Experiment 01: Study of Zener Diode and IC 7805

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(Subgroup - A7)

1 Aim

- To study Zener diode as a voltage regulator.

- To study IC 7805 as a voltage stabiliser.
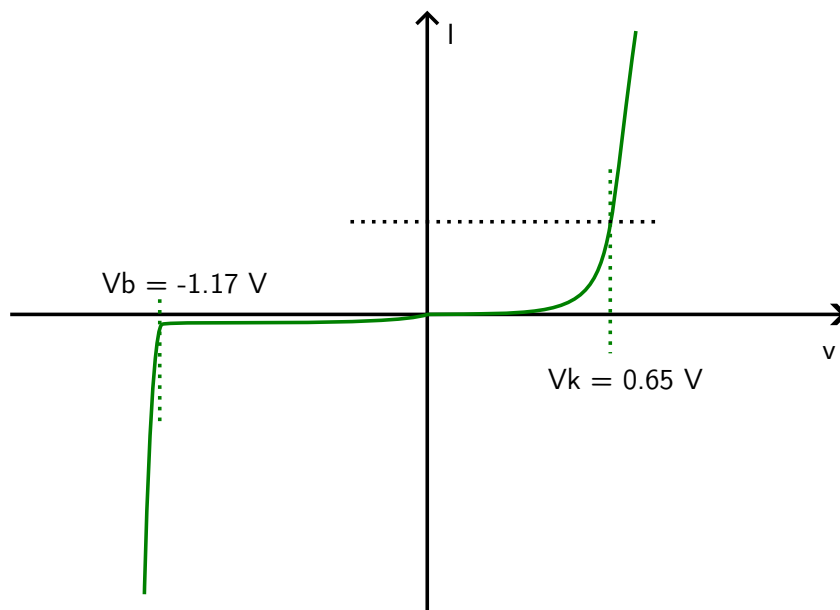
2 Theory

2.1 Zener Diode

Figure 1: Typical Zener diode characteristic curve

Zener diode is a specialised diode which works as a regular diode when forward biased but on reverse biasing, the voltage remain constant for a wide range of current after *Avalanche* breakdown. Thus, Zener diode is used as a shunt voltage regulator for regulating voltage across small loads.

Initially there is negligible current in the diode in the reverse bias condition but as breakdown voltage is reached, the current increases rapidly, however the voltage across the diode remains nearly constant.
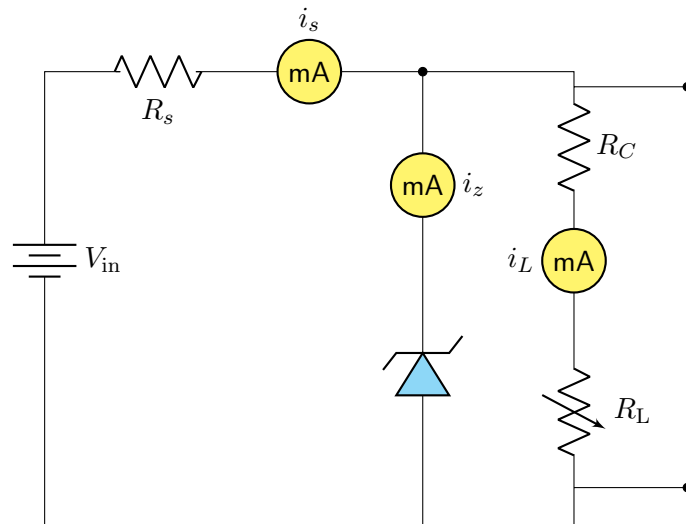
Figure 2: Circuit Diagram for Load and Line Regulation Using a Zener Diode

From the above circuit diagram, we have:

$$\mathrm{I_s} = I_z + I_L \tag{1}$$

$$\mathrm{I_s} = \frac{V_i - V_z}{R_s} \tag{2}$$

$$\mathrm{I_L} = \frac{V_o}{R_L} \tag{3}$$

Hence in line regulation, where R_s and R_L are kept constant and V_o becomes constant after breakdown, from where we get $\delta \mathrm{I_s} = \delta \mathrm{I_z}$. Thus, we are expected to get a linear graph between $\mathrm{I_z}$ and $\mathrm{I_s}$ with slope 1.

