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Preamble for Experiment 6: Energy Gap of a Semiconductor

Working of silicon and germanium diodes, LEDs with various colors, photodiodes, thermistors, LDRs and solar cells is based on the concept of energy gap of a semiconductor. What is energy gap of a semiconductor? and how can it be measured?

The first semiconductor was invented by Michael Faraday in 1833

Michael Faraday: (1791-1867): He was the most influential Physicist in the history. He mainly contributed in the fields of electricity, magnetism, electromagnetism, diamagnetism and electrochemistry. He also evaluated the effect of magnetic field on light which is related with Faraday effect and Zeeman effect. He was also the discoverer of electricity. It was his work due to which electric generators and electric motors came in to existence. The modern power stations are based on Dynamo, which was invented by Faraday himself. He made significant contributions in chemistry also, one of which was discovery of Benzene and another was invention of Bunsen burner. Faraday was an excellent experimentalist. His works were admired by Maxwell, Einstein and Rutherford. He twice refused to become president of Royal society. In 1847 he became the first Physicist to produce gold nano-particles. This was the birth of nanoscience. Faraday was also an excellent lecturer. The SI unit of capacitance (farad) is named in his honor.

Pledge

I solemnly affirm that I am presenting this journal based on my own experimental work. I have neither copied the observations, calculations, graphs and results from others nor given it to others for copying.

Signature of the student

Experiment 6: Energy gap of Semiconductor

Aim: To measure energy gap of given semiconductor

Apparatus
- (i) Semiconductor (thermistor with NTC)
- (ii) Heating arrangement with mini-oven filled with sand powder and secondary windings of a step down transfer for controlled electrical heating.
- (iii) Digital Multimeter (DMM)

(Refer Fig 7.2)

Significance of the experiment: *The energy gap, i.e. the gap between valance band and conduction band decides the conductivity of a material. The typical energy gaps of the semiconductors which are in the range 1 eV to 3 eV impart many useful properties to the semiconductors. The ability of the semiconductors to conduct due to electrons as well as holes, their ability to convert light in to electricity and electricity in to light, decrease in the resistance with temperature are all due to their typical energy gaps. The electronics (PN junction diode, NPN or PNP transistor), photonics (LED, laser diode, photodiode, solar cell, LDR etc.) and thermistors, are all based on the typical energy gaps of semiconductors. The energy gap of silicon (1.1 eV) makes it more applicable than germanium (0.72 eV). This experiment demonstrates one of the simplest methods of measuring the energy gap of semiconductors.*

Theory: Individualatoms are characterized by discrete energy levels. When atoms come together and form bonds, their energy levels split and become bands. This happens due to the overlapping of electron wave-functions and Pauli's exclusion principle. Crystalline solids are characterized

