Faculty of Engineering & Technology Electrical & Computer Engineering Department
ENEE2103
CIRCUITS AND ELECTRONICS LABORATORY

Report III :Experiment 11
Zener Diode and Voltage Regulator

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Abstract

This experiment aims to achieve three objectives related to the use of a zener diode as a voltage regulator. Firstly, the I-V characteristic of a zener diode will be constructed, providing a graphical representation of its behavior under varying voltage and current conditions. Secondly, the experiment will demonstrate the practical application of the zener diode as a voltage regulator, regulating the output voltage despite changes in input voltage and load resistance. Finally, the operation of the voltage regulator will be examined in more detail, exploring the mechanisms by which it maintains a constant output voltage and investigating the effects of varying components and conditions.

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Theory

1. Zener Diode

A Zener diode is a semiconductor diode that is heavily doped and intended to operate in the reverse direction. Its design is optimized for the breakdown region, which makes it well-suited for specific applications.
The Zener diode is represented symbolically as shown in the figure below.

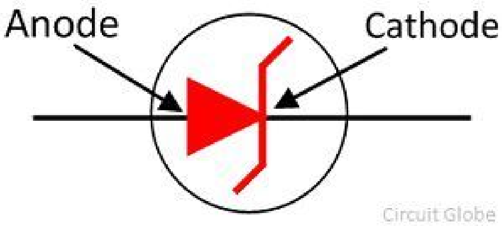

Figure 1. Zener Diode Symbol

1.1 Working of Zener Diode

The Zener diode is composed of semiconductor material that has been heavily doped with impurities to increase its conductivity. This high-level doping results in a very thin depletion region in the Zener diode. As a consequence, even small reverse voltages generate an intense electric field across the depletion region.
When no biasing voltage is applied to the Zener diode, the electrons in the p-type material remain in the valence band and no current flows through the diode. The valence band is the energy band that contains the outermost orbit electrons. When an external energy is applied to the diode, the electrons in the valence band can easily move from one band to another.

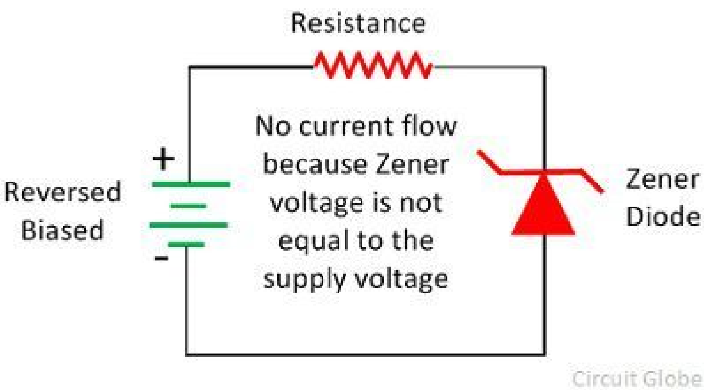

Figure 2. Working of zener diode

When a reverse bias is applied to a Zener diode, and the supply voltage equals the Zener voltage, the diode conducts in the reverse direction. The Zener voltage is the voltage at which the depletion region of the diode disappears entirely.
Increasing the reverse bias voltage across the diode intensifies the electric field across the depletion region. This allows electrons to move from the valence band of the p-type material to the conduction band of the n-type material. As a result, the barrier between the p-type and n-type materials is reduced. Once the depletion region vanishes entirely, the diode begins conducting in the reverse direction.

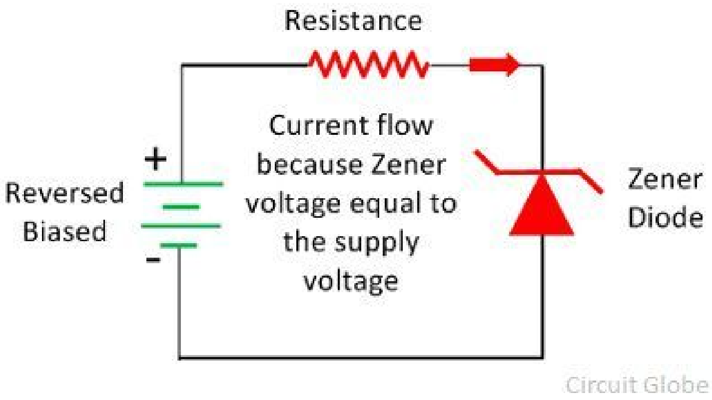

Figure 3. Working of zener diode

1.2 Zener Diode I-V Characteristics

The Zener diode is used in a special way called "reverse bias" or "reverse breakdown" mode. This means that its anode is connected to the negative side of the power supply. When we look at the graph showing how the diode behaves, we see that in this mode, it has a region where the voltage stays almost the same, no matter how much current is flowing through it.
This constant voltage remains stable even if the current changes, as long as it stays within a certain range called the breakdown current (IZ(min)) and the maximum current rating (IZ(max)) of the diode.
This unique property of the Zener diode to control its own voltage can be very useful for regulating or stabilizing a power supply against variations in the input voltage or changes in the load connected to it. The fact that the voltage across the diode remains constant in the breakdown region is an important characteristic that makes it suitable for simple types of voltage regulators.
The main function of a voltage regulator is to keep the output voltage steady, even when there are fluctuations in the input voltage or changes in the load current. A Zener diode can continue to regulate the voltage as long as its current stays above a minimum value called IZ(min) in the reverse breakdown region.