In load regulation, we keep V_i constant and vary R_L. $\mathrm{I_s}$ becomes independent of load resistance, hence from above equation we get $\delta \mathrm{I_z} = -\delta \mathrm{I_L}$. Thus, we are expected to get a linear graph between $\mathrm{I_z}$ and $\mathrm{I_L}$ with slope -1.

2.2 Integrated Circuit based Regulator

In Zener diode, the regulation is not perfect and output voltage increases very slowly with increasing reverse input voltage. To resolve this, we use Integrated Circuit (IC) based voltage regulators. We will use IC 7805 for the experiment. The 7805 IC voltage regulator has 3 pins. Pin 1 takes the input voltage and Pin 3 produces the output voltage. The ground of both input and output are given to Pin 2.
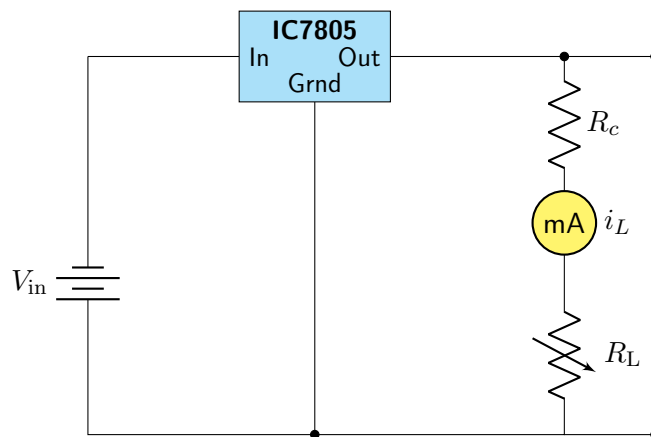

Figure 3: Circuit Diagram for load and line regulation using IC 7805

3 Data and Calculation

3.1 Zener Diode:

3.1.1 Line Regulation

For the line regulation, we first fixed the load resistance to $R_L = 1.1\,\mathrm{k\Omega}$ and varied the input voltage. The output voltage, current across zener diode and the current in the circuit was measured for each input voltage. The data is tabulated below:

V_i (V)	Is (mA)	Iz (mA)	Vo (V)
0.0	0.00	0.00000	0.01
0.6	0.00	0.00000	0.40
1.0	0.12	0.00000	0.69
1.6	0.23	0.00000	1.02
2.1	0.35	0.00000	1.31
2.4	0.46	0.00000	1.52
3.0	0.12	0.00000	1.85
3.5	0.23	0.00000	2.16
3.9	0.58	0.00000	2.43
4.5	0.69	0.00000	2.77
5.0	0.81	0.00002	3.09
5.4	0.93	0.00008	3.31
6.0	1.05	0.00023	3.68
6.5	1.18	0.00040	3.92
7.0	1.27	0.00083	4.23
7.5	1.39	0.00161	4.57
8.0	1.51	0.00337	4.87
8.5	1.63	0.00637	5.16
8.9	1.74	0.01132	5.40
9.5	1.86	0.01666	5.71
10.0	1.98	0.03700	6.05
10.5	1.58	0.04000	6.35
11.0	2.11	0.10000	6.50
11.5	2.30	0.30000	6.53
11.9	2.50	0.50000	6.57
12.5	2.74	0.70000	6.55
13.0	3.01	1.00000	6.56
13.6	3.24	1.30000	6.57
13.9	3.41	1.40000	6.57
14.5	3.67	1.70000	6.57
15.0	3.89	1.90000	6.58

Proportionality of Zener and circuit current:

From the data, we plotted I_z vs I_s and found that the graph is linear. Intially the current was very low (in range of microamperes). At around $V_{in} = 10.5\,\mathrm{V}$, the current started to increase rapidly (in range of milliamperes). The graph for data points after $V_{in} = 10.5\,\mathrm{V}$ is shown below along with linear fit curve:
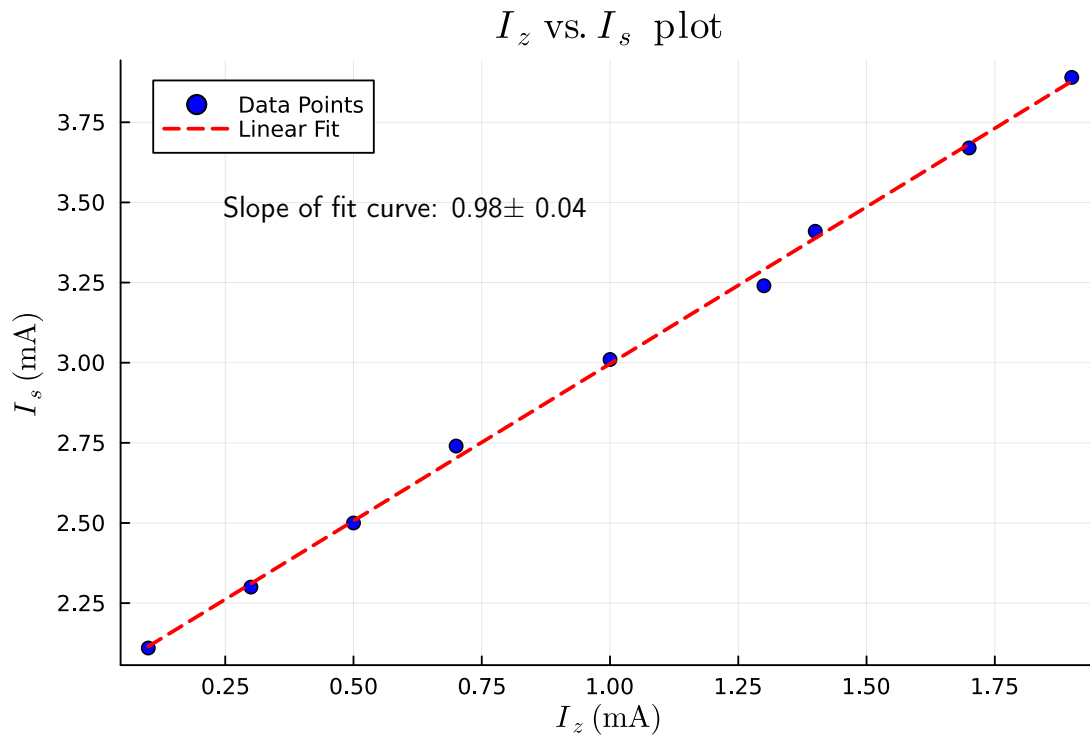
Figure 4: Plot of Iz vs Is with constant load

From the linear fit, we obtained the slope to be $m = 0.98 \pm 0.04$ which verifies $\delta Iz = \delta Is$.

Estimating Breakdown Voltage

From the above table, we plot the input vs the output voltage.
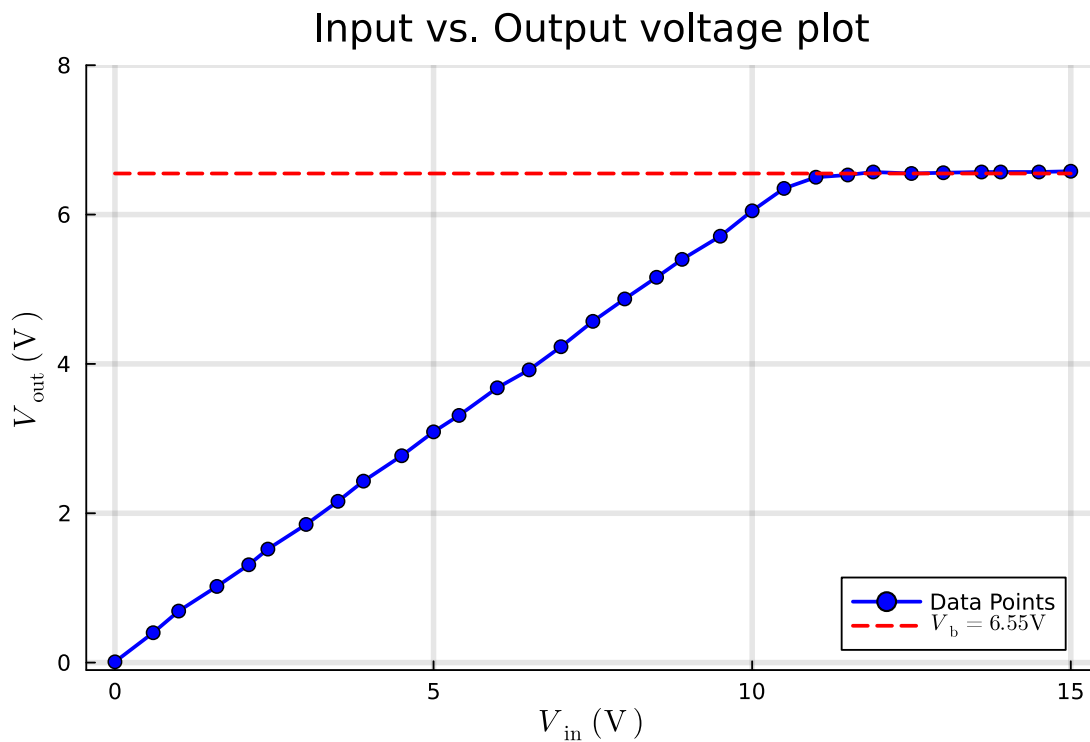

