Student ID:

Name:

Lab Section:

Lab Group:

Experiment No. 6

Verification of Thevenin's Theorem and Maximum Power Transfer Theorem

Objective

The aim of this experiment is to validate Thevenin's Theorem for linear circuits as well as the condition for the Maximum Power to be delivered to the load of any linear two terminal circuit

Part 1: Thevenin's Theorem

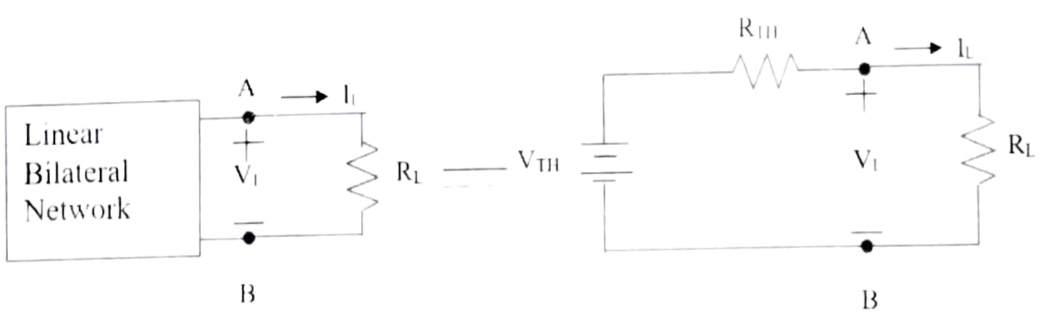
Theory

It is often desirable in circuit analysis to study the effect of changing a particular branch element while all other branches and all the sources in the circuit remain unchanged. Thevenin's theorem is a technique to this end and it greatly reduces the number of computations that we have to do each time a change is made. Using Thevenin's theorem the given circuit except the particular branch to be studied is reduced to the simplest equivalent circuit possible and then the branch to be changed is connected across the equivalent circuit.

Thevenin's theorem states that any two-terminal linear bilateral networks containing sources and passive elements can be replaced by an equivalent circuit consisting of a voltage source (V_{Th}) in series with a resistor (R_{Th}) where,

V_{Th} = The open circuit voltage (V_{OC}) at the two terminals A and B

R_{Th} = The resistance looking into terminals A and B of the network with all sources removed



There are several methods for determining Thevenin resistance R_{Th}. An attractive method for determining R_{Th} is: (1) determine the open circuit voltage, and (2) determine the short circuit current I_{SC} as shown in the figure, then

$$R_{th} = \frac{Voc}{ISC}$$

Methodology of Determining Thevenin's Circuit Parameters (V_{OC}, I_{SC}, R_{th})

Procedure to determine the Thevenin's Circuit Parameters (V_{OC}, I_{SC}, R_{Th}) and Thevenin equivalent circuit for any linear two-terminal linear circuit is given below.

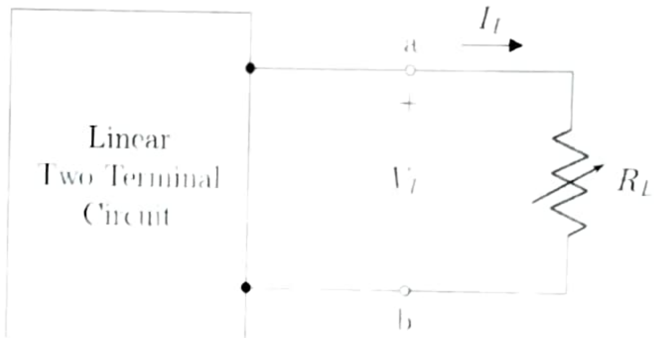


Figure 1: Original Circuit

Step 1: Determining V_{OC}

Remove the load resistance R_l and find the open circuit voltage between terminals a & b. This voltage is called Thevenin's voltage, i.e., $V_{Th} = V_{OC}$. It is also known as the Open Circuit Voltage.

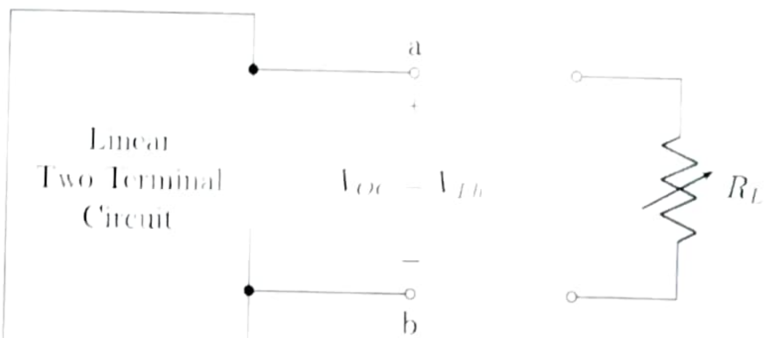


Figure 2: Circuit for finding V_{OC}

Step 2: Determining I_{SC}

Place a short circuit between terminals a and b (simply connect them through a wire). The current through the short circuit is called Norton's Current, i.e., $I_N = I_{SC}$. It is also known as the Short Circuit Current.

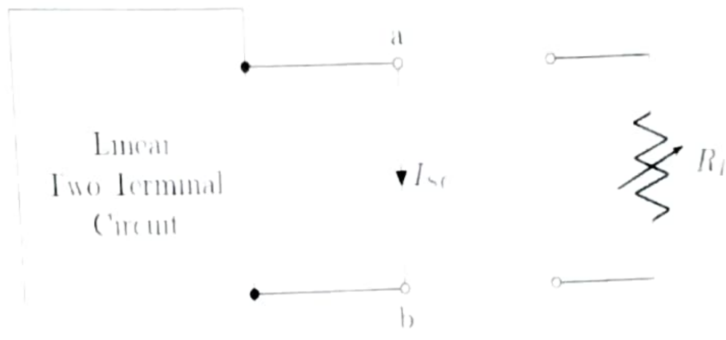


Figure 3: Circuit for finding I_{SC}

Step 3: Determining R_{th}

Divide the Open Circuit Voltage by the Short Circuit Current to determine the Thevenin's Resistance

$$R_{Th} = \frac{V_{OC}}{I_{SC}}$$

Alternatively, turn off all the independent sources and determine the equivalent resistance between terminals $a - b$. This is the Thevenin resistance, that is, $R_{ab} = R_{Th}$.

Step 4: Constructing Thevenin's Equivalent Circuit

Construct Thevenin's equivalent circuit as shown in the following figure setting the voltage source at V_{Th} volts and the series resistance at R_{Th} ohms. The values shown here should closely match the corresponding values you determined from the earlier steps.

