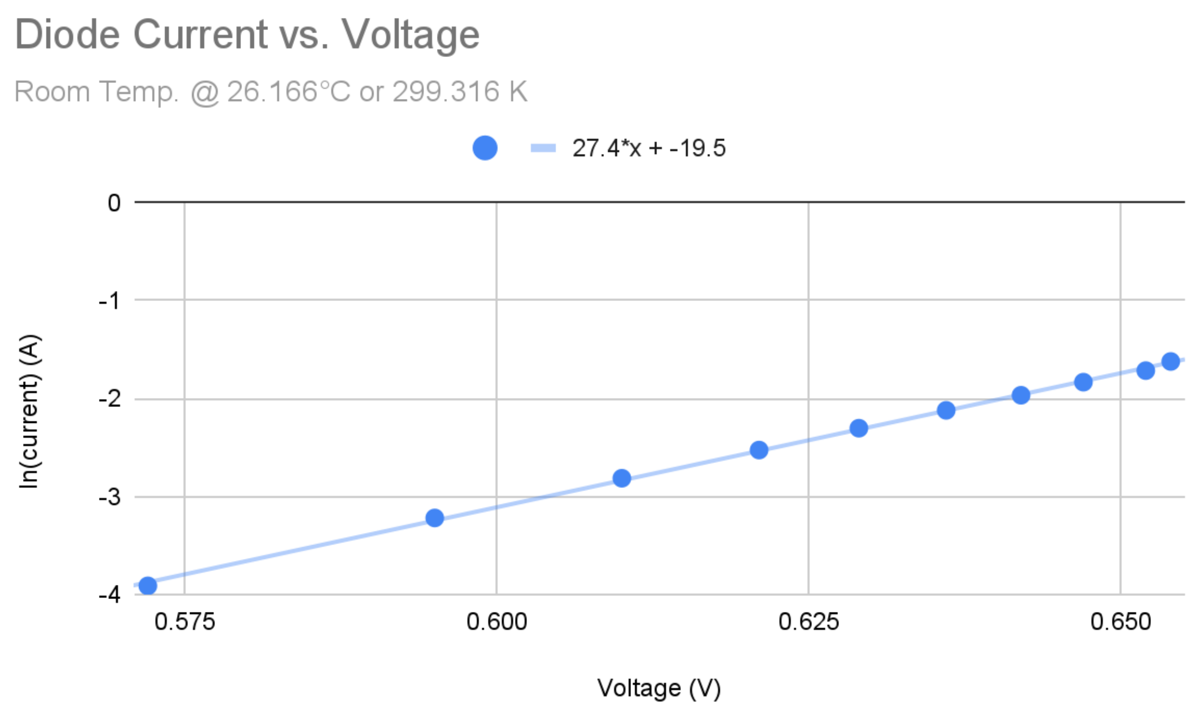
Current (mA)	Voltage (V)
20.0 ± 0.05 mA	0.450 ± 0.0005 V
40.0 ± 0.05 mA	0.479 ± 0.0005 V
60.0 ± 0.05 mA	0.500 ± 0.0005 V
80.0 ± 0.05 mA	0.509 ± 0.0005 V
100.0 ± 0.05 mA	0.520 ± 0.0005 V
120.0 ± 0.05 mA	0.529 ± 0.0005 V
140.0 ± 0.05 mA	0.538 ± 0.0005 V
160.0 ± 0.05 mA	0.545 ± 0.0005 V
180.0 ± 0.05 mA	0.553 ± 0.0005 V
197.6 ± 0.05 mA	0.558 ± 0.0005 V