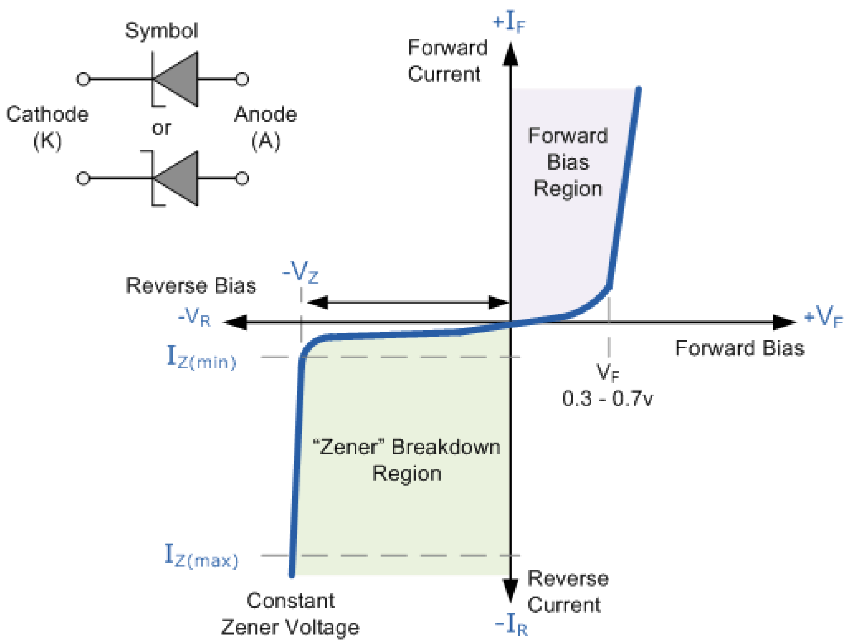

Figure 4. I-V Characteristic

2. Zener Diode as Voltage Regulator

In order to protect the diode and regulate the current, a series resistor is connected to the circuit. This resistor is connected to the positive terminal of the DC power source. Its purpose is to ensure that even when the diode is reverse-biased and in breakdown conditions, it can still function properly. We cannot use a regular diode because it has a low power rating and can get damaged if we apply a reverse bias above its breakdown voltage.
To ensure the Zener diode operates correctly, the current flowing through it should always be kept at a minimum, even when the minimum input voltage and maximum load current are applied.
To simplify the selection of components, we choose a Zener diode with a voltage rating close to the desired output voltage. This means the Zener voltage (VZ) is approximately equal to the load voltage (VL).
The value of the series resistor (RS) can be calculated using the formula RS = (VL - VZ)IL. When the voltage across the diode increases, the current through the diode also increases, resulting in a voltage drop across the resistor. Similarly, when the voltage across the diode decreases, the current through the diode decreases as well. The voltage drop across the resistor is minimal, allowing the output voltage to remain stable.

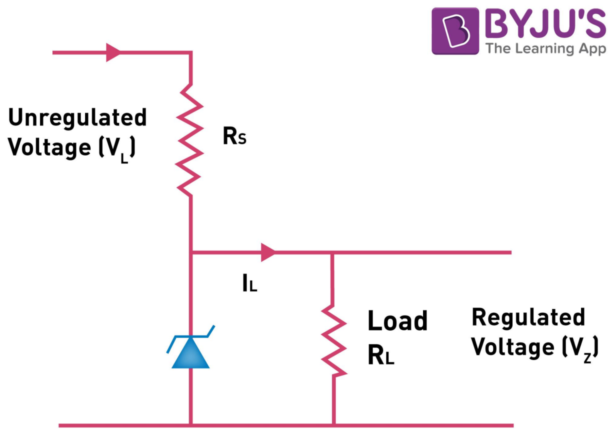

Figure 5. Zener Diode as Voltage Regulator

3. 7805 Voltage Regulator

The 7805 Voltage Regulator is a device with three terminals that provides a fixed output voltage of 5V, which is used in many applications. It can be manufactured by different companies and is available in various packages like TO-3, TO-220, TO-263, and SOT-223. The device has several features including thermal shutdown, internal current limiting, and protection against short circuit and thermal overload. It can deliver a current up to 1.5A, operates at input voltages of 7V to 25V, and has a maximum junction temperature of 125 degrees Celsius. The device is available in KTE and TO-220 packages, and its pin diagram consists of three pins - input, ground, and output - each with its own function.

Figure 6. LM7805 Component

- Pin 1, or the Input, serves as the point of entry for a positive unregulated voltage.
- Pin 2, or Ground, acts as a common point for both the input and output connections.
- Pin 3, or Output, provides access to the regulated 5V output voltage that can be obtained from this pin.

The IC 7805 voltage regulator is characterized by the following features:

- It requires minimal components to function properly.
- It has a current delivery capacity of up to 1.5 A.
- It includes internal current limiting and thermal shutdown capabilities.