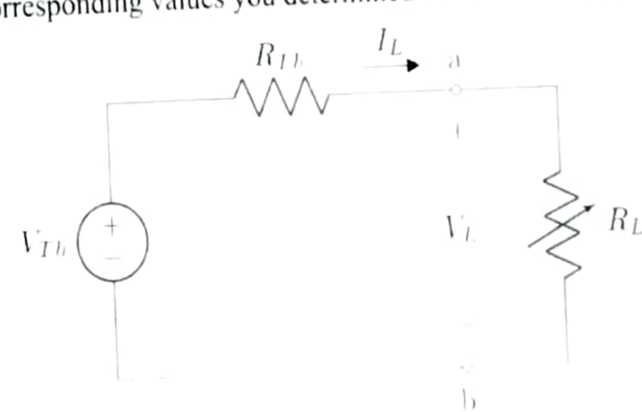


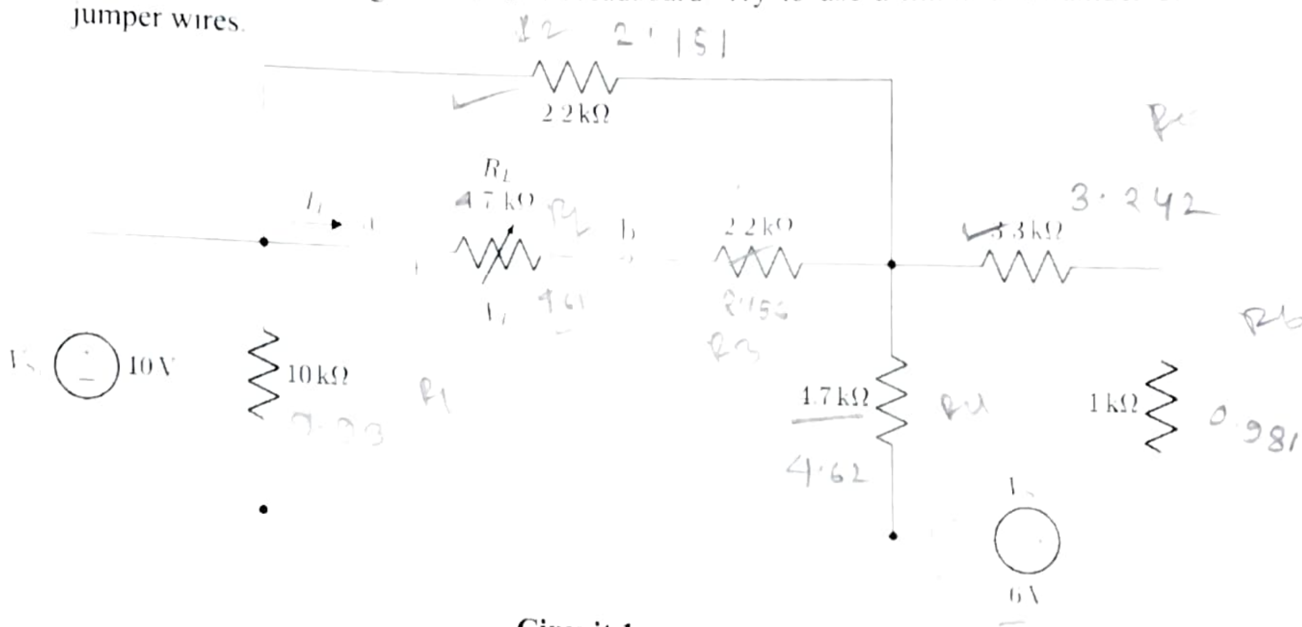
Figure 4: Thevenin Equivalent Circuit

Apparatus

- Multimeter
- Resistors ($1\ k\Omega$, $2.2\ k\Omega$ x 2, $3.3\ k\Omega$, $4.7\ k\Omega$ x 2, $10\ k\Omega$).
- DC power supply
- Breadboard
- Jumper wires

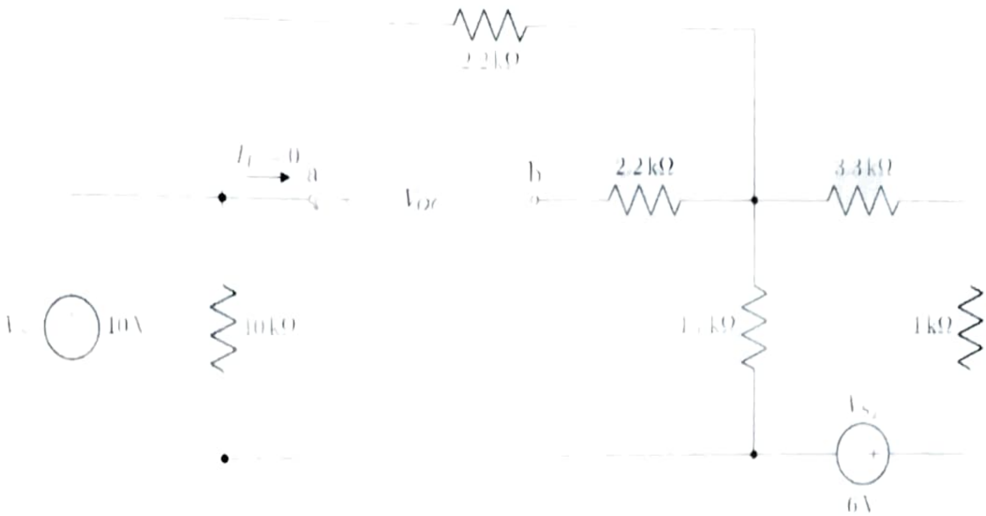
Procedures

- Measure the resistances of the provided resistors and fill up the data table.
- Construct the following circuit on a breadboard. Try to use a minimum number of jumper wires.