Table 2.0: Table of Diode Current and Measured Voltage in Boiling Water

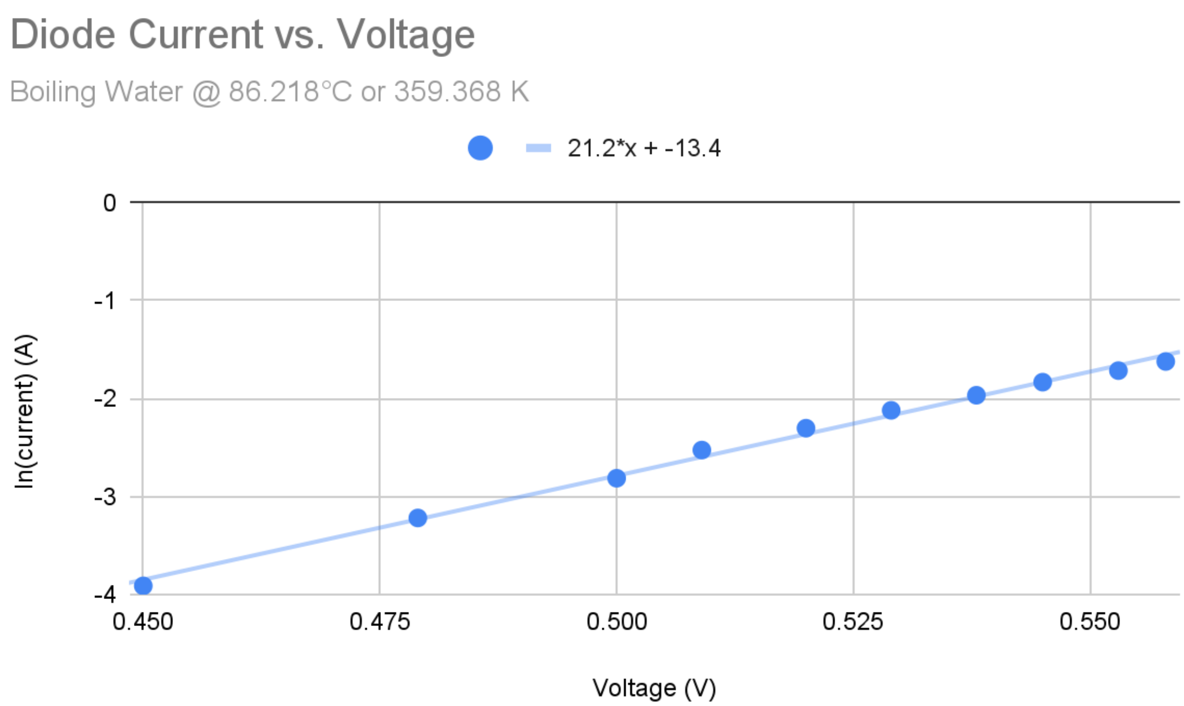
Ice Water 3.061 ± 0.0005 ℃ = 276.211 K

Current (mA)	Voltage (V)
20.0 ± 0.05 mA	0.614 ± 0.0005 V
40.0 ± 0.05 mA	0.636 ± 0.0005 V
60.0 ± 0.05 mA	0.648 ± 0.0005 V
80.0 ± 0.05 mA	0.657 ± 0.0005 V
100.0 ± 0.05 mA	0.664 ± 0.0005 V
120.0 ± 0.05 mA	0.671 ± 0.0005 V
140.0 ± 0.05 mA	0.678 ± 0.0005 V
160.0 ± 0.05 mA	0.684 ± 0.0005 V
180.0 ± 0.05 mA	0.690 ± 0.0005 V
197.6 ± 0.05 mA	0.697 ± 0.0005 V