Figure 5: Plot between input and output voltage with constant load

From the plot, we can see that initially there is gradual change in the output voltage with changing input but after

$V_{\text{in}} = 10.5\,\text{V}$, the output voltage saturated and became almost constant. This indicates breakdown has occured and breakdown voltage equals to the output voltage of the circuit. We take the average of the voltage obtained after $V_{\text{in}} = 10.5\,\text{V}$. Thus, from the experimental plot, we estimate the breakdown voltage of the given Zener diode to be:

$$\boxed{V_{\text{b}} = 6.55\text{V}}$$

3.1.2 Load Regulation

Without R_{c} :

For the load regulation, we fixed the input voltage to $V_{\text{in}} = 15$ V and varied the load resistance using a potentiometer. The output voltage, current across zener diode and the load current was measured for each load resistance. The data is tabulated below:

R_L (kΩ)	I_L (mA)	Iz (mA)	V_o (V)
0.007	6.92	0	0.2
0.057	6.76	0	0.5
0.106	6.61	0	0.9
0.153	6.5	0	1.2
0.203	6.36	0	1.4
0.249	6.25	0	1.7
0.304	6.11	0	2.1
0.354	6.02	0	2.3
0.396	5.92	0	2.6
0.452	5.78	0	2.8
0.513	5.64	0	3.1
0.551	5.53	0	3.3
0.609	5.44	0	3.5
0.655	5.34	0	3.7
0.713	5.24	0	3.9
0.751	5.16	0	4.1
0.802	5.06	0	4.3
0.856	5.00	0	4.5
0.906	4.92	0	4.7
0.955	4.84	0	4.9
1.017	4.73	0	5.0

From the above table, we see that the maximum output voltage reached without using R_{c} is $V_o = 5$ V which is less than the output voltage obtained after reaching the breakdown voltage (6.55 V) calculated from the previous part. Thus, it indicates that the breakdown has not been reached and explains why we are obtaining negligible current through the zener diode since breakdown has not been reached.

With R_{c} : $2.2\text{k}\Omega$

We now introduce a current limiting resistor $R_c = 2.2$ kΩ

R_L (kΩ)	I_L (mA)	Iz (mA)	V_o (V)
0.065	2.83	1.22	6.4
0.107	2.78	1.33	6.4
0.154	2.72	1.41	6.4
0.177	2.68	1.46	6.4
0.242	2.63	1.41	6.6
0.312	2.55	1.45	6.52

