Constructor University Bremen

Natural Science Laboratory
Electrical Engineering Module I

Fall Semester 2024

Lab Experiment 4 – Single PN - Junction

Experiment 5 – DC Network - Data

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Place of execution	: Teaching Lab 53
Date of execution	: Oct.25 , 2024

1 Introduction

This report focuses on the characteristics and applications of PN junction diodes, specifically a standard silicon diode (1N4001) and a Zener diode (BZX85C5V6), by analyzing their voltage-current (V-I) behavior in forward and reverse bias conditions. A PN junction diode is formed by joining a P-type semiconductor, with an abundance of holes, and an N-type semiconductor, rich in electrons. This combination creates a depletion region at the junction, which acts as a barrier to charge carriers. The PN junction is foundational in many semiconductor devices, such as diodes, transistors, and regulators, due to its directional current behavior and voltage-dependent properties.

In forward bias, where a positive voltage is applied to the P-type region relative to the N-type, the depletion region is reduced, allowing current to flow across the junction. In this experiment, the 1N4001 silicon diode was used to observe the forward V-I curve. As the applied forward voltage increased, an initial small rise in current was recorded until the forward voltage reached a threshold level (around 0.7V for silicon diodes). At this point, current increased exponentially with further voltage, demonstrating the diode’s characteristic "on" state, where it conducts with minimal resistance. This behavior is crucial for applications like AC to DC conversion, where diodes direct current flow in one direction to produce a steady output.

In reverse bias, however, the PN junction behaves differently. The applied negative voltage on the P-type region relative to the N-type increases the width of the depletion region, blocking current flow almost entirely until the breakdown voltage is reached. This effect is particularly valuable in Zener diodes, which are specifically designed to allow controlled breakdown without damage. For the BZX85C5V6 Zener diode, the reverse V-I characteristics showed that current remained minimal as voltage increased until reaching the Zener breakdown voltage at around 5.6V. Beyond this point, the Zener diode allowed current to flow while maintaining a nearly constant voltage, making it useful for applications in voltage regulation.

Further analysis involved constructing a Zener shunt regulator circuit, where the Zener diode stabilized the output voltage at its breakdown value, even as load resistance and current fluctuated. This demonstrates the Zener diode’s ability to maintain a fixed output voltage, essential for circuits requiring a stable reference voltage. By studying the V-I characteristics of the 1N4001 and BZX85C5V6 diodes, this experiment highlights the unique properties of silicon and Zener diodes and their critical roles in electronic applications like rectification, voltage stabilization, and current control.

2 Execution

2.1 Experimental Setup

Workbench No.5

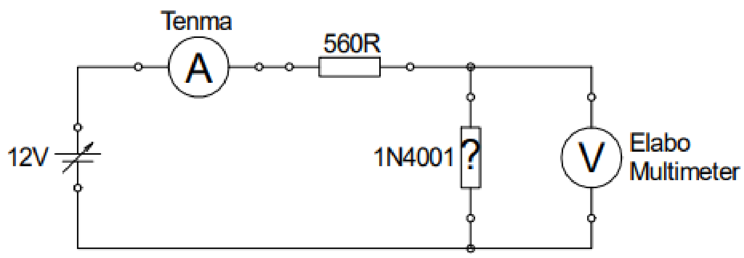
Used tools and Instruments:

- Breadboard, Tools box from workbench
- TENMA Multimeter
- ELABO Voltmeter
- Power supply ELABO
- 560 - ohm resistor
- 1N4001 Type Diode

2.1.1 Experimental Part 1 – Determination of Anode and Cathode

- **The objective** - The objective of this experiment is to determine the anode and cathode of a silicon diode, distinguishing between the P-type (anode) and N-type (cathode) semiconductor regions. This identification process provides foundational knowledge about diode polarity and is essential for correctly orienting diodes in circuits.