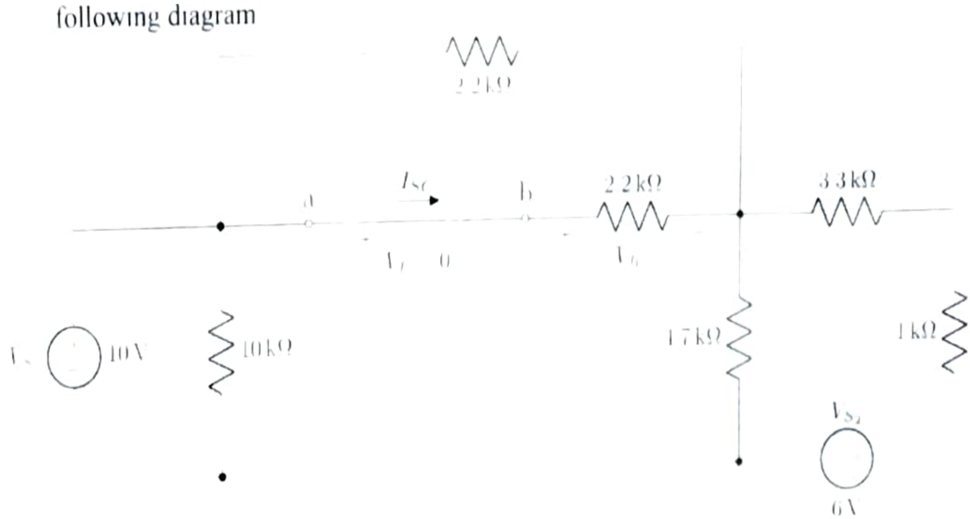
Circuit 1

- Connect two DC voltage sources or two channels of a DC source with voltages set to $6\ V$ and $10\ V$ as shown in the figure.
- We will model the load resistance (R_L) by a $4.7\ k\Omega$ resistor for simplicity. Connect a $4.7\ k\Omega$ resistor as R_L.
- Measure the voltage (V_L) across the load resistance. Measure the current (I_L) through the load using Ohm's law as $I_L = \frac{V_L}{R_L}$. Record the values in the corresponding data table.
- Now, disconnect the load resistor and leave the terminals $a - b$ open. The circuit should look like the one shown below.



Circuit 2

- Notice that, as the load is open circuited, the load current (I_L) is zero. Measure the open circuit voltage V_{OC} and record in the corresponding data table.
- Now short the terminals $a - b$ by connecting a wire between them as shown in the following diagram

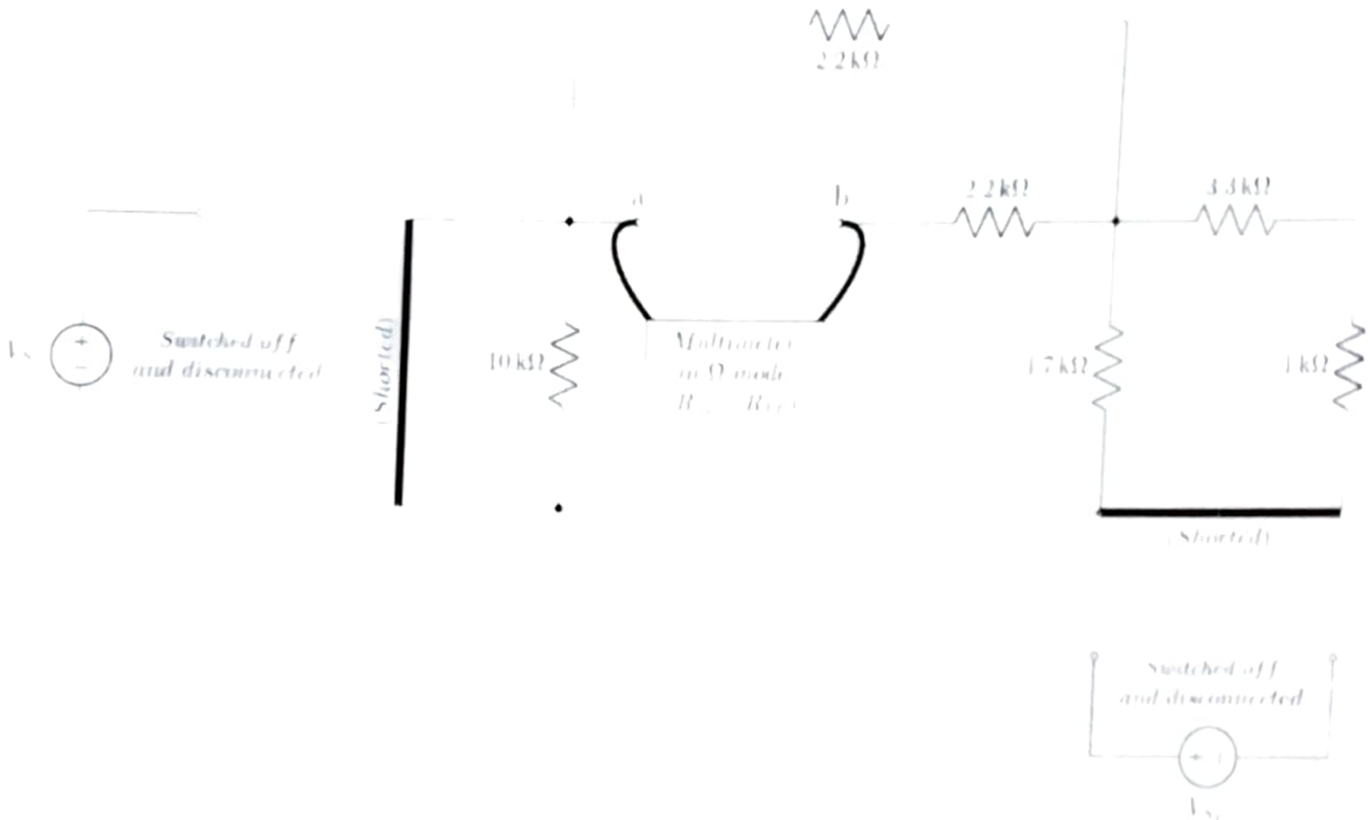


Circuit 3

- Notice that, as the load is short circuited, the load voltage (V_L) is zero. Measure the short circuit current I_{SC} and record in the corresponding data table. I_{SC} is the current flowing through the R_3 resistor, that is $I_{SC} = \frac{V_{R_3}}{R_3}$
- Use V_{Th} from **Circuit 2** and I_{SC} from **Circuit 3** to calculate R_{Th} as $R_{Th} = \frac{V_{Th}}{I_{SC}}$ in data Table 5.