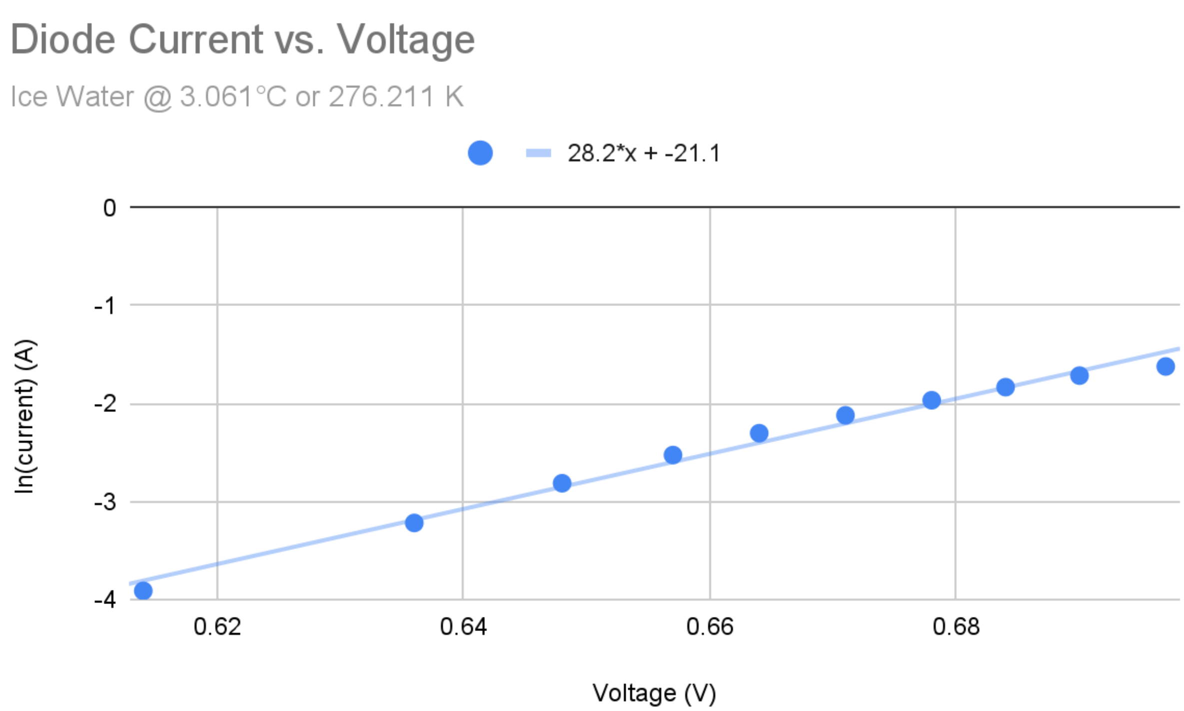
Table 3.0: Table of Diode Current and Measured Voltage in Ice Water



Graph 1.0: Linear Relationship Between Natural log of Current vs. Voltage at Room Temperature



Graph 2.0: Linear Relationship Between Natural log of Current vs. Voltage in Boiling Water



Graph 3.0: Linear Relationship Between Natural log of Current vs. Voltage in Ice Water

$Slope = m = \frac{|q|}{K_B T} \rightarrow K_B = \frac{|q|}{mT}$

$x - intercept = b = ln(I_0) \rightarrow I_0 = e^b$

Room Temperature

m = 27.4 b = -19.5 T = 299.316 K

$K_B = \frac{|q|}{mT} = \frac{|1.602\times10^{-19}C|}{(27.4)(299.316\,K)} = 1.95 \times 10^{-23}\frac{J}{K}$

$Uncertainty\ of\ K_B = z\sqrt{(\frac{\Delta x}{x})^2 + (\frac{\Delta y}{y})^2} = 1.95 \times 10^{-23}\sqrt{(\frac{5\times10^{-2}}{27.4})^2 + (\frac{5\times10^{-4}}{299.316})^2} = \pm\ 3.56 \times 10^{-26} J/K$

$\%\ error\ of\ K_B = \left|\frac{measured - accepted}{accepted}\right| \times 100 = \left|\frac{1.95\times10^{-23} - 1.38\times10^{-23}}{1.38\times10^{-23}}\right| \times 100 = 41\%$

$I_0 = e^b = e^{-19.5} = 3.40 \times 10^{-9} A$

$Uncertainty\ of\ I_0 = z\sqrt{(\frac{\Delta x}{x})^2} = 3.40 \times 10^{-9}\sqrt{(\frac{5\times10^{-2}}{19.5})^2} = \pm\ 8.72 \times 10^{-12} A$

Boiling Water

m = 21.2 b = -13.4 T = 359.368 K

$K_B = \frac{|q|}{mT} = \frac{|1.602\times10^{-19}C|}{(21.2)(359.368\,K)} = 2.10 \times 10^{-23}\frac{J}{K}$