- **Test Circuit**



2.1.2 Experimental Part 1 – Execution and Results

Description of the measurement

To execute this experiment, measurements were performed to observe the diode’s behavior under different orientations in the circuit and to determine its polarity using a multimeter. The following steps were carried out:

First, the voltage drop across the diode and the current through it were measured while noting the diode's orientation. The orientation was recorded using the ring marking on the diode as a reference. Next, the diode was reversed in the circuit, and the orientation was recorded once more. The voltage drop and current were measured again in this reversed configuration. These measurements enabled observation of the diode's response to forward and reverse bias conditions.

Position1

V(V)	12.08
I(uA)	1.11
Orient	reverse

Position2

V(V)	0.71
I(mA)	20.162
Orient	forward

Table 1. Determination of the anode and cathode

In Position 1, the diode is in reverse orientation, indicated by the measured voltage of 12.08 V and a very low current of 1.11 µA. In reverse bias, the P-type (anode) of the diode is connected to the negative side of the circuit, while the N-type (cathode) is connected to the positive side. This orientation widens the depletion region, creating a high resistance that restricts the flow of charge carriers, allowing only a minimal leakage current. The high voltage and low current observed here align with the expected behavior of a diode in reverse bias.

In Position 2, the diode is in forward orientation, as demonstrated by the measured voltage drop of 0.71 V and a significantly higher current of 20.162 mA. In forward bias, the P-type (anode) is connected to the positive side of the circuit and the N-type (cathode) to the negative side. This configuration narrows the depletion region, enabling the free flow of charge carriers and allowing current to pass through the diode more easily. The voltage drop and high current observed in Position 2 are consistent with a diode's behavior when forward biased, confirming this orientation.

With the diode in forward bias, a voltage drop of 0.71V was recorded across it, with a corresponding current of 20.162 mA flowing through the circuit. This indicated that current was indeed passing through, confirming that the terminal connected to the positive side of the power supply was the anode, while the terminal connected to the negative side was the cathode.

In reverse bias, minimal current was observed, and the voltage across the diode remained close to the supply voltage of 12V, confirming the diode’s blocking behavior. The terminal with the ring was identified as the cathode, while the unmarked terminal was the anode. This measurement confirmed that, as indicated by the ring, the marked terminal on the diode consistently serves as the cathode.

3 Experimental Part 2: Forward V-I- Curve of a general purpose diode

3.1 Experimental Setup:

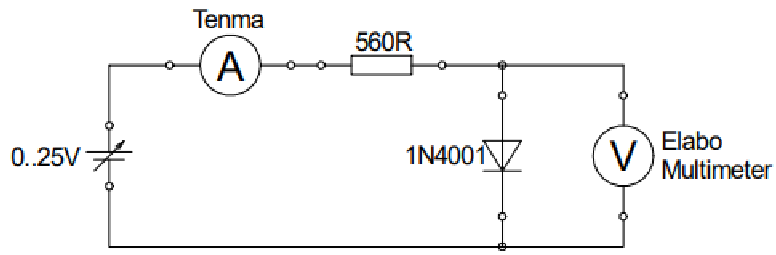
Workbench No.5

Used tools and Instruments:

- Breadboard, Tools box from workbench
- TENMA Multimeter
- ELABO Voltmeter
- Power supply ELABO
- 1N4001 Type Diode
- 560 Ohm resistor

3.1.1 Experimental Setup

- **Test Circuit:**



3.2 Experimental Part 2: Execution and Results

Description of the measurement:

To execute this experiment, the forward V-I characteristics of the 1N4001 diode were recorded by measuring the forward current (IF) and the corresponding forward voltage (UF) across the diode. The experiment was conducted with the following procedure:

The Tenma ammeter was used to set the forward current by adjusting the supply voltage. Current values were set approximately at: 0 µA, 50 µA, 100 µA, 200 µA, 500 µA, 1000 µA, 2 mA, 3 mA, 4 mA, 5 mA, 10 mA, 20 mA, and 40 mA. The lowest possible range on the Tenma multimeter was selected to improve accuracy, ensuring each current level was set as closely as possible to these values.

For each current value, the forward current (IF) was recorded from the ammeter, while the resulting forward voltage (UF) across the diode was measured using a voltmeter. This data collection allowed the relationship between IF and UF to be established, enabling the generation of a V-I curve for the diode in forward bias.