➢ Now let's determine R_{Th} using another method which is called the Universal Method. To do this, again open the terminals $a - b$ (remove the shorting wire in **Circuit 3**)

➢ Turn the switches of the voltage source(s). Replace them with short circuits as shown in the following diagram

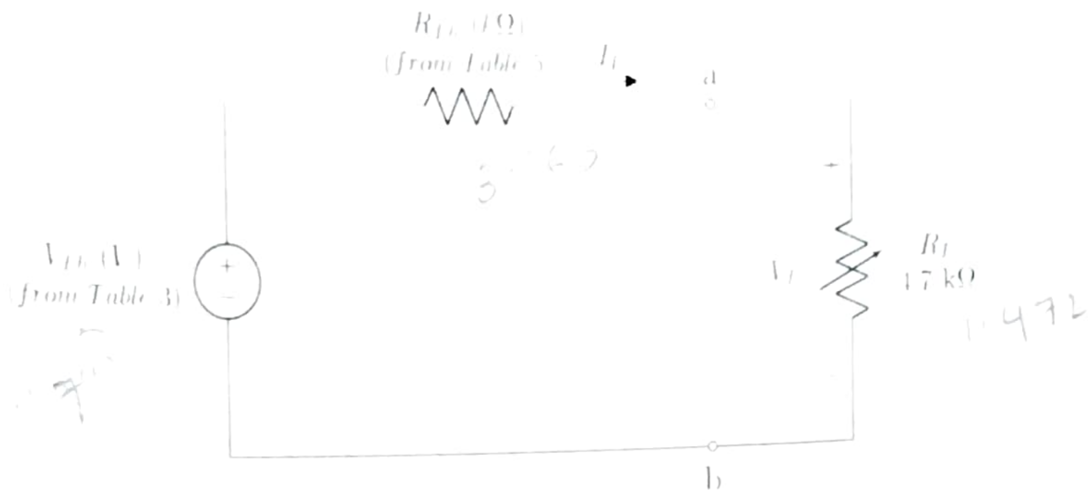


Circuit 4

➢ Measure the equivalent resistance between terminals $a - b$. This the Thevenin resistance R_{Th}

➢ Now construct the following Thevenin equivalent circuit shown in the following diagram

➢ Set the value of the voltage source equal to V_{Th} (from Table 3). Use R_{Th} from Table 5



Circuit 5

➢ Measure the voltage (V_L) across the load resistance. Measure the current (I_L) through it using Ohm's law as $I_L = \frac{V}{R}$. Record the values in the corresponding data table.

Data Tables

Signature of Lab Faculty:	AM	**Date:**	12/07/23

** ***For all the data tables, take data up to three decimal places, round to two, then enter into the table.***

Table 1: Resistance Data

For all your future calculations, please use the observed values only **(even for theoretical calculations)**.

Notation	Expected Resistance	Observed Resistance (kΩ)	Notation	Expected Resistance	Observed Resistance (kΩ)
R_1	10 kΩ	9.93	R_5	3.3 kΩ	3.242
R_2	2.2 kΩ	2.151	R_6	1 kΩ	0.981
R_3	2.2 kΩ	2.156	R_l	4.7 kΩ	4.51
R_4	4.7 kΩ	4.65			

Table 2: Data from Circuit 1

In the following table, V_L is the voltage drop across the load resistor R_l and I_L is the current through the load with polarity and direction respectively as shown in **Circuit 1**. Solving the circuit and calculate theoretical V_l and I_l. Also, calculate the percentage of error between experimental and theoretical values of V_L.

Observation	V_{S_1} (V) (from dc supply)	V_{S_1} (V) (using multimeter)	V_{S_2} (V) (from dc supply)	V_{S_2} (V) (using multimeter)	V_L (V)	$I_L = \frac{V_L}{R_L}$ (mA)
Experimental	10	10.06	6	6.07	1.992	0.423
Theoretical	10		6		1.69	0.56

Percentage of Error $= \left|\frac{Experimental - Theoretical}{Theoretical}\right| \times 100\%$

Here, Percentage of Error in V_L calculation = 8.04 %

Table 3: Data from Circuit 2

In the following table, V_{OC} is the open circuit voltage across the open terminals with $I_L = 0$. This is the Thevenin voltage V_{Th}. Calculate the percentage of error between experimental and theoretical values of V_{OC}.

Observation	V_{S_1} (V) (from dc supply)	V_{S_1} (V) (using multimeter)	V_{S_2} (V) (from dc supply)	V_{S_2} (V) (using multimeter)	$V_{OC} = V_{Th}$ (V)
Experimental	10	10.06	6	6.07	3.379
Theoretical	10		6		3.21

Here, % error in $V_{OC} = V_{Th}$ calculation = 5.26 %

Table 4: Data from Circuit 3

In the following table I_{SC} is the current through the shorted terminals with $V_L = 0$

Theoretically calculate the short circuit current and calculate the percentage of error between experimental and theoretical values of I_{SC}

Observation	V_S (V) (from dc supply)	V_S (V) (using multimeter)	V_S (V) (from dc supply)	V_S (V) (using multimeter)	V_R (V)	$I_{SC} = \frac{V_R}{R}$ (mA)
Experimental	10	10.06	6	6.07	2.253	1.0449
Theoretical	10		6			1.024

Here, % error in I_{SC} calculation = 2.03 %

Table 5: R_{Th} calculation

Comparison of the two methods to determine R_{Th}

Here, ΔR_{Th} = (R_{Th} *using* V_{Th}/I_{SC} *method*) − (R_{Th} *using the Universal method*)

Observation	V_{Th} (V) (from data Table 3)	I_{SC} (mA) (from data Table 4)	$R_{Th} = \frac{V_{Th}}{I_{SC}}$ (kΩ)	R_{Th} (kΩ) (using multimeter from Circuit 4)	ΔR_{Th} (kΩ)
Experimental	3.379	1.0449	3.338	3.250	0.08
Theoretical	3.21	1.024	3.1347	3.1347	0.0123

Table 6: Data from Circuit 5

In the following table, V_L is the voltage drop across the load resistor R_L and I_L is the current through the load with polarity and direction respectively as shown in **Circuit 1** and **Circuit 5**. Measure the value of V_L from **Circuit 5**. Then calculate I_L using the measured V_L. Finally compare the values with those in Table 1. Here,

ΔV_L = (V_L *from Table 2*) − (V_L *measured for Circuit* 5 in Table 6) and

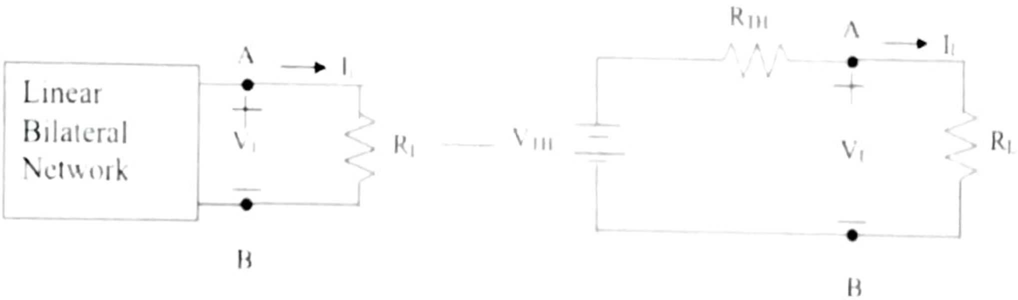
ΔI_L = (I_L *from Table 2*) − (I_L *calculated for Circuit* 5 in Table 6)