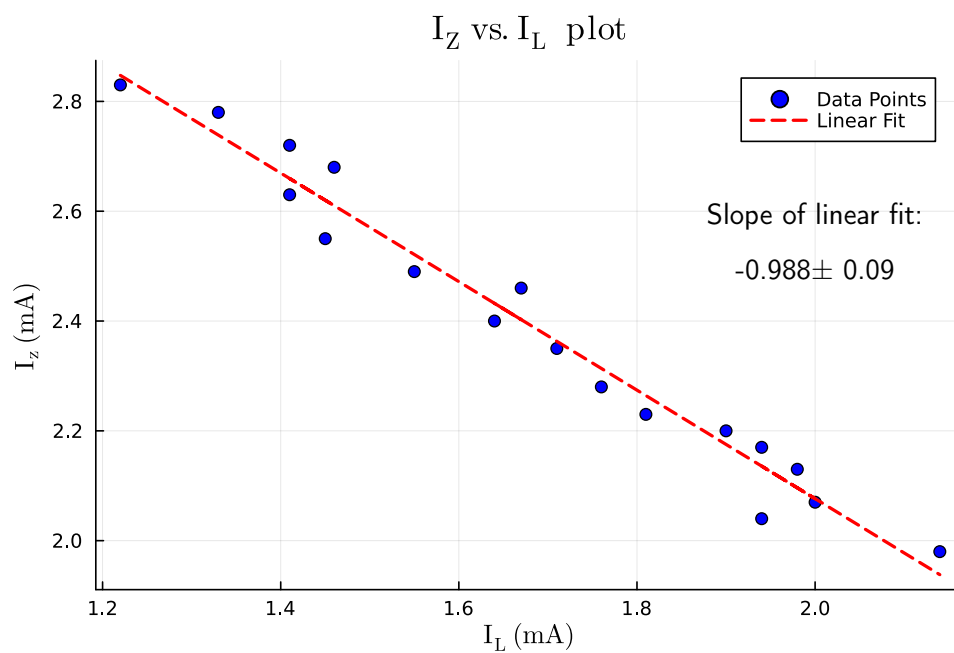| R_L (kΩ)	I_L (mA)	Iz (mA)	V_o (V)
0.317	2.49	1.55	6.6
0.406	2.46	1.67	6.6
0.467	2.4	1.64	6.6
0.532	2.35	1.71	6.7
0.61	2.28	1.76	6.6
0.672	2.23	1.81	6.4
0.713	2.2	1.9	6.6
0.752	2.17	1.94	6.6
0.815	2.13	1.98	6.6
0.902	2.07	2.00	6.6
0.951	2.04	1.94	6.6
1.033	1.98	2.14	6.6

Figure 6: Plot of I_z vs I_L with $R_c = 2.2$kΩ

From the above plot, we obtained the slope for the linear fit curve as: $m = -0.98 \pm 0.09$, thus verifying $\delta I_z = -\delta I_L$

Constancy of Output Voltage:

In this case, with the use of R_c, we see that the output voltage is greater than 6.55V, indicating that breakdown has already been reached. Thus, it remains constant for a wide range of load resistance. The plot of output voltage vs load resistance is shown below:
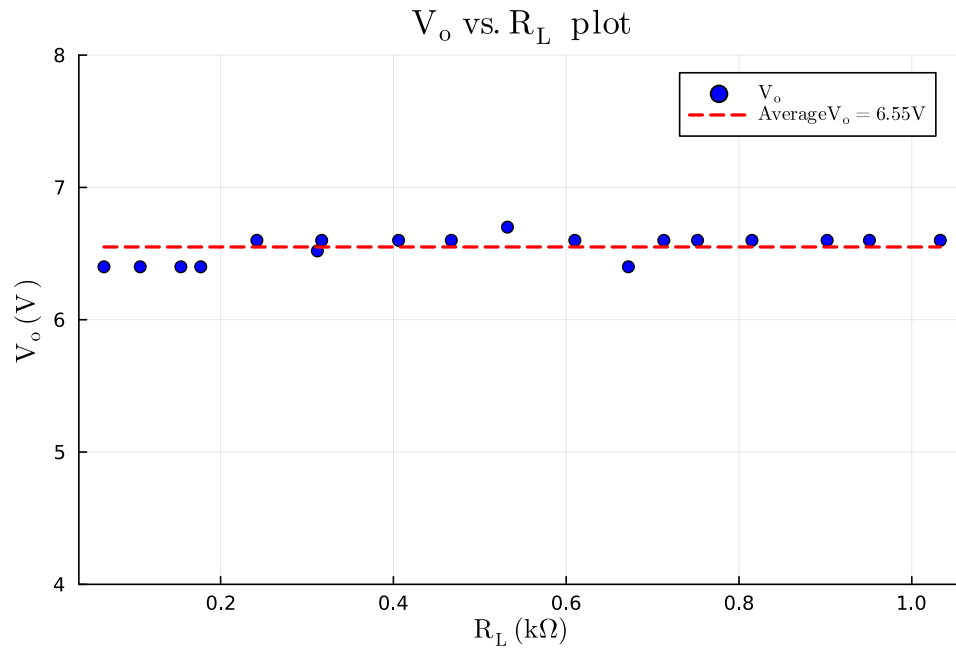
Figure 7: Plot of V_o vs R_L with $R_c = 2.2k\Omega$