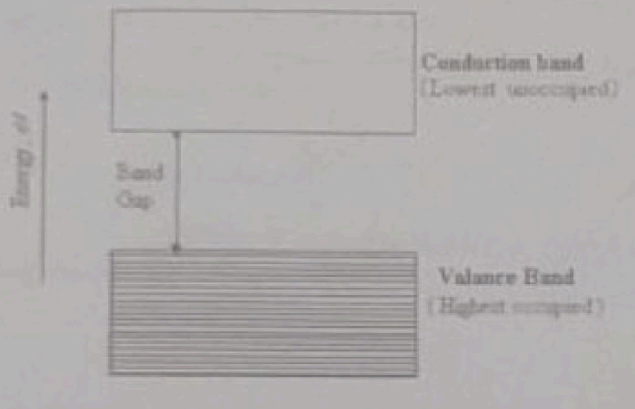

Figure 6.1: Concept of energy gap

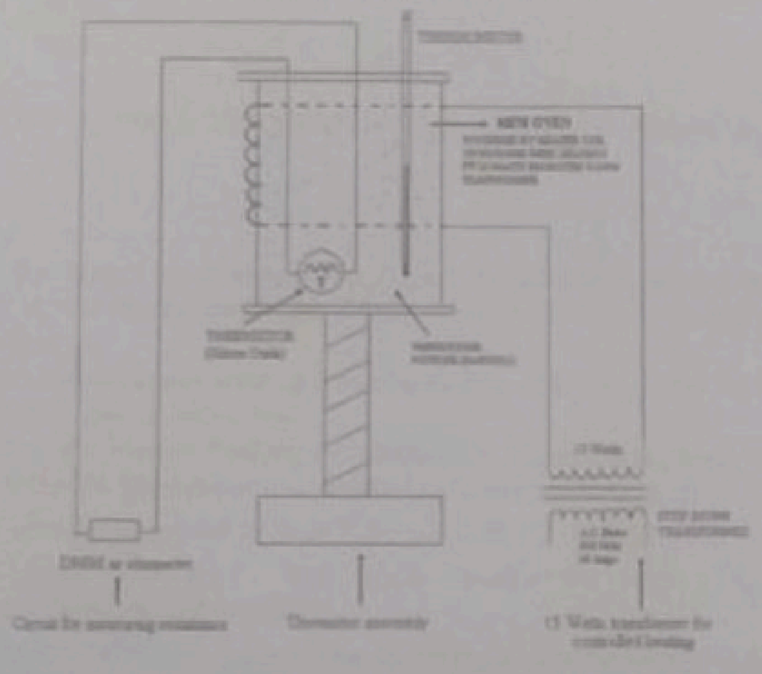

Figure 6.2: Experimental arrangement for the band gap experiment

by energy band diagrams. The energy band diagram of a solid is characteristic to it's atom and inter-atomic spacing. The highest occupied band in such energy bands is called as valance band while the lowest unoccupied band is called as conduction band. The valance band and conduction band are separated by a group of quantum mechanically forbidden energy levels called as energy gap (refer Fig 7.1). The size or value of this energy gap varies with the material. In conductors like copper, aluminum, gold, silver etc. the energy gap is zero, while it is high in insulators like diamond (5 to 6 eV). Elemental semiconductors such as silicon, germanium and compound semiconductors such as gallium arsenide, zinc sulphide, gallium phospide, etc are characterized by intermediate energy gaps (0.66 to 3.6 eV).

The resistance (R_T) of a semiconductor having energy gap (E_g) decreases with the temperature (T), according to following relation

$$R_T = R_{TO} e^{\frac{E_g}{2KT}} \qquad \ldots(6.1)$$

Where K is the Boltzmann's constant

By taking logarithms and rearranging

$$lnR_T = lnR_{TO} + \left(\frac{E_g}{2K}\right) \times \frac{1}{T} \qquad \ldots(6.2)$$

Eqn (7.2) signifies a straight line ($\Rightarrow y = mx + c$) Thus the graph of lnR_T Vs $\frac{1}{T}$ is a straight line having slope $m = \frac{E_g}{2K}$. Thus

$$E_g = 2Km \qquad \ldots(6.3)$$

Eqn (6.3) provides a simple and straightforward method of measuring energy gap of a semiconductor.

Procedure:

1. Connect the circuit as shown in the circuit diagram and get it checked. Connect the terminals of the thermistor to the DMM. Operate DMM in resistance mode and with appropriate scale.
2. Record the room temperature and corresponding resistance (R_T) of thermistor. Express resistance in Ω (not in kΩ or MΩ).
3. Start heating the oven by making AC mains ON. Record decreasing values of resistances (in Ω) at different temperatures as shown in the observation table.
1. Calculate various quantities such as T $(= t + 273\ K)$, $\frac{1}{T}$ and lnR_T
2. Plot the graph of R_T Vs T. This graph exhibits the NTC (Negative Temperature Coefficient) property of thermistor.
4. Plot the graph of lnR_T Vs $\frac{1}{T}$. Calculate its slope (m) and the energy gap using Eqn (7.3)