Observation	V_L (V) (from data Table 2)	I_L (mA) (from data Table 2)	V_L (V) (from Circuit 5 using multimeter)	$I_L = \frac{V_L}{R}$ (V) (for Circuit 5)	ΔV_L (V)	ΔI_L (mA)
Experimental	1992	0.4321	2.223	0.481	0.231	-.0489
Theoretical	1.69	0.46	2.323	0.472	-0.533	-0.012

Part 2: Maximum Power Transfer Theorem

Theory

The Maximum Power Transfer Theorem is a fundamental concept in electrical engineering that relates to the transfer of maximum power from a source to a load. The Maximum Power Transfer theorem states that ***A resistive load will receive maximum power when its total resistive value is exactly equal to Thevenin's resistance of the network as "seen" by the load.***



We know that any circuit A terminated with a load R_L can be reduced to its Thevenin's equivalent. Now according to this theorem, the load R_L will receive maximum power when $R_L = R_{Th}$. We can calculate the Maximum Power theoretically using the formula,

$$P_{max} = \frac{V_{Th}^2}{4R_{Th}}$$

The theorem focuses on the transfer of power between a source and a load. In electrical circuits, power is transferred from a source (such as a generator) to a load (such as a resistor) through a transmission medium (such as wires or conductors).

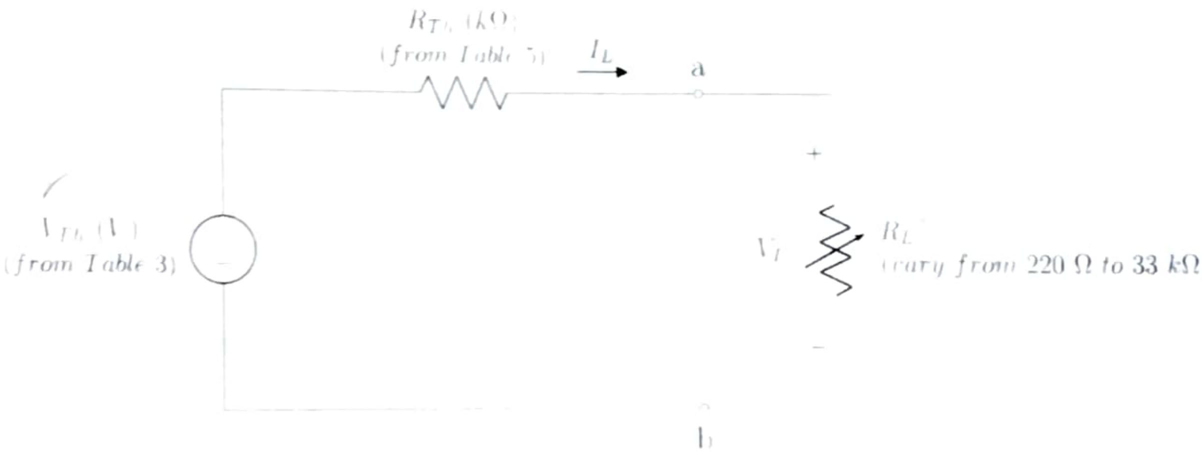
It's worth noting that the Maximum Power Transfer Theorem is a theoretical concept and is not always practical or desirable in real-world scenarios. In many practical applications, impedance matching is employed to achieve efficient power transfer, but it may not always result in maximum power transfer Design considerations, system constraints, and other factors often influence the choice of impedance matching in electrical circuits

Apparatus

- Multimeter
- Resistors(220 Ω, 1 kΩ, 1 5 kΩ, 2 2 kΩ, 3 3 kΩ x 2, 4 7 kΩ, 5 6 kΩ, 10 kΩ, 18 kΩ, 33 kΩ)
- DC power supply
- Breadboard
- Jumper wires

Procedures

- Construct the following reduced Thevenin equivalent circuit



Circuit 6

- Vary R_L from 220 Ω to 33 kΩ. For each resistors listed in the **Apparatus** section, measure V_L. Calculate I_L using $I_L = \frac{V_L}{R_L}$ and record in the corresponding data table.

Data Tables

Signature of Lab Faculty: [signature] **Date:** 12/07/23

** ***For all the data tables, take data up to three decimal places, round to two, then enter into the table.***

Table 7: Data from Circuit 6

In the following table, P_{In} is the power supplied by the dc source, value set equal to V_{Th} and P_{Load} is the power consumed by the load. η is the power efficiency. Theoretically, η is 50% at the maximum power transfer condition.

R_L (Expected)	R_L (kΩ) (Measured)	V_{Th} (V) (using multimeter)	V_L (V)	$I_L = \frac{V_L}{R_L}$ (mA)	$P_{In} = V_{Th} I_L$ (mW)	$P_{Load} = V_L I_L$ (mW)	Efficiency $\eta = \frac{P_{Load}}{P_{In}} \times 100$ (%)
220 Ω	0.2167		0.21	0.969	3.30429	0.2034	6.158
1 kΩ	0.987		0.785	0.8002	2.728	0.628	23.020
1.5 kΩ	1.472		1.056	0.717	2.4449	0.757	30.96
2.2 kΩ	2.156		1.352	0.627	2.1380	0.8477	39.648
max → 3.3 kΩ	3.263	3.41	1.694	0.5191	1.7707	0.879	49.677
4.7 kΩ	4.62		1.993	0.4313	1.470	0.859	58.44
5.6 kΩ	5.52		2.134	0.3865	1.317	0.824	62.580
10 kΩ	9.93		2.559	0.257	0.876	0.657	75.043
18 kΩ	17.73		2.872	0.1619	0.552	0.464	84.2228
33 kΩ	32.47		3.09	0.095	0.323	0.293	90.61