- The minimum and maximum input voltages are 7V and 25V, respectively.
- The operating current is 5mA.
- It offers protection against short circuits and thermal overload.
- The maximum junction temperature is 125 degrees Celsius.
- It is available in KTE and TO-220 package configurations

4. The LM317T Adjustable Voltage Regulator

The LM317T is a versatile 3-terminal positive voltage regulator that can deliver up to 1.5 amps with an output voltage range between 1.25 and 30 volts. By adjusting the ratio between two resistances, one of which is fixed and the other variable (or both fixed), we can set the output voltage to a desired level, while the input voltage can range anywhere from 3 to 40 volts.

This variable voltage regulator also incorporates current limiting and thermal shutdown capabilities, making it suitable for use in low voltage applications or as part of a DIY bench power supply.

The output voltage of the LM317T is determined by the ratio of two feedback resistors, R1 and R2, which create a potential divider network across the output terminal, as illustrated below.

The LM317 adjustable voltage regulator offers several features, including:

- The capacity to deliver an output current over 1.5 A
- Adjustable output voltage from 1.2 V to 37 V
- Internal thermal overload protection
- Constant internal short circuit current limiting with temperature
- Output transistor safe-area compensation
- Suitable for floating operation in high voltage applications
- Elimination of the requirement to stock various fixed voltages [10]

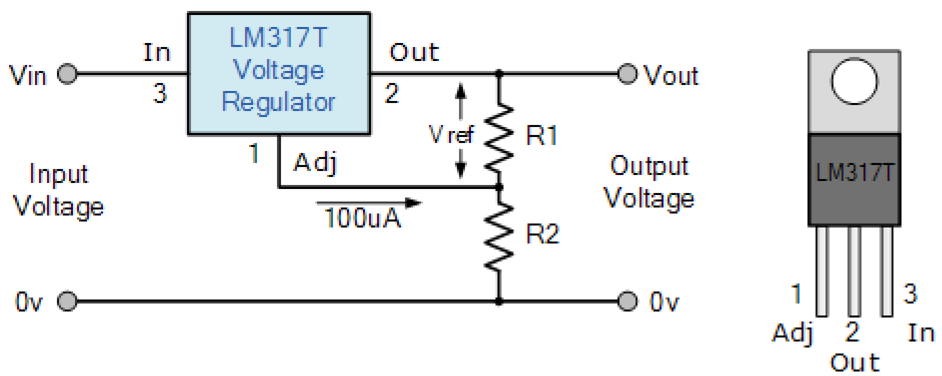

Figure 7. LM317T Voltage Regulator Circuit

Procedure

1.Zener Diode

The figure below illustrates the experimental setup where the applied voltage, E, was set to the values 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1, 2, 3,4,5 and 6V. The voltage across the resistor 1k, the voltage across the zener diode and the current passing through it were measured for each value of E. The recorded data is tabulated below for reference.

- Circuit 1

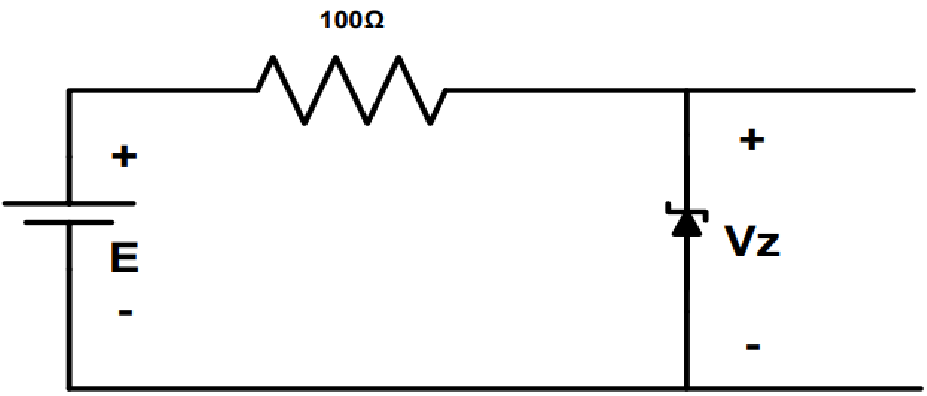

Figure 8. Zener Diode Circuit 1

E(V)	VZ(V)	Vr(V)	I(mA)
0.1	0.09	0.01	0.1
0.2	0.175	0.025	0.25
0.3	0.296	0.004	0.04
0.4	0.389	0.011	0.11
0.5	0.505	0.005	0.05
0.6	0.601	0.001	0.01
0.7	0.709	0.009	0.09
0.8	0.801	0.001	0.01
0.9	0.903	0.003	0.03
1	1.027	0.027	0.27
2	1.992	0.008	0.08
3	2.615	0.385	3.85
4	2.927	1.073	10.73

5	3.113	1.887	18.87
6	3.245	2.755	27.55

Table 1. Circuit 1 Result

At first zener diode is at saturation region so it's open circuit (vo=vi)
Then , Zener in breakdown region (Vz almost stationary)

- Circuit 2

The circuit was constructed and tested in the laboratory by setting the applied voltage, E, to 10, 11, 12, 13, and 14. The load voltage, VL, was measured and recorded in the table below for each value of E.