To analyze the behavior of the diode, the IF=f(UF) curve was plotted, along with a data table. This curve was examined to ensure data accuracy, and additional data points were added in regions where current changed rapidly to capture the diode's response more precisely. This approach was essential for accurate evaluation and characterization of the diode's forward-bias V-I behavior.

IF(A)	UF(V)
0	0.002
0.00005017	0.462
0.00010133	0.488
0.0001998	0.513
0.0005001	0.551
0.0009987	0.581
0.002004	0.612
0.002999	0.631
0.004007	0.643
0.004992	0.653
0.010001	0.683
0.02003	0.711
0.04005	0.738

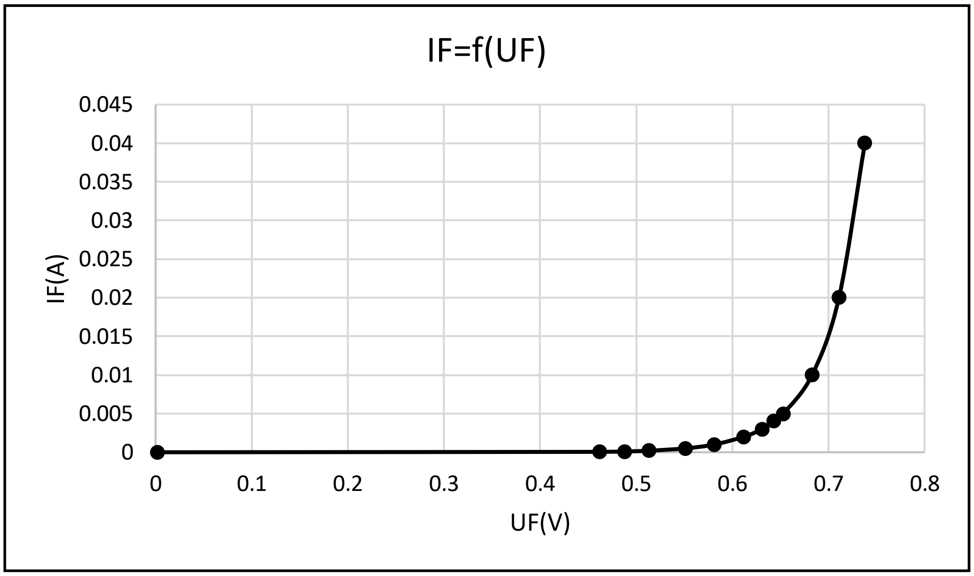


Table 2. Measurement of the currents and voltages through the diode

This relationship between voltage and current is exponential because, in forward bias, each increase in voltage results in a proportionally larger increase in the number of charge carriers that can cross the junction. This exponential increase is characteristic of semiconductor diodes, which exhibit low current below the threshold and a sharp current rise as the forward voltage overcomes the depletion barrier.

4 Experimental Part 3: Reverse and Forward Characteristic of a Z-Diode

‘**4.1 Experimental Setup:**

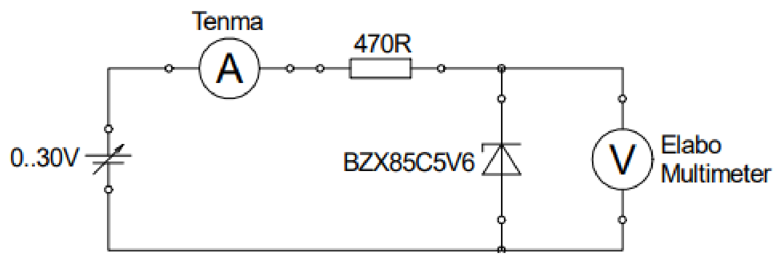
Workbench No.5

Used tools and Instruments:

- Breadboard, Tools box from workbench
- TENMA Multimeter
- ELABO Voltmeter
- Power supply ELABO
- BZX85C5V6 Type Diode
- 470 Ohm resistor

4.1.1 Experimental Setup

- **Test Circuit:**



4.2 Experimental Part 3: Execution and Results

Description of the measurement:

To execute this experiment, the reverse and forward V-I characteristics of the BZX85C5V6 Zener diode were measured by recording the reverse current (IR) and reverse voltage (UR), as well as the forward current (IF) and forward voltage (UF).