Maximum Power found from the Table 7, P_{max} = $\boxed{0.8794 \text{ mW}}$

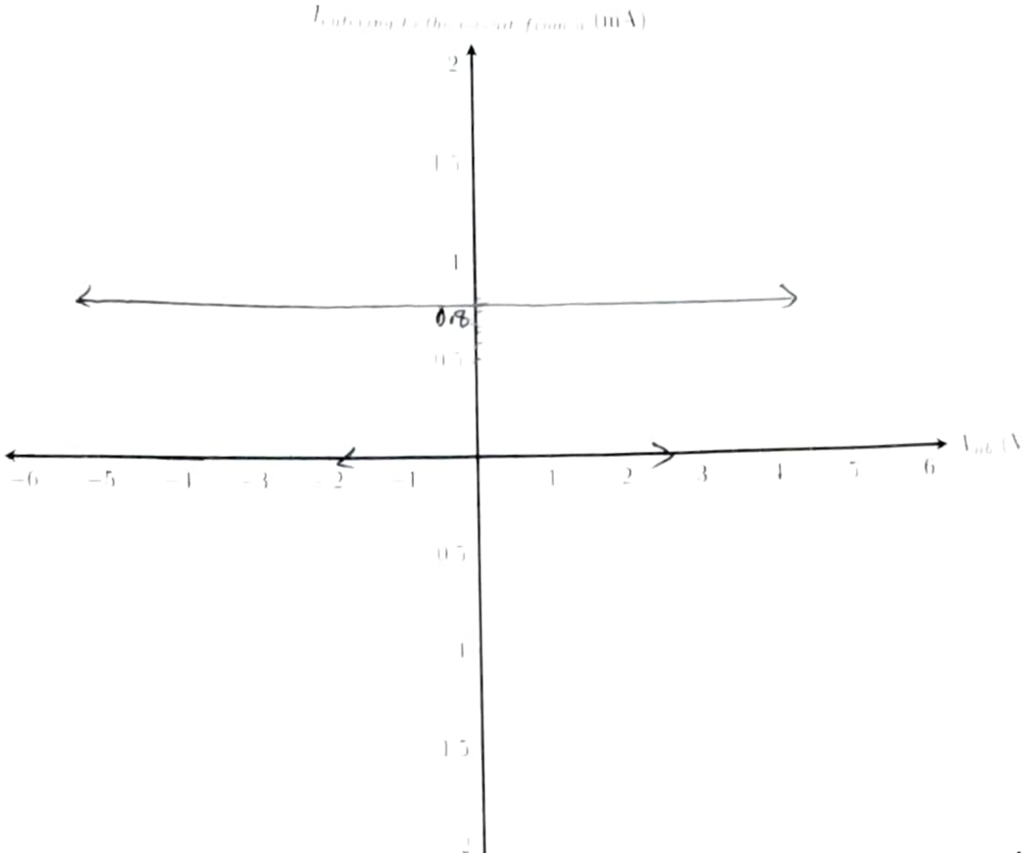
Theoretical Maximum Power, $P_{max} = \frac{V_{Th}^2}{4R_{Th}} =$ $\boxed{0.89446 \text{ mW}}$

Here, percentage error in Maximum Powers calculation = $\boxed{0.02 \text{ \%}}$

Questions

1. Circuit equivalency

(a) Draw the $I - V$ characteristic of the **Circuit 5** with respect to the terminals $a - b$ in the template provided below.



The straight line intersects x-axis at ~~3.3~~ 0 V

does not intere
x axis as it i
a horizontal

The straight line intersects y-axis at 0.83 mA

Slope of the straight line, m = 0 $k\Omega^{-1}$

Resistance from the plot, $\frac{1}{m}$ = 0 $k\Omega$

(b) Comparing the values to those measured for **Circuit 1** in Tables 3, 4, and 5, do they match?

☐ Yes ☑ No

2. Now in the same plot provided above, plot the $I - V$ curve of **Circuit 4**

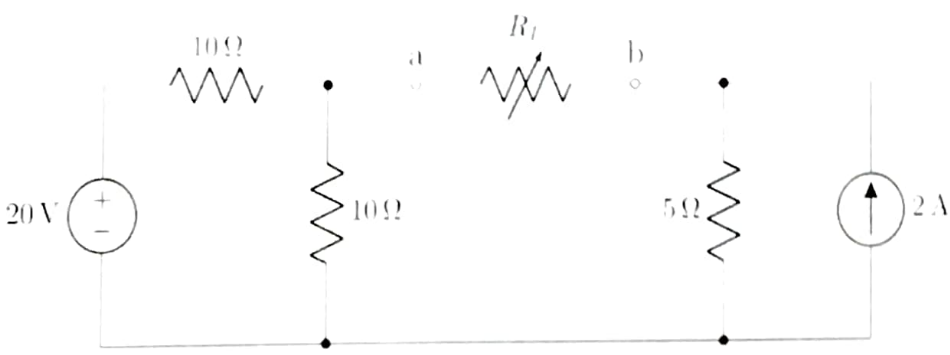
Slope of the straight line, m = | 0 $k\Omega^{-1}$ |

Resistance from the plot, $\frac{1}{m}$ = | 0 $k\Omega$ |

Explain why there is a shift in the $I - V$ curve of Circuit 4

there is a straigt line which is on the (0,0) point of the axis. so there is no shift in th curve but the first graph has some value in y axis.

3. Determine the open circuit voltage (V_{OC}) and the short circuit current (I_{SC}) with respect to the terminals $a - b$ for the circuit shown below.



Open circuit voltage, V_{OC} = | -8.2 V |

Short circuit current, I_{SC} = | 2 mA |

Have you been able to calculate the Thevenin resistance (R_{Th}) using $R_{Th} = \frac{V_{oc} = V_{Th}}{I_{sc}}$?