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ROUGH WORK

Observation table

Sr. No.	Observations		Calculations		
	Temperature $T, {}^{0}C$	Resistance R_T, Ω	Temperature, T (K)	$1/T$ (Expressed in 10^{-3}) K^{-1})	$\ln R_T$
1	R.T. = 30	1500	303	3.3	7.3
2	35	1000	308	3.2	6.9
3	40	900	313	3.1	6.8
4	45	760	318	3.1	6.6
5	50	680	323	3.0	6.5
6	55	600	328	3.0	6.3
7	60	525	333	3.0	6.2
8	65	475	338	2.9	6.1
9	70	440	343	2.9	6.0

Calculations:

Slope of the graph of lnR_T Vs $\frac{1}{T} = m =$ 2786 K

Energy gap, $E_g = 2Km$, where K = Boltzman's constant = 1.37×10^{-23} J/K

$= 2 \times 1.37 \times 10^{-23} \left(\frac{J}{K}\right) \times m\,(K) = 2 \times 1.37 \times 10^{-23} \left(\frac{J}{K}\right) \times 2786\,(K)$

$= 7633 \times 10^{-23}$ J $= \frac{7633\times10^{-23}\,(J)}{1.6\times10^{-19}\frac{J}{eV}} = 0.477$ eV

Result: The energy gap of given semiconductor (thermistor) is 0.4771 eV

FAIR WORK

Observation table

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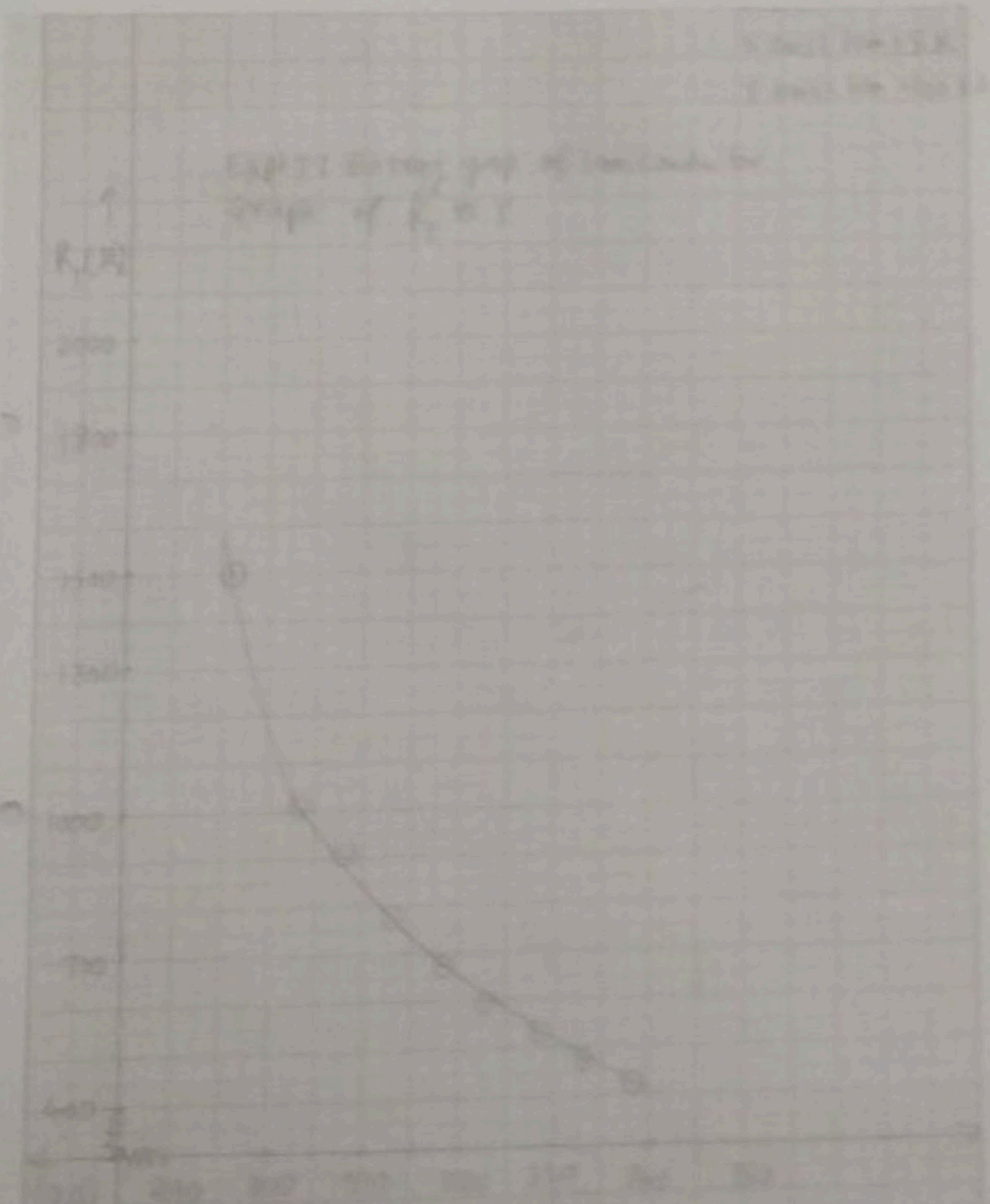
Model Graph-I for Expt. 6, Energy Gap of Semiconductor