First, to record the reverse V-I curve, the Tenma ammeter was used to set the reverse current by adjusting the supply voltage. Current values were set approximately at: 0 µA, 100 µA, 200 µA, 500 µA, 700 µA, 1000 µA, 1100 µA, 1.5 mA, 2 mA, 5 mA, 10 mA, 20 mA, 40 mA, and 45 mA. For each value of IR, the reverse voltage UR was recorded, and the data was plotted simultaneously

to form a smooth IR=f(UR) curve. This curve allowed for a clear observation of the Zener diode’s behavior as it approached and surpassed its breakdown voltage.

After completing the reverse bias measurements, the diode polarity was reversed to obtain the forward V-I characteristics. The forward current was set using the Tenma ammeter with values up to 30 mA. Data points were recorded for IF and UF, following the same procedure as in the reverse measurements. This forward-bias data enabled analysis of the diode’s response when conducting current in the forward direction, providing a complete profile of the BZX85C5V6 Zener diode's performance in both biasing conditions.

IR(A)	UR(V)
0	0.002
0.00010013	4.851
0.00019901	5.056
0.0004991	5.267
0.0006998	5.327
0.0010059	5.381
0.0011062	5.393
0.00151	5.43
0.002006	5.457
0.005022	5.519
0.010055	5.553
0.020036	5.593
0.04005	5.656
0.04498	5.679

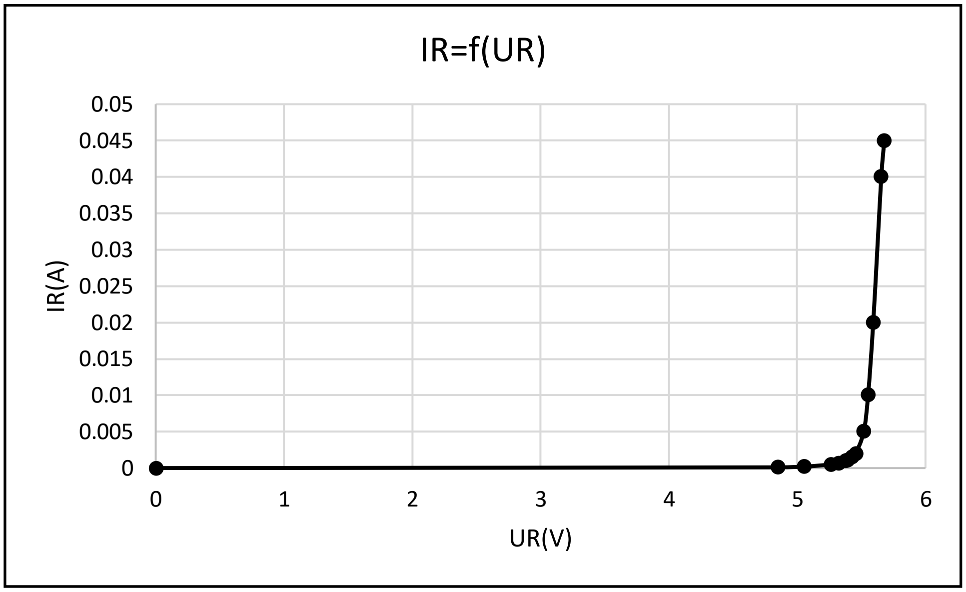
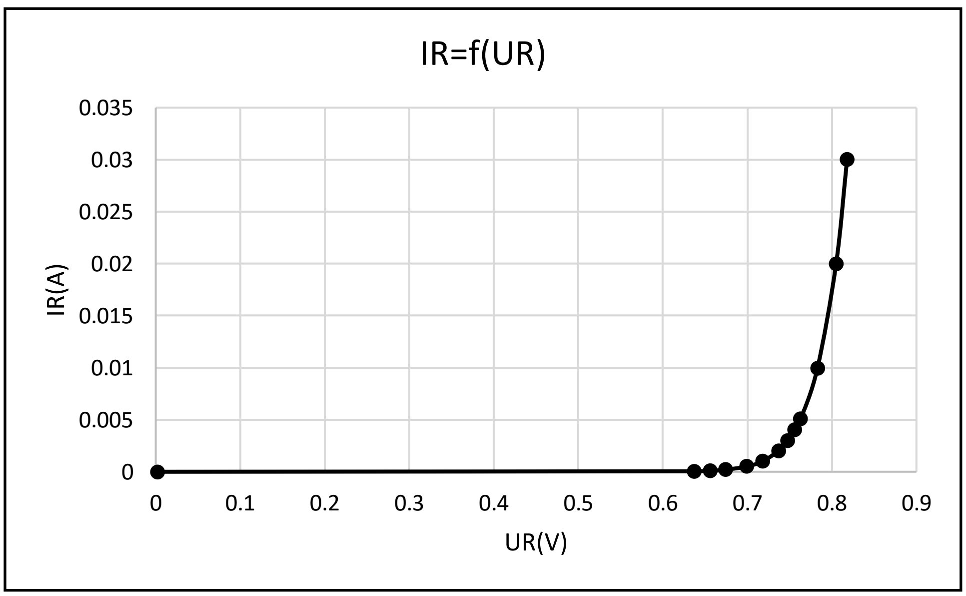