3.2 IC 7805

3.2.1 Line Regulation

For the line regulation, kept the resistance $R_c + R_L = 2.2$ kΩ and varied the input voltage. The output voltage, current across IC 7805 and the current in the circuit was measured for each input voltage. The data is tabulated below:

$V_{in}(V)$	$I_L(mA)$	$V_o(V)$
0	0	0
0.12	0	0
0.13	0	0
0.14	0.01	0.01
0.15	0.76	0.18
1.6	0.85	0.38
1.7	1.04	0.46
1.8	1.17	0.51
2.5	1.76	0.77
3	1.02	2.23
3.4	1.22	2.66
4	1.47	3.2
4.5	1.67	3.62
5.1	1.92	4.17
5.4	2.03	4.41
5.5	2.12	4.6
5.8	2.21	4.79
5.9	2.25	4.89
6	2.3	4.99
6.5	2.31	5.0
7.1	2.3	5.0
7.5	2.3	5.0
8	2.3	5.0

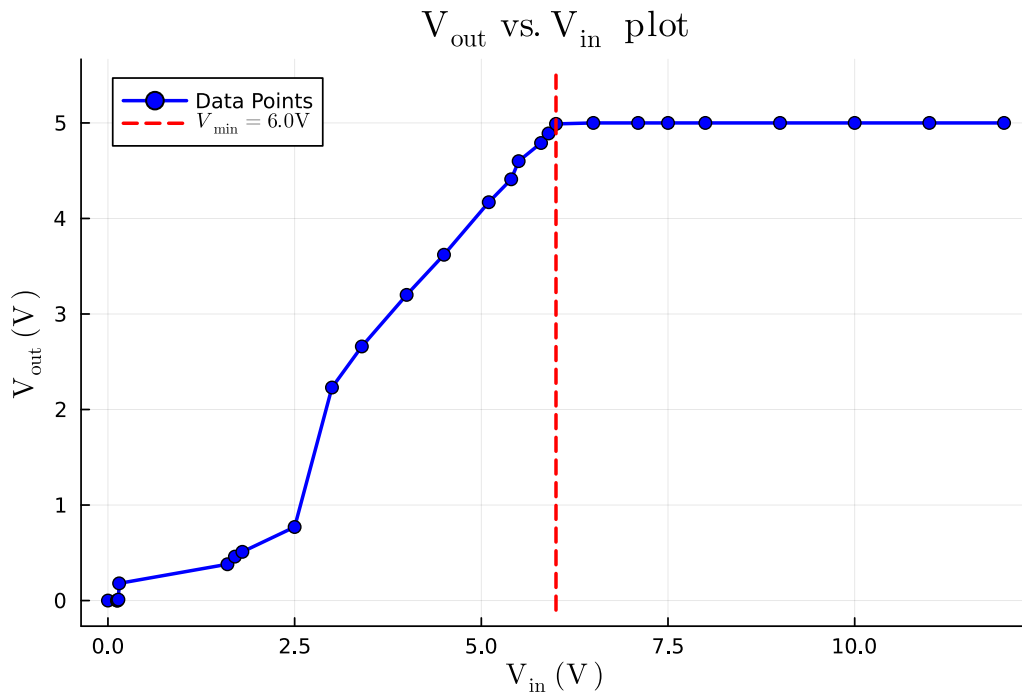| V_{in}(V)	I_L(mA)	V_o(V)
9	2.3	5.0
10	2.3	5.0
11	2.3	5.0
12	2.3	5.0

Figure 8: Plot of V_o vs V_i for IC 7805

We plotted the input voltage by varying the output voltage. From the plot, we can see that the output voltage remains constant for a wide range of input voltage after $V_{in} = 6$ V. Thus, from the experimental plot, we can estimate the minimum voltage of the given IC to be 6 V. The stable voltage obtained after the minimum applied voltage is 5 V which matches with the expectation since the last digit of the IC implies so.