$Uncertainty\ of\ K_B = z\sqrt{(\frac{\Delta x}{x})^2 + (\frac{\Delta y}{y})^2} = 2.10 \times 10^{-23}\sqrt{(\frac{5\times10^{-2}}{21.2})^2 + (\frac{5\times10^{-4}}{359.368})^2} = \pm\ 4.95 \times 10^{-26} J/K$

$\%\ error\ of\ K_B = \left|\frac{measured - accepted}{accepted}\right| \times 100 = \left|\frac{2.10\times10^{-23} - 1.38\times10^{-23}}{1.38\times10^{-23}}\right| \times 100 = 52\%$

$I_0 = e^b = e^{-13.4} = 1.52 \times 10^{-6} A$

$Uncertainty\ of\ I_0 = z\sqrt{(\frac{\Delta x}{x})^2} = 3.40 \times 10^{-9}\sqrt{(\frac{5\times10^{-2}}{13.4})^2} = \pm\ 1.27 \times 10^{-11} A$

Ice Water

m = 28.2 b = -21.1 T = 276.211 K

$K_B = \frac{|q|}{mT} = \frac{|1.602\times10^{-19}C|}{(28.2)(276.211\,K)} = 2.06 \times 10^{-23}\frac{J}{K}$

$Uncertainty\ of\ K_B = z\sqrt{(\frac{\Delta x}{x})^2 + (\frac{\Delta y}{y})^2} = 2.06 \times 10^{-23}\sqrt{(\frac{5\times10^{-2}}{28.2})^2 + (\frac{5\times10^{-4}}{276.211})^2} = \pm\ 3.65 \times 10^{-26} J/K$

$\%\ error\ of\ K_B = \left|\frac{measured - accepted}{accepted}\right| \times 100 = \left|\frac{2.06\times10^{-23} - 1.38\times10^{-23}}{1.38\times10^{-23}}\right| \times 100 = 49\%$

$I_0 = e^b = e^{-21.1} = 6.86 \times 10^{-10} A$

$Uncertainty\ of\ I_0 = z\sqrt{(\frac{\Delta x}{x})^2} = 3.40 \times 10^{-9}\sqrt{(\frac{5\times10^{-2}}{21.1})^2} = \pm\ 8.06 \times 10^{-12} A$

Discussion

1. It is common to say that a diode does not allow any current to flow when it is reverse biased because the reverse saturation current is so small, typically in the µA range, that people often just neglect it. We can see this is true if we look at our data, as the I_0 values that we measured are very small.
2. $V_t = \frac{K_B T}{|q|}$ $\quad V_t room$ =0.036 V $\quad V_t boil$ =0.047 V $\quad V_t ice$ =0.036 V
   Looking at our results, V_t is smaller than V by a factor of 10. It might seem as though the assumption does not hold true, but since the maximum power output of the current source was 200 mA, the assumption is valid. However, if the current source were able to supply a greater current, the assumption would not be considered.
3. If the temperature were to increase, the reverse saturation current would also increase because they are proportional to each other. This would therefore lead to an increase in current as well.

Conclusions

In this experiment, we successfully learned how to calculate Boltzmann's constant and the reverse saturation current of a diode using the linear relationship between the natural log of current and voltage across the diode. We also learned that as the temperature around a diode increases, the reverse saturation current also increases, leading to an increase in current as well. The voltage, however, decreases. Our percent errors were higher than we had hoped, and it could have been due to the surrounding temperature constantly increasing and decreasing to reach room temperature. We can see this is true with our data, as the data from the room temperature part yielded the lowest percent error and the data from the boiling water part had the highest since the temperature difference from room temperature was greater than the ice water.

References

W. Moebs, S. J. Ling, and J. Sanny, "university physics volume 1," *OpenStax*, 19-Sep-2016. [Online]. Available: https://openstax.org/books/university-physics-volume-1. [Accessed: 18-Oct-2023].