Table 3. Dependence of the Current on the Voltage



IR(A)	UR(V)
0	0.002
0.00004935	0.637
0.00010177	0.656
0.0001985	0.674
0.0005009	0.699
0.0009988	0.718
0.002033	0.737
0.002999	0.748
0.004022	0.756
0.005066	0.763
0.009978	0.783
0.019978	0.805
0.030028	0.818

Table 4. Dependence of the Current on the Voltage reversed polarity

Evaluation

- Determine the differential resistance of the diode at $Z_{ZT}@I_{ZT}$ = 45 mA and $Z_{ZK}@I_{ZK}$ = 1 mA in reverse direction from your experimental data? Compare with the data sheet. What information do you get from the differential resistance?

To calculate the differential resistance the following calculations were made:

$Z_{ZK}@I_{ZK}$ = 1 mA

$I_1 = 0.0005009\,A \rightarrow V_1 = 0.699\,V$

$I_2 = 0.0009988\,A \rightarrow V_2 = 0.718\,V$

$$r_z = \frac{V_2 - V_1}{I_2 - I_1} = \frac{0.718 - 0.699}{0.0009988 - 0.0005009} = \frac{0.019}{0.0004979} = 38.16\Omega$$

$Z_{ZT}@I_{ZT}$ = 45 mA

$I_1 = 0.019978\,A \rightarrow V_1 = 0.805\,V$

$I_2 = 0.030028\,A \rightarrow V_2 = 0.818\,V$

$$r_z = \frac{V_2 - V_1}{I_2 - I_1} = \frac{0.818 - 0.805}{0.030028 - 0.019978} = \frac{0.013}{0.01005} = 1.29\Omega$$

The differential resistance of a diode provides insight into how the diode responds to small changes in voltage in that region. For a Zener diode, in particular a low differential resistance in the breakdown region indicates its ability to stabilize voltage effectively, as it allows the diode to handle fluctuations in input voltage or load without significant changes in the output voltage. This property is essential for applications requiring stable voltage regulation, as it signifies that the diode can maintain a nearly constant output even when minor variations occur in current.
These differential resistance values reveal how the Zener diode's resistance varies with current. At higher current levels (closer to 45 mA), the differential resistance is significantly lower (1.29 Ω), indicating that the diode can better stabilize voltage in the breakdown region, as it responds less to minor voltage changes. Conversely, at lower current levels (around 1 mA), the differential resistance is higher (38.16 Ω), showing greater sensitivity to voltage changes. This characteristic highlights the Zener diode's effectiveness as a voltage stabilizer, especially at its rated operating conditions, where low differential resistance ensures stable output voltage.