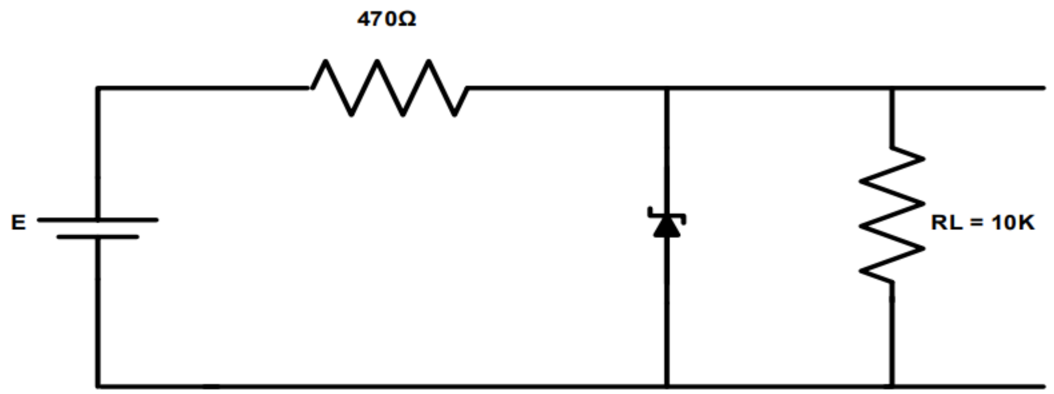

Figure 9. Zener Diode Circuit 2

The table below displays the obtained results:

E	**10**	**11**	**12**	**13**	**14**
VL	3.550	3.559	3.636	3.651	3.669

Table 2. Circuit 2 Results

Then, the applied voltage, E, was set to 10 volts and the load resistor, RL, was substituted with a variable resistor. The load voltage, VL, was measured for each value of RL and tabulated below.

E	**8.2K**	**6.8K**	**4.7K**	**2.2K**
VL	3.527	3.508	3.512	3.504

Table 3. Circuit 2 Results

Both tables indicate that the voltage is consistently regulated at 3.5 volts, regardless of the fluctuations in both RL and VIN values. Since the diode in the breakdown region.

2. The voltage Regulated Power Supply

- Circuit 1

To evaluate the performance of the circuit, the following configuration was implemented. The load resistance (RL) was adjusted to different values as indicated in the table provided. Subsequently, the corresponding output voltage and output current were measured and recorded in the table.

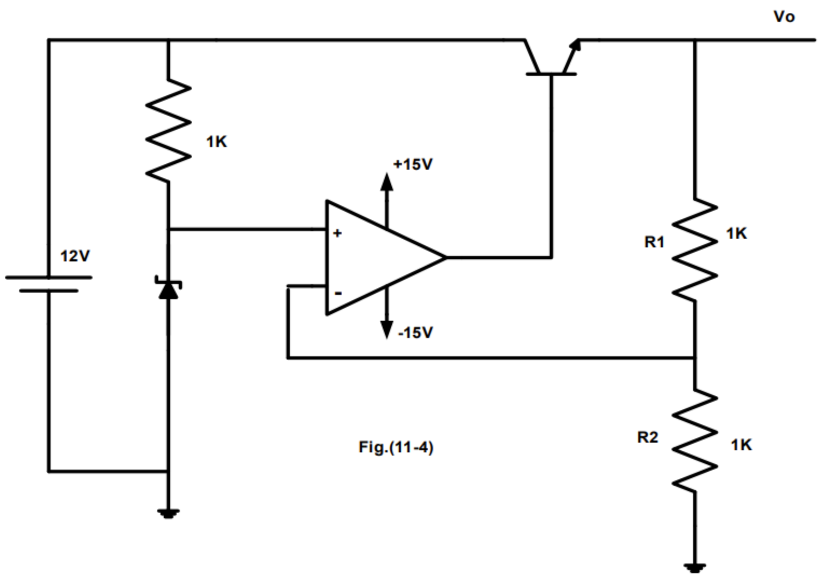

Figure 10. The voltage regulator power supply circuit 1

The table below displays the obtained results:

RL	open	1K	680Ω	470Ω	220Ω	100Ω	50Ω
Vo	5.724	5.371	5.369	5.370	5.370	5.367	5.369
Io	0	5.37	7.86	8.53	24.12	52.63	102.46

Table 4. Result of voltage regulator power supply circuit 1

The voltage output (Vo) is maintained at a steady 5.3 volts. This is achieved through the equation Vo = Vz(1 + Rf/R2),Then, Vz is almost 2.866 volts in this circuit (practically)

After that , We set the value of RL to 1K, and We measure Vo with R2 **470Ω** and **2.2K**.

RL	R2	Vo
1K	**470Ω**	8.470
1K	**2.2K**	4.153

Table 5. Result of measuring Vo

- Measuring Vo theoretically when R2=470Ω

Vo = 2.866 (1 + 1000/470) = 8.964 volts.
Theoretical and practical values are almost the same.

- Measuring Vo theoretically when R2=470Ω

Vo = 2.866 (1 + 1000/2200) = 4.169 volts
Theoretical and practical values are almost the same.

- ❖ Circuit 2

In this section, the circuit illustrated in the figure below was assembled. The load resistance was varied by using a variable resistor and set to the values tabulated below. The output voltage and output current were measured for each value of RL and recorded in the table below.