3.2.2 Load Regulation

For the load regulation, we fixed the input voltage to $V_i = 15$ V and varied the load resistance using a potentiometer. The output voltage, current across load was measured for each load resistance. The data is tabulated below:

R_L (Ω)	i_L (A)	V_0 (V)
0.001	2.35	5.09
0.025	2.29	5.03
0.033	2.27	4.98
0.082	2.23	5.02
0.143	2.16	5.00
0.196	2.12	5.00
0.28	2.07	5.06
0.342	2.00	5.03
0.403	2.08	5.42
0.492	1.95	5.19
0.557	1.88	5.12
0.63	1.83	5.12

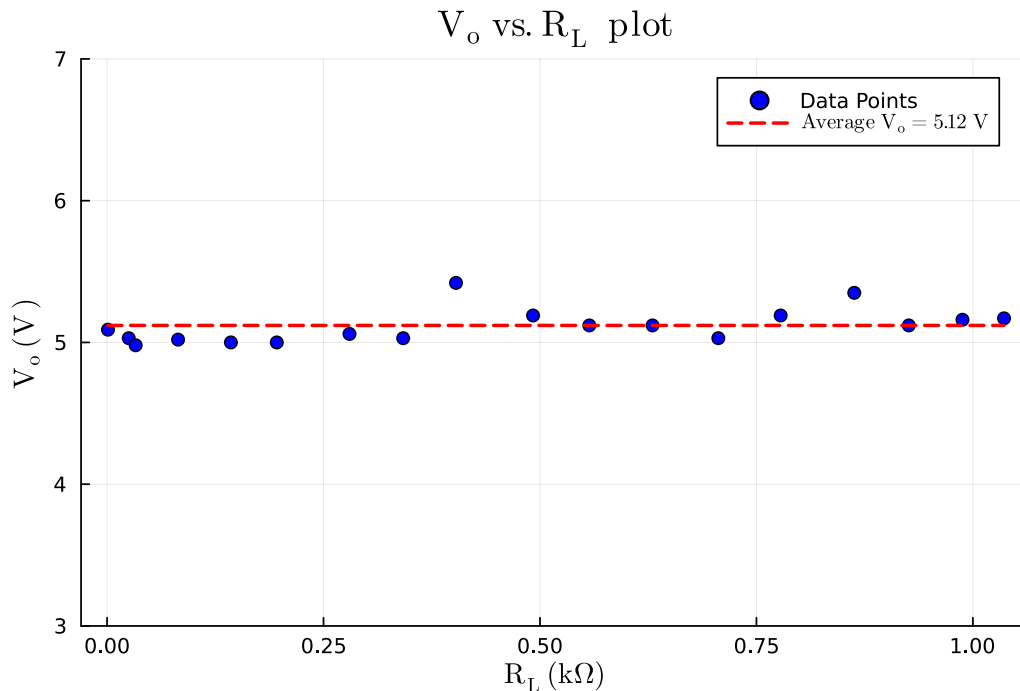| R_L (Ω)	i_L (A)	V_0 (V)
0.706	1.75	5.03
0.778	1.77	5.19
0.863	1.76	5.35
0.926	1.66	5.12
0.988	1.64	5.16
1.036	1.61	5.17

Figure 9: Plot of V_o vs R_L for IC 7805

From the above plot, we can see that the output voltage remains constant for a wide range of load resistance. The output voltage remains constant at an average voltage of 5.12 V which matches closely with out expectation for IC7805. Thus, the IC 7805 is a good voltage stabiliser.

4 Discussion and Conclusion

We studied the line and load regulation of Zener diode. From the line regulation, we found out the average **breakdown voltage** of the Zener diode to be **6.55 V**. We found out that the voltage across the diode remains almost constant for increasing input voltage once breakdown voltage is reached. This was verified by load regulation.

To improve the regulation, we used IC 7805 as voltage regulator. From the line regulation, we found out the minimum voltage required for the IC to achieve a stable voltage to be **6.0 V**. The stable votage for the IC was found to be **5.0 V** as expected.

5 Sources of Error

Some possible sources of error due to which the results show some deviation from theoretical expectation:

1. The multimeters have some finite resistance which might have affected the result.

2. Smaller currents of microamperes range could not be properly recorded by the multimeter.

3. Resistance measured by the potentiometer might not exactly be exact.