5 Experimental Part 4: A Zener Shunt Regulator

‘5.1 Experimental Setup:

Workbench No.5

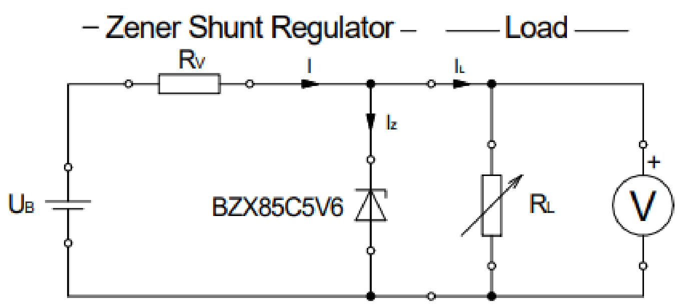
Used tools and Instruments:

- Breadboard, Tools box from workbench

- TENMA Multimeter
- ELABO Voltmeter
- Power supply ELABO
- BZX85C5V6 Type Diode
- Resistor Decade

5.1.1 Experimental Setup

- **Test Circuit:**



5.1.2 Calculating the Rv

To calculate Rv for each case the following formula was used:

$$R = \frac{V_{S_{min}} - V_{Z0} - r_z I_{Z_{min}}}{I_{Zmin} + I_{Lmax}}$$

Vsmin	15(V)
Vzo	5.6(V)
rz	0(Ohm)
Izmin	0.01(A)
ILmax	0.01(A)
R2	470(Ohm)

Vsmin	15(V)
Vzo	5.6(V)
rz	0(Ohm)
Izmin	0.001(A)
ILmax	0.01(A)
R1	854.5(Ohm)

Table 5. Calculating the Rv for each case

5.2 Experimental Part 4: Execution and Results

Description of the measurement:

To demonstrate the voltage regulation capability of the Zener diode, a Zener shunt regulator circuit was constructed. The circuit included the TENMA ammeter to monitor current and the ELABO voltmeter to measure voltage. The Zener diode was connected in reverse bias, positioning it to regulate voltage across the load. Measurements were taken by adjusting the load resistance in the circuit and recording the corresponding current and voltage values. The current was monitored via the ammeter, while the voltmeter provided precise readings of the voltage across the load. The observed data allowed for analysis of the Zener diode's behavior under varying load conditions. By observing the changes in current alongside a relatively stable voltage output, the Zener diode’s ability to maintain a consistent output voltage despite fluctuations in load resistance was demonstrated. This confirms its effectiveness in providing voltage stabilization in circuits.

854(Ohm)

R	I(mA)	U(V)
56	16.35	0.92
560	11.116	5.428
5600	10.981	5.55
Without	10.964	5.562

470(Ohm)

R	I(mA)	U(V)
56	28.18	1.586
560	19.876	5.547
5600	19.782	5.59
Without	19.778	5.593

Table 6. Measuring current and voltage through the Zener diode

Evaluation

- Describe the function of the circuit

  Regardless of fluctuations in input voltage or variations in load, a stable output voltage of 5.6V is maintained by the Zener shunt regulator circuit. This circuit employs a Zener diode in reverse bias, which begins to conduct when the applied voltage surpasses its breakdown threshold. A series resistor is utilized to limit current, ensuring the circuit operates safely. As changes occur in the input voltage or load, the Zener diode modulates the current flow to maintain a constant voltage across the load without fluctuations. When input voltage increases or load resistance decreases, the diode restricts excess current, thus preventing voltage spikes. This characteristic ensures proper functionality, making the circuit suitable for effective voltage regulation.

- Why is it not advisable to use loads with a too law resistance?

  If the load resistance is too low, there is little to no current flow through the Zener diode itself. Instead, most of the current flows directly through the load due to its low resistance, effectively bypassing the Zener diode. This situation prevents the Zener diode from reaching its breakdown voltage, so it cannot regulate the output voltage. As a result, the output voltage will drop below the Zener voltage, and the circuit loses its ability to maintain stable voltage regulation.