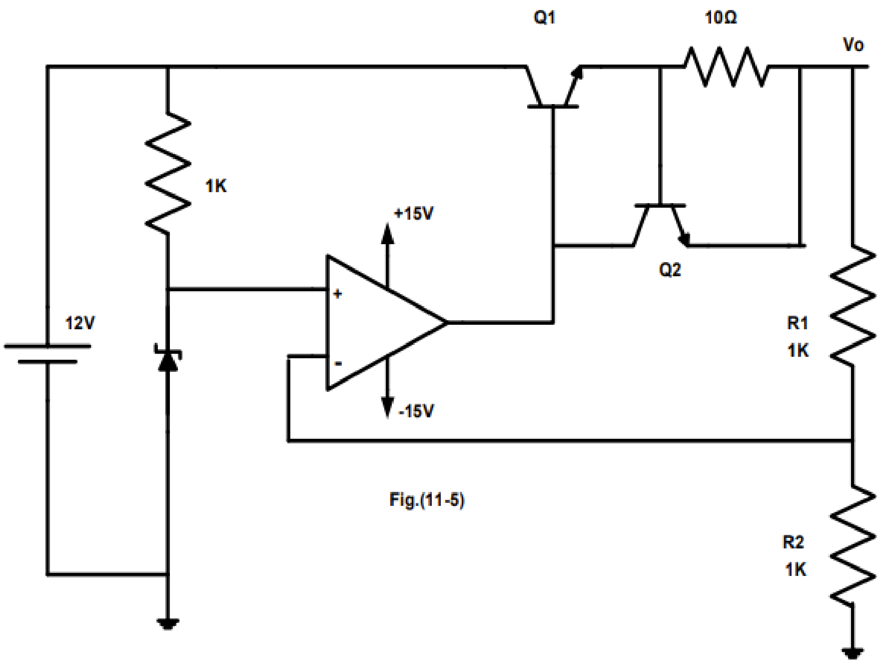

Figure 11. The voltage regulator power supply circuit 2

The table below displays the obtained results:

RL	open	1K	680Ω	470Ω	220Ω	100Ω	50Ω	40Ω
Vo	5.419	5.385	5.385	5.381	5.383	5.382	5.383	5.383
Io	0	3.3	7.88	9.24	24.18	52.70	75.53	75.64

Table 6. Result of voltage regulator power supply circuit 2

As can be observed from the table above, the output voltage remains regulated at 5.38volts.

3. Three Terminal Fixed Voltage Regulator 7805

In this section, the circuit shown below was constructed with VIN set to 10 volts. The load resistance was varied using a variable resistor, with values recorded in the table below. The voltage and current of the load were measured for each value of RL and tabulated below.

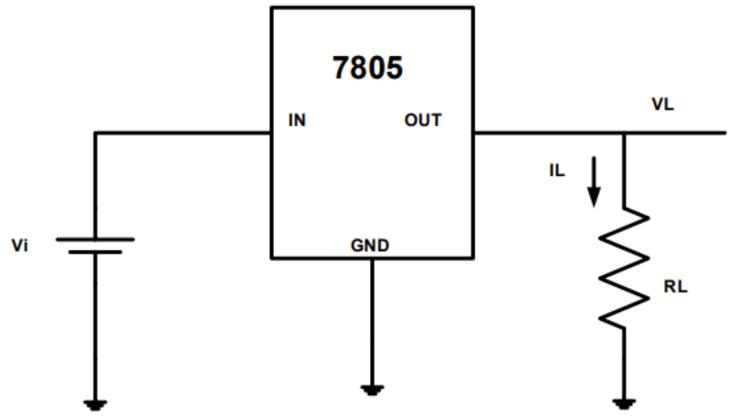

Figure 12. 7805 Circuit

RL(Ω)	VL(V)	IL(mA)
25	4.991	185.03
50	4.992	95.6
100	4.994	49.06
200	4.995	24.72
400	4.996	12.45
600	4.997	8.32
800	4.998	6.25
1000	4.999	5.02

Table 7. Result of 7805 Circuit

Based on the obtained results, the load regulation of the 7805 is 0, as the voltage remains constant for all values of RL. This can be seen from the fact that load regulation is given by ΔVL/ΔIL, and since the voltage remains the same for all RL values, ΔVL is zero.

Then, RL was adjusted to 100 ohms and VL and IL were measured for each input voltage, as listed in the table below.

Vi(V)	VL(V)	IL(mA)
8	4.938	49.17
9	4.940	49.19
10	4.941	49.2
11	4.942	49.21
12	4.942	49.21
13	4.941	49.20
14	4.941	49.20
15	4.941	49.20

Table 8. Result of measuring VL and IL

From the obtained results, the line regulation of the 7805 is 0, as the voltage remains constant for all input voltages. Hence, the value of ΔVL is zero, which makes the line regulation, defined as ΔVL/ΔVI, also zero.

4. The LM317 Adjustable Voltage Regulator

In this section, the circuit shown below was constructed with VI = 10 volts, R1 = 100 ohms, and RL = 1K. R2 was varied using a variable resistor with values recorded in the table below. The voltage and current of the load were measured for each value of R2 and tabulated below.