☑ Yes ☐ No

If not, suggest an alternative approach and determine R_{Th}

We can determine R_{Th} by

$$i = -\frac{V}{R_{th}} + i_{sc} = -\frac{V}{R_{th}} + i_{sc}\frac{R_{th}}{R_{th}}$$

$$= \frac{1}{R_{th}}\left(-V + i_{sc} \cdot R_{th}\right)$$

$$R_{th} = -V + V_{oc}$$

Calculation

$$R_{th} = -20 - 8.2$$

$$= -28.2\ \Omega$$

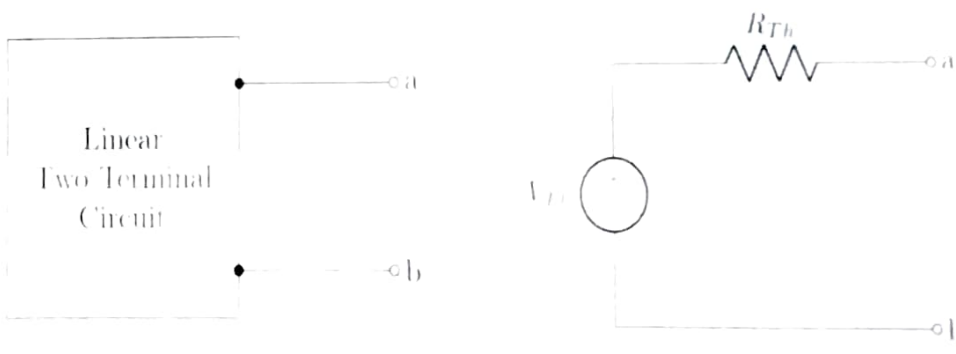
or,

$$V = IR_{th}$$

$$R_{th} = \frac{V}{I} = \frac{20}{2} = 10\ \Omega$$

Ans

4. If the following voltage source is in series with a resistor is the Thevenin equivalent of the linear two-terminal circuit, for each of the circuit elements listed in the column 1 of the following table, write the values of V_{Th} and R_{Th}. Write 'Unknown' if unable to specify



The linear two-terminal circuit is composed of only a/an	V_{Th} (V)	R_{Th} (Ω)
Short circuit	Unknown	Unknown
Open circuit	Unknown	Unknown
− 2 V voltage source	Unkrown	Unknow
3 A current source	Unknown	unknown
5 kΩ resistor	5	5

5. Efficiency and Maximum Power

(a) From the η and P_{Load} vs R_L plot, what is the efficiency at the maximum power position?

$\eta = \frac{Pload}{Pin}$% at the maximum power point position.

(b) For a load resistance R_L,

we can **increase** the power efficiency of the load by –

☐ Increasing R_L than R_{Th} ☑ Decreasing R_L than R_{Th} ☐ By equating R_{Th} and R_L

(c) We can **maximize** the power transfer of the load by –

☐ Increasing R_L than R_{Th} ☐ Decreasing R_L than R_{Th} ☑ By equating R_{Th} and R_L

(d) "We cannot maximize both the power of a load and the power efficiency of the circuit" – justify the statement.

the statement resulth maximum power transfer but not a maximum efficiency. If the bad resistance is smaller than source resistance, power dissipated at the load is reduced which mos of the power is dissipated

6. Specify by putting × *or* ✔, what should be the first priority: maximizing the power or increasing the efficiency for the following applications –

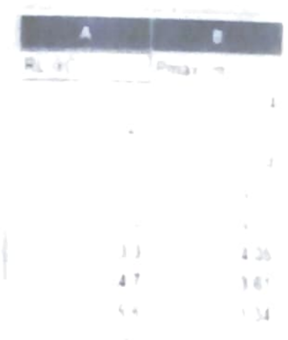
Application	Should Maximize the power transferred to the load	Should try to operate the load with the highest efficiency possible
An antenna sending signal to the Mars		✔
A motor running to pull water to a tank placed in a higher position	✔	
A mic used to amplify voice		✔

Report

1. Fill up the theoretical parts of all the data tables.
2. Answer to the questions.
3. Attach two data plots, one should include V_L, I_L, and P_{Load} vs. R_L plotted together in the same pane and the other should include η and P_{Load} vs. R_L plotted together in the same pane. There is a guideline of plotting data using google sheet in the next page.
4. Discussion *[comment on the obtained results and discrepancies]*. Start writing below the line.

Part 3: Plotting Circuit Characteristics on Google Sheets

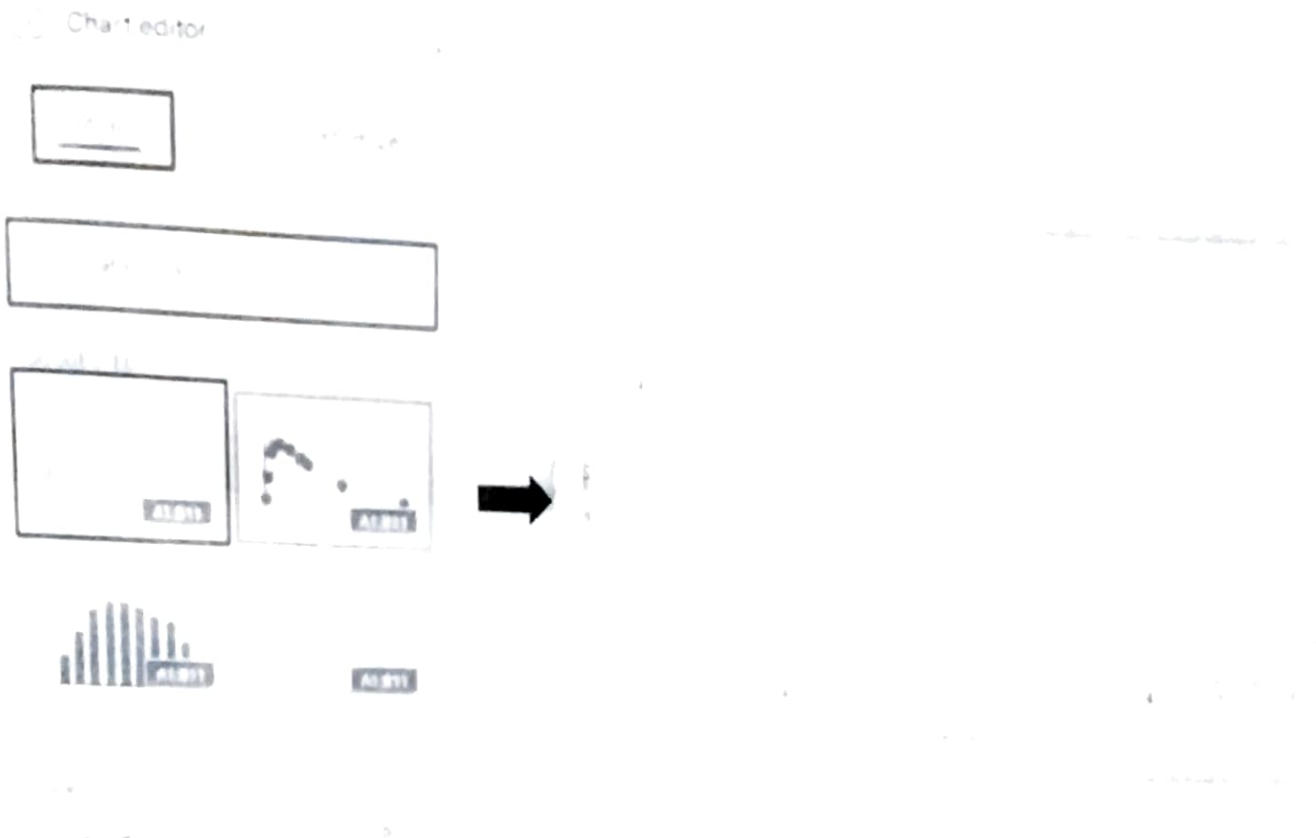
1. Create a Google spreadsheet by visiting https://docs.google.com/spreadsheets
2. Fill in the spreadsheet with the data that you've collected in the lab (refer to your lab sheet). Select the column R_L (kΩ) and any other column you want to plot with (to select a column, click on the column head, e.g., "A". Then hold CTRL while clicking the second column, e.g., "B", to select both columns)