6 Conclusion

In this experiment, the electrical characteristics of PN junction diodes and Zener diodes were investigated under various circuit conditions to enhance the understanding of their operational principles and applications.

Initially, the anode and cathode of a 1N4001 diode were determined. Through the application of forward and reverse bias, it was demonstrated that current flows solely in the forward-biased condition, while the reverse bias effectively blocked current. A voltage drop of approximately 0.7V was observed in forward bias, validating the expected performance of a silicon diode. This behavior is critical in circuits where diodes facilitate the conversion of alternating current (AC) to direct current (DC) by permitting current flow in a single direction.

Subsequently, the I-V curve for the 1N4001 diode was plotted under forward bias conditions. The curve illustrated a significant increase in current as the forward voltage surpassed 0.7V, confirming the diode's effectiveness in regulating current flow, which is essential in power supply applications.

The behavior of the BZX85C5V6 Zener diode was then assessed. In reverse bias, a stable output voltage of 5.6V was maintained once the breakdown voltage was reached, regardless of increases in current. This characteristic is vital for voltage regulation, as it protects circuits from overvoltage conditions by clamping the output at a predetermined level. For example, when the load resistance was set at 560 ohms, a stabilized output voltage of 5.53V was achieved, illustrating the diode's capacity to provide consistent voltage under varying load and supply conditions.

Finally, the construction of a Zener shunt regulator allowed for the observation of voltage stabilization across different load resistances. The results confirmed that a constant voltage of 5.6V was maintained, even as the load resistance was altered. For instance, with a load of 5.6k ohms, the output voltage remained close to 5.57V, demonstrating the effectiveness of Zener diodes in voltage stabilization applications, which are critical for protecting sensitive electronic components.

Throughout the experiment, several sources of potential error may have affected the accuracy of the results. Instrumental error is one factor, as slight inaccuracies in multimeters and power supplies can introduce discrepancies in voltage and current measurements. Calibrating these instruments before use would help mitigate such effects. Additionally, connection issues, including variations in wire resistance or loose terminal connections, can lead to inconsistent readings, particularly at lower current levels.

Thermal effects may also influence the results. Extended operation, especially of the Zener diode, can result in component heating, temporarily altering the diode's voltage and current characteristics. Allowing sufficient time for cooling or incorporating heat sinks could reduce these thermal effects.

In summary, this experiment provided valuable insights into the distinctive properties of PN junction and Zener diodes. The ability of the PN junction diode to permit current flow in a single direction is advantageous for rectification purposes, while the Zener diode's voltage regulation capabilities in reverse bias confirm its role in maintaining stable voltage levels across loads. The importance of selecting appropriate diodes based on circuit requirements was emphasized, with PN junctions used for current control and Zener diodes for voltage stabilization. The data collected corroborated the anticipated theoretical outcomes and underscored the practical significance of these components in contemporary electronic applications.

7 References

1. Uwe Pagel, Natural Science Laboratory - General Information for EE Labs, Chapter II, Page 12-19
2. https://en.wikipedia.org/wiki/Diode
3. https://en.wikipedia.org/wiki/Zener_diode

8 Appendix – Experiment 5: DC Networks

Part 1: Measure All network voltages									
	Measured Voltages						Calculated Currents		
6V	V1	6.021	V				I1	0.00502	A
3V	V2	3.0381	V	Resistance			I4	0.00242	A
	VR1	4.833	V	R1	1500		I2	0.00322	A
	VR2	1.1834	V	R2	1500		I6	0.00079	A
	VR3	1.799	V	R3	1000		I3	0.0018	A
	VR4	4.22	V	R4	1000		I5	0.00422	A
Part 2: Determine current I1 through source V1									
	Experimental			Theoretical					
	A-B								
	Vth	0.0082		Vth					
	Rth	1195.6		Rth					
						I1	0.00503		
Part 3: Determine current I4 through source V2						I4	0.00243		
	Experimental			Theoretical					
	A1-B1								
	Ino	0.00000965		Ino					
	Rno	1246.7		Rno					