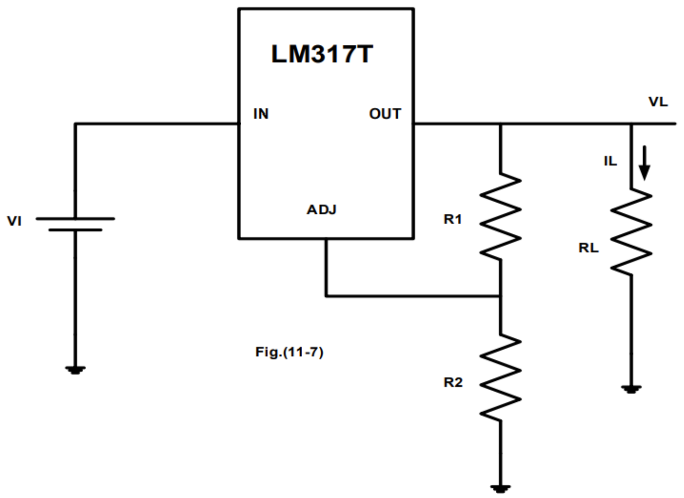

Figure 13. LM317T Circuit

The table below displays the obtained results:

R2(Ω)	VL(V)	IL(mA)
0	1.264	1.29
100	2.530	2.57
200	3.802	3.86
300	5.066	5.14
500	7.592	7.70
700	8.553	8.67

Table 9. Result of LM317T Circuit

Theoretically

Vin was set to 10V,R1 = 100Ω , RL = 1K

- When R2 = 0;

IREF = VREF/R1

VREF = VR1. IREF = 1.26

IREF = VREF/R1 = 1.26/100 = 12.6mA

- When R2 = 100Ω

VO = IREF (R1+R2)

VO = 12.6mA (100+100) = 2.52V

- For R2 = 100Ω.

Vo theoretically is 2.52V

Vo practically is 2.53V

- We can notice that theoretical and practical values are almost the same.

Then, with RL set to 1k, R1 set to 100Ω, and R2 set to 220Ω, the load voltage and current were measured for each value of VIN, as demonstrated in the table below.

Vi(V)	VL(V)	IL(mA)
10	4.056	4.12
12	4.057	4.12
14	4.058	4.12
15	4.059	4.12
16	4.059	4.12

17	4.060	4.12

Table 10. Result of LM317T Circuit

Theoretically

Vo = IREF (R1+R2) = 12.6m (100+220) = 4.032V

Furthermore, based on the obtained results, the line regulation of the LM317T is 0, as the voltage remains constant for all input voltages. Therefore, the value of ΔVL is zero, which makes the line regulation, defined as ΔVL/ΔVI, also zero.

Then, VI was set to 10V, R1 was set to 100Ω, and R2 was set to 220Ω. The load resistance was varied using a variable resistor, and the values are tabulated below. For each value of RL, the voltage and current of the load were measured and recorded in the table below.

RL(Ω)	VL(V)	IL(mA)
100	4	39.20
200	4	18.887
400	4	9.712
500	4	7.811
600	4	6.533
700	4	5.611
1000	4	4

Table 11. Measure of VL and IL

Conclusion

Throughout This experiment, we gained knowledge on how to connect circuits that utilize zener diodes. We were introduced to the zener diode, its operational mode, and its function as a voltage regulator. We applied this knowledge to construct various circuits that utilized zener diodes as voltage regulators and examined their operation. We also created I-V characteristics of zener diodes when they were forward and reverse biased. During the experiment, we utilized a DDM to measure resistors, currents, and voltages required for the zener diode circuits. As a result of this experiment, we have a deeper understanding of zener diodes, voltage regulators, and their respective circuits.

References

[1] https://circuitglobe.com/zener-diode.html
Accessed on 16 June 3:00 pm.

[2] https://www.electronics-tutorials.ws/diode/diode_7.html
Accessed on 16 June 3:15 pm.

[3] https://byjus.com/physics/zener-diode-as-a-voltage-regulator/
Accessed on 16 June 4:00 pm.

[4] https://www.elprocus.com/what-is-7805-voltage-regulator-its-working/
Accessed on 17 June 1:00 pm.

[5] https://www.electronics-tutorials.ws/blog/variable-voltage-power-supply.html
Accessed on 17 June 1:40 pm.

[6] LM317 - Voltage Regulator – Adjustable Output, Positive 1.5 A (onsemi.com)
Accessed on 17 June 3:00 pm.

Appendix

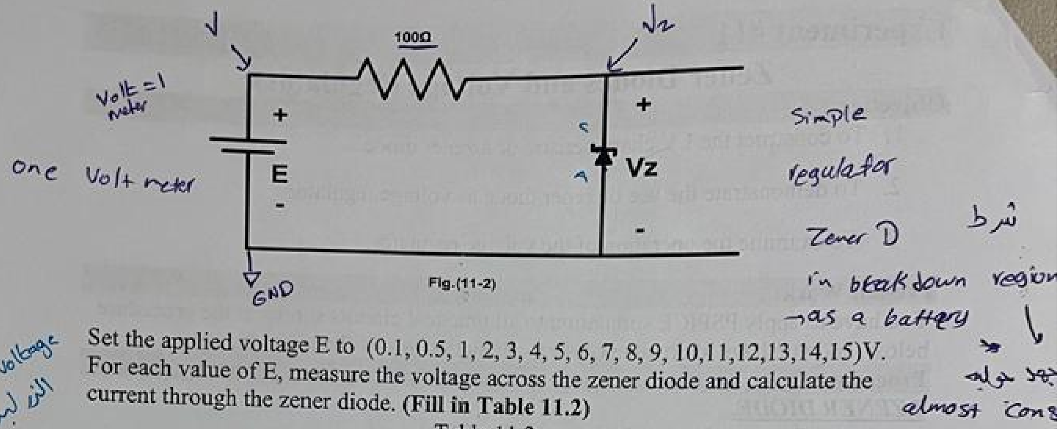

Fig.(11-2)