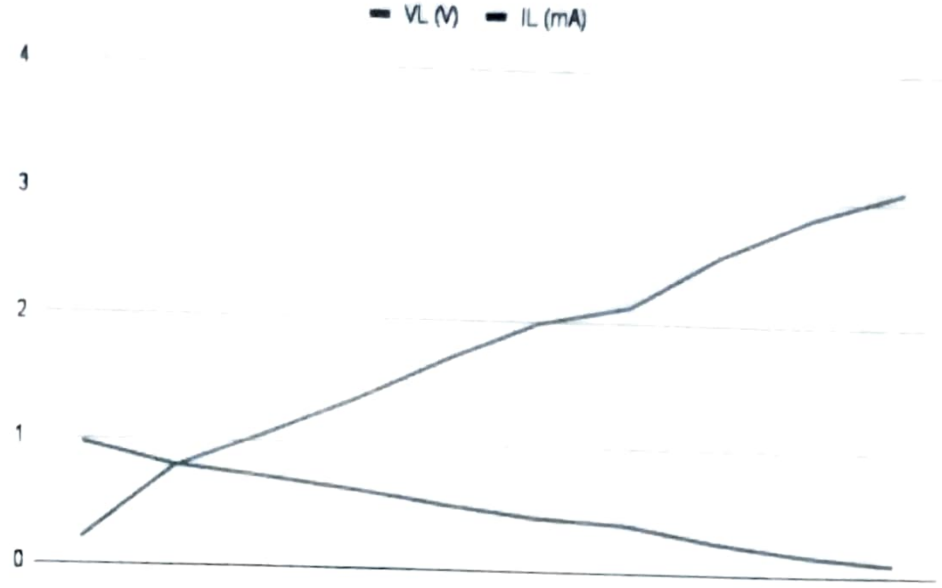
Note This is sample data collected from a simulation. Your data may not match with this.

3. Select Insert → Chart. You should be getting a graph that looks like the following diagram

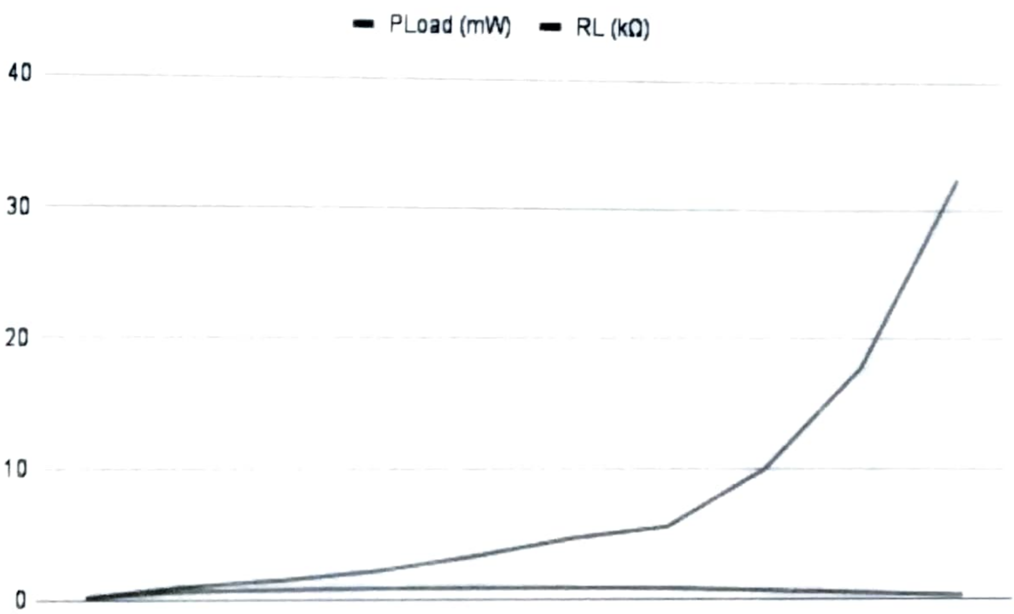
4. A Chart Editor section should pop up at the right side of your screen. If it doesn't show up, then double click on the graph. Go to the setup section in the chart editor and change the "Chart type" to "Line chart". Your graph should be changed into a line plot as shown below



VL (V) and IL (mA)



PLoad Vs. RL



A	B	C	D	E	F	G	H	I	J	K
RL (kΩ)	Pmax (mW)	VL (V)	IL (mA)	PIn (mW)	PLoad (mW)	LOSS (mW)	%η	%VR	Vth	Rth
0.2167	13.414	0.21	0.969	3.30429	0.20349	3.1008	6.158357771	1499.769266	3.41	3.25
0.981	2.963	0.785	0.8002	2.728682	0.628157	2.100525	23.02052786	331.2945973		
1.472	1.974	1.056	0.717	2.44497	0.757152	1.687818	30.96774194	220.7880435		
2.156	1.348	1.352	0.627	2.13807	0.847704	1.290366	39.64809384	150.742115		
3.263	0.8909	1.694	0.5191	1.770131	0.8793554	0.8907756	49.67741935	99.60159363		
4.62	0.629	1.993	0.4313	1.470733	0.8595809	0.6111521	58.4457478	70.34632035		
5.52	0.526	2.134	0.3865	1.317965	0.824791	0.493174	62.58064516	58.87681159		
9.93	0.2927	2.559	0.257	0.87637	0.657663	0.218707	75.04398827	32.72910373		
17.73	0.1639	2.872	0.1619	0.552079	0.4649768	0.0871022	84.2228739	18.33051325		
32.47	0.0895	3.09	0.095	0.32395	0.29355	0.0304	90.61583578	10.0092393