This Model Graph is only for cross-checking your graph with its nature and style of presentation. As such, your Graph must be based on your own observations and calculations. Only formatting and presentation needs to be as per the Model Graph.



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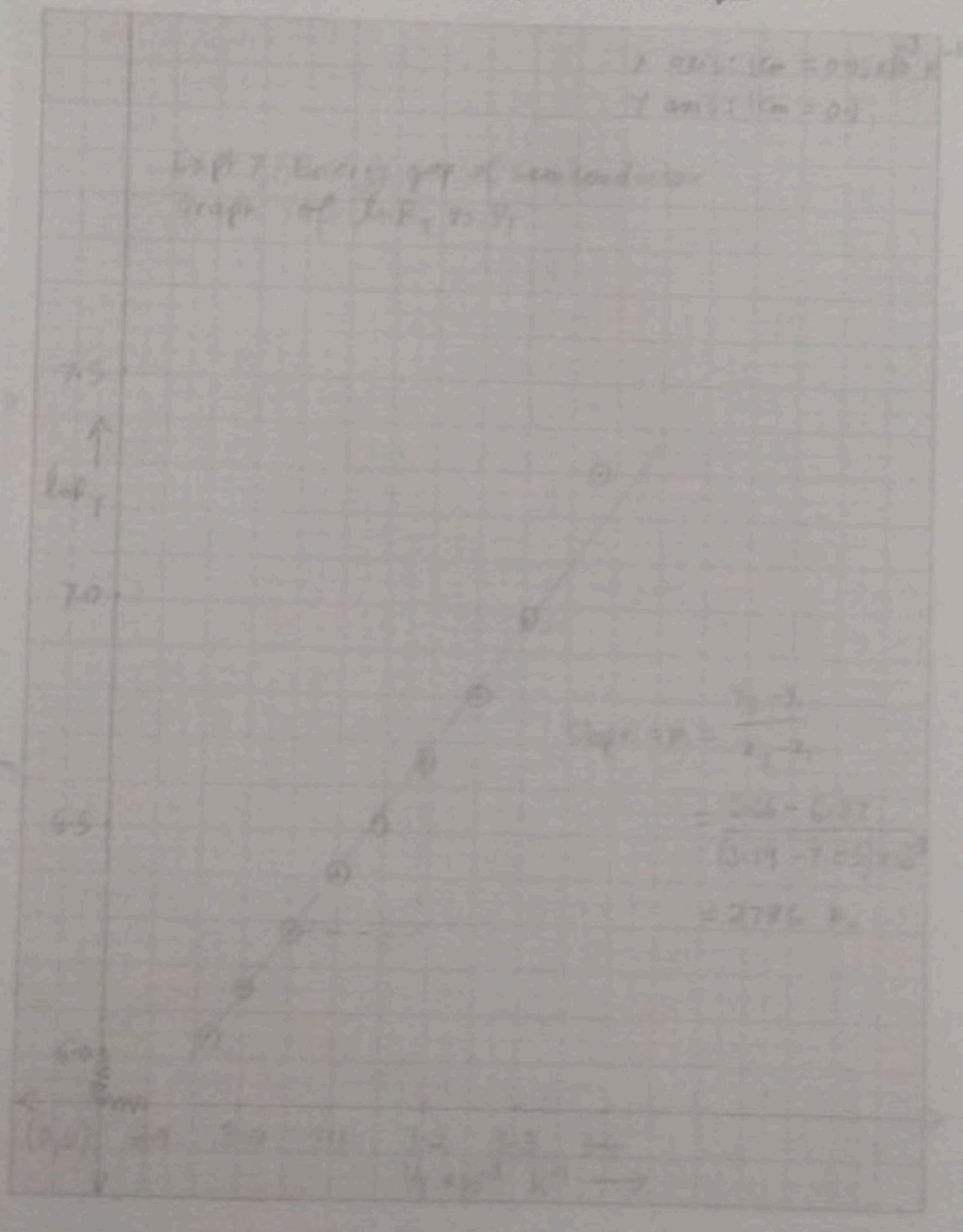
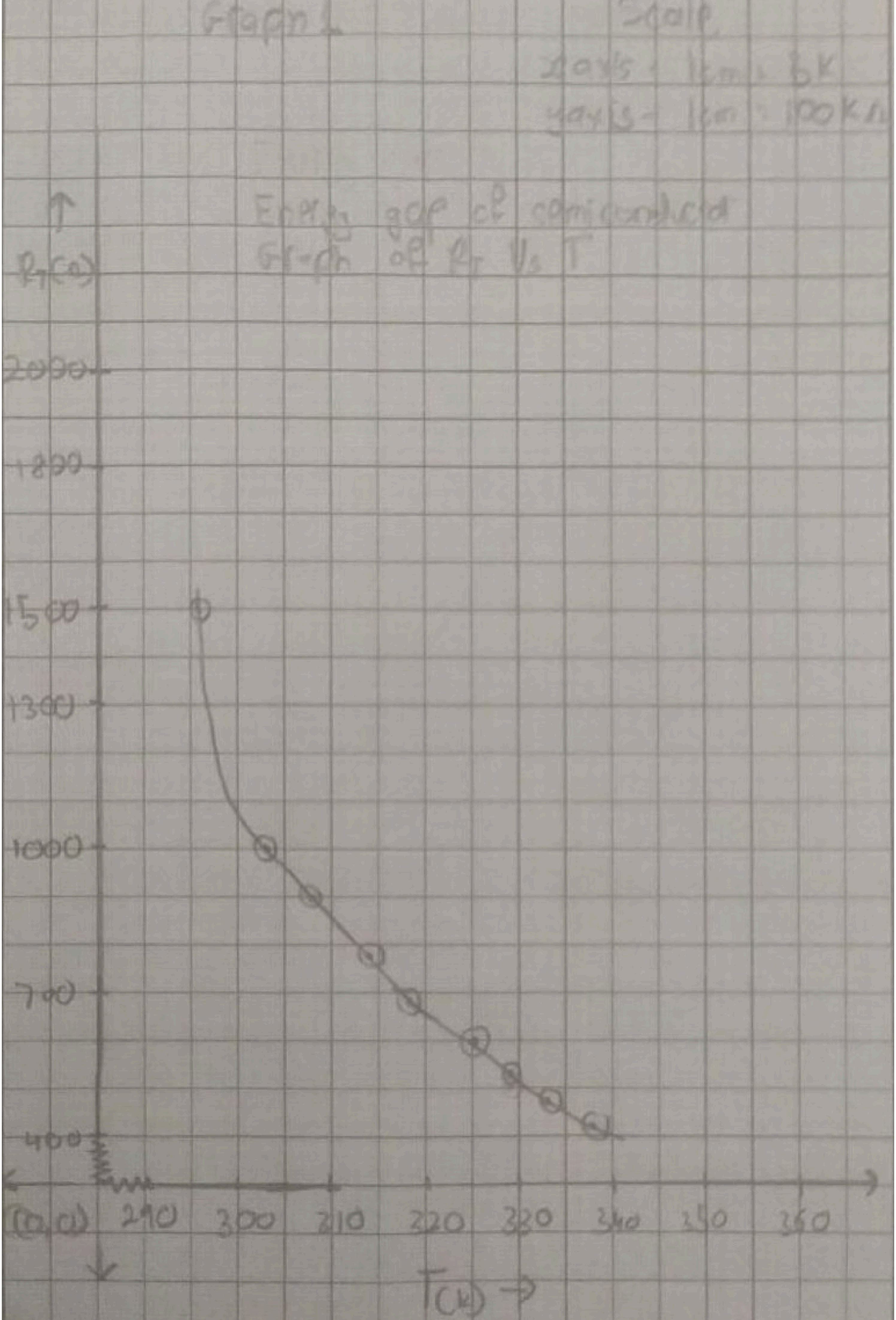
Model Graph-II for Expt. 6, Energy Gap of Semiconductors