DC voltage اللي لبدل

Set the applied voltage E to (0.1, 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10,11,12,13,14,15)V. For each value of E, measure the voltage across the zener diode and calculate the current through the zener diode. **(Fill in Table 11.2)**

Table 11.2

at first Zener Diode is at Sat region → so it's open circuit

$V_o = V_i$

Zener in Break down region

V_z بتصير شبه ثابتة

Set	**Measure**	**Calculate**	
E(V)	**V_Z(V)**	**V_R(V)**	**I(m A)**
0.1	0.097 V		
0.2	0.175		
0.3	0.296		
0.4	0.389		
0.5	0.505		
0.6	0.601		
0.7	0.709		
0.8	0.801		
0.9	0.903		
1	1.027		
2	1.992		
3	2.615		
4	2.927		
5	3.113		
6	3.245		

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4. Using the results obtained in steps 3 and 6 constitute a graph of the characteristic of the zener diode.

5. Connect the circuit shown in Fig(11-3).

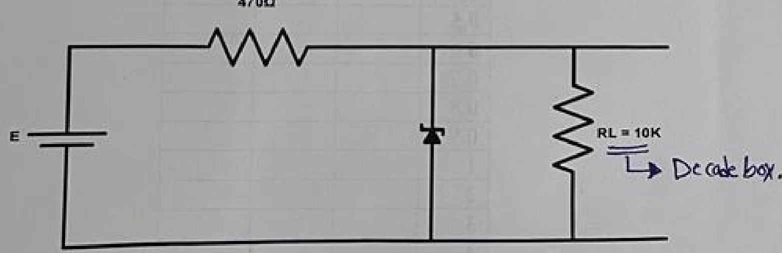

Fig.(11-3)

مهما غيرنا بضل ثابتة طالما
بال breakdown region

1. Set E to (10,11,12,13,14)V and measure the load voltage V_L. (Fill Table 11.3)

تغير الانبوت

V_i

Table 11.3

E	10	11	12	13	14
V_L	3.550	3.599	3.636	3.651	3.669

6. With E set to 10V measure the load voltage V_L for R_L=(8.2K,6.8K,4.7K,2.2K) and Fill in Table 11.4

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تغير اللود

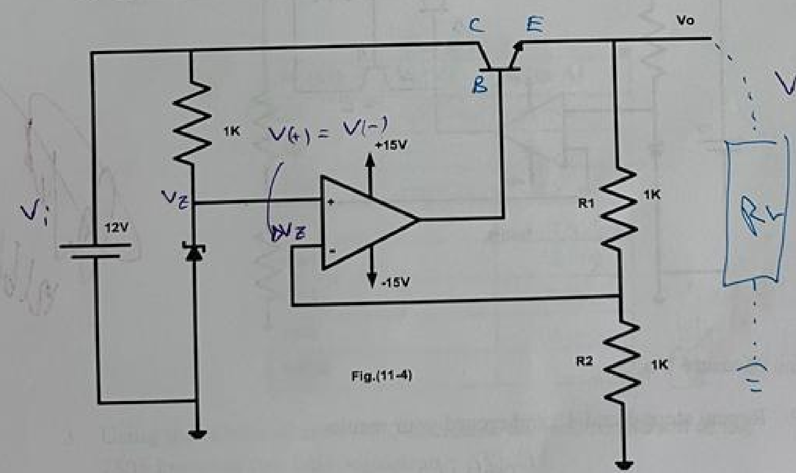
R_L

Table 11.4

R_L	8.2k	6.8k	4.7 k	2.2k
V_L	3.527	3.508	3.512	3.504

II. THE VOLTAGE REGULATED POWER SUPPLY. $V_i > V_o$

1. connect the circuit of Fig.(11-4).



$$V_o = \left(1 + \frac{R_1}{R_2}\right) V_z$$

Fig.(11-4)

2. Measure Vo.
3. Attach a 1k load resistor to the output. Measure Io and Vo.
4. Repeat step 3 for load resistance RL = (680 , 470 , 220 , 100) ohm.

Table 11.5

$V_Z = 2.866$

5.7.

R_L	open	1kΩ	680 Ω	470 Ω	220 Ω	100 Ω	50Ω
Vo	5.724	5.371	5.369	5.370	5.370	5.367	5.369
Io	0	5.37 mA	7.86 mA	8.53 mA	24.12 mA	52.63	102.46

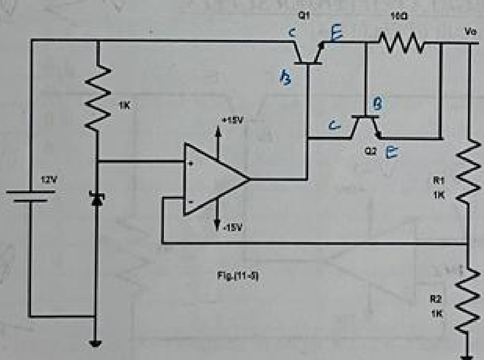
5. Set RL back to 1K .Change the value of R2 to 470 ohm .
   What is the new output voltage.

6. Change R2 to 2.2k. What is the output voltage now

Table 11.6

RL	R2	Vo
1kΩ	470 Ω	4.470
1kΩ	2.2kΩ	4.153

7. Connect the circuit shown in Fig.(11-5).



12/6/23

8. Measure Vo.

9. Repeat steps 3 and 4 . and record your results .

Table 11.7

$V_Z = 2.865$

R_L	Open	1kΩ	680 Ω	470 Ω	220 Ω	100 Ω	50Ω	40Ω
Vo	5.419	5.385	5.385	5.381	5.383	5.382	5.383	5.383
Io	0	3.3	7.88	9.24	24.18	52.70	75.53	75.89

Table 11.8

RL	R2	Vo
1kΩ	470 Ω	8.290

II. THREE TERMINAL FIXED VOLTAGE REGULATOR 7805.

1. Connect the circuit of Fig (11.6).

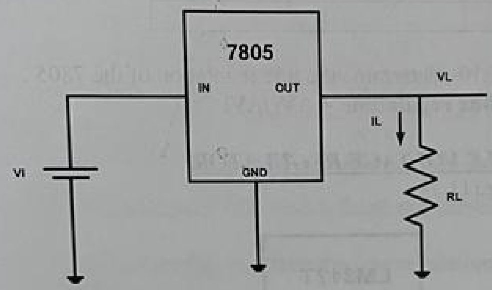


Fig.(11-6)

2. With Vi=10V measure IL and VL for the load resistances listed in the table 11.9.

Table 11.9.

$R_L(\Omega)$	$V_L(V)$	I_L(m A)
25	~~5.017~~ 4.991	185.03
50	4.992	95.6
100	4.994	49.06
200		24.72
400		12.45
600		8.32
800		6.25
1000		5.02 mA

12/6/23

3. Using the results of table 9.2 , determine the load regulation of the 7805.knowing that load regulation = $\Delta V_L / \Delta I_L$.

4. Set RL=100 ohm , adjust the input voltage Vi as listed in table 11.10. Measure V_L and I_L for each input voltage in the table.

Table 11.10

Vi(V)	V_L(V)	I_L(m A)
8	4.936	49.17
9	4.940	49.19
10	4.941	49.2
11	4.942	49.21
12	4.942	49.21
13	4.941	49.20
14	4.	
15		

Using the results of table 11.10 , determine the line regulation of the 7805 .

line regulation $= \Delta V_L / \Delta Vi$

III. THE LM317 ADJUSTABLE VOLTAGE REGULATOR.

1. Connect the circuit of Fig.(11.7).

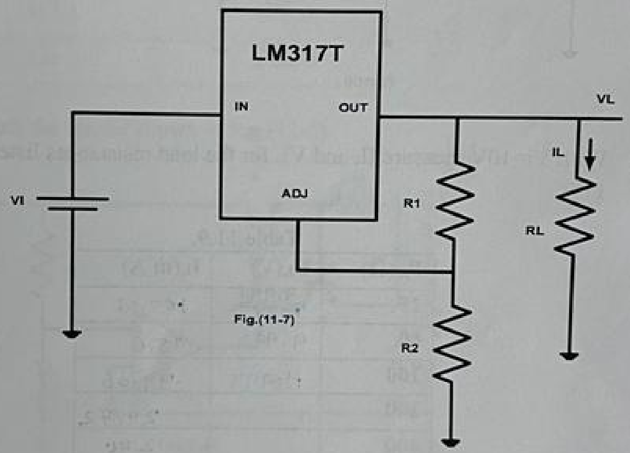


Fig.(11-7)

2. With Vi=10V, R1=100Ω, RL=1k , adjust R2 as shown in table 11.11.

Table 11.11

$\boxed{1.25}$

R_2(Ω)	V_L(V)	I_L(m A)
0	1.264	~~8.67~~ 1.29
100	2.530	2.57
200	3.802	3.86
300	5.066	5.14
500	7.592	7.70
700	8.553	8.67

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3. Measure and record VL,IL for each R value.

4. With RL =1k , R1=100 ohm , R2=220 , adjust Vi as listed in table 11.12.

Table 11.12

V_i(V)	V_L(V)	I_L(m A)
10	4.056	4.12
12	4.057	4.12
14	4.058	4.12
15	4.059	4.12
16	4.059	4.12
17	4.066	4.12

5. Measure and record the load voltage and current for each input voltage value.

6. Using your results, calculate the line regulation for the LM317T voltage regulator.

7. With Vi=10V, R1=100 0hm , R2=220 , adjust RL as shown in table 11.13.

Table 11.13

$R_L(\Omega)$	V_L(V)	I_L(m A)
100	4	39.20.
200	4	18.887
400	4	9.712
500	4	7.611
600	4	6.533
700	4	5.611A
1000	4	4A

8. Measure and record V_L,I_L for each R_L value.

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