This Model Graph is only for cross-checking your graph with its nature and style of presentation. As such, your Graph must be based on your own observations and calculations. Only formatting and presentation needs to be as per the Model Graph.




Graph 1
Scale
x axis - 1cm = 5K
y axis - 1cm = 100kΩ
Energy gap of semiconductor
Graph of R_T Vs T
R_T (Ω)
2000
1800
1500
1300
1000
700
400
(0,0)
290
300
310
320
330
340
350
360
T(K)

Graph-2

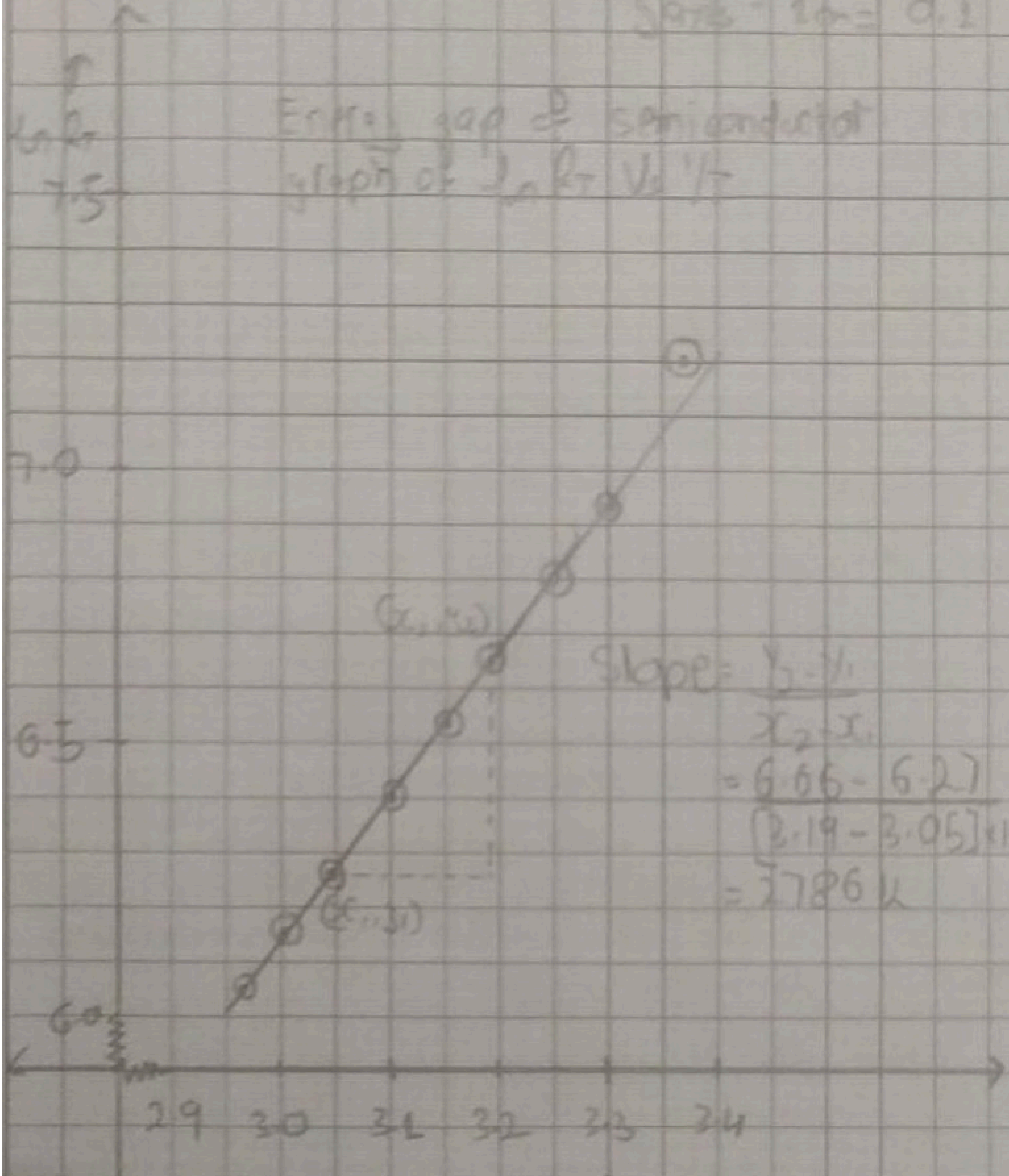
Scale

x axis - 1cm = 0.05×10^{-3}

y axis - 1cm = 0.1

Energy gap of semiconductor

graph of $\ln R_T$ Vs $1/T$



$$\text{Slope} = \frac{y_2 - y_1}{x_2 - x_1}$$

$$= \frac{6.66 - 6.27}{[3.19 - 3.05] \times 10^{-3}}$$

$$= 2786\ K$$

Viva Voce

1. Mention the energy gaps of as many semiconductors (elemental as well as compound) as known to you.
2. Why energy gap is treated as a significant property of semiconductor? Enlist the applications of semiconductors due to their typical band gaps
3. Why band gap is also called as forbidden gap?
4. The energy levels in the band gap are forbidden/not allowed for the electrons. Why?
5. Why does the resistivity of a semiconductor decrease with temperature?
6. The resistivity of semiconductors decreases with the temperature, while resistivity of metals increases with temperature. Why?
7. Diamond is transparent to the light, but silicon is not. Why?
8. The diodes made up of germanium and silicon emit heat when forward biased, but the diodes made up of compound semiconductors such as GaAs, CdS, GaP emit light when forward biased. Why?
9. What is "hole"? Why does it exist in semiconductors only and not in conductors and insulators?
10. Electrons migrate through conduction band while hole through valance band. Why can not it be opposite manner?
11. "Due to their relatively large band gap as compared to germanium, silicon devices have extra thermal stability and less leakage current than germanium" Comment
12. Define electron-volts
13. Why the semiconductors are the efficient absorbers and efficient emitters of light?

My Understanding of the Experiment

(Not exceeding 5 to 6 lines)

Energy gap is the gap between valance bond and conduction band and it decides the conductivity of the given material. The above experiment is one of the simplest methods to measure the energy gap of a given semiconductor. We calculate the energy gap ~~by~~ with the help of temperature and resistance of the given semiconductor.