Programme: **M. Sc.**	Year: I	Semester: VII
Subject: **Physics**		
Course Code: **B010705P**	Course Title: **General Lab**	

Course Outcomes (COs)

In this course the experiments are designed to give understanding of heat, magnetism, electricity and optics experiments.

1. By determining the velocity of ultrasonic waves in a liquid at different temperatures using Ultrasonic interferometer, students build understanding of Ultrasonics as a non-destructive testing tool for measuring mechanical and elastic properties of solid and liquid materials.
2. Optical Properties of Quartz experiment helps the students not only in understanding the behaviour of light passing through different axes of crystal but also in understanding birefringence and chirality of quartz crystal.
3. Determination of Stefan’s constant by electrical method helps students to clarify the concept of black body radiation.
4. Fabry-Perot Interferometer and Edser-Butler fringes experiments make students aware of different optical interference techniques being used in the field of Physics.
5. Fresnel’s Formula and Study of Total Internal Reflection experiments help the students to understand the refraction and reflection phenomena.
6. By Curie Temperature experiment and Quincke’s tube method experiment, students learn about magnetic properties of materials.
7. Iodine Absorption spectra experiment helps students learn about absorption spectra and associated parameters and properties of Iodine and thus other materials.

Credit: **4**	Core Compulsory
Max. Marks: 25+75	Min. Passing Marks:

Total No. of Lectures-Tutorials-Practical-Research (in hours per week): L-T-P-R: 0-0-8-0

List of Experiments

1. Concave Grating, Hg Source Arc
2. Optical Properties of Quartz
3. Cornu’s fringes
4. Fabry-Perot Interferometer
5. Edser-Butler Fringes
6. Fresnel’s Formula
7. Study of Total Internal Reflection
8. Curie Temperature
9. Quincke’s Tube method
10. Iodine Absorption Spectra
11. Stefan’s Constant
12. Ultrasonic Interferometer – Variation of velocity with temperature
13. Forbidden Energy Gap of semiconductors
14. Laser Intensity diffraction pattern of different objects
15. Fourier Analysis

Suggested Readings

1. The Feynman Lectures on Physics, Vol. II: The New Millennium Edition: Mainly Electromagnetism and Matte, Richard P. Feynman, Robert B. Leighton, Matthew Sands (Pearson Education India, 2012)
2. Optics, Ajoy Ghatak (McGraw Hill, 2020)
3. Fundamentals of Optics, Francis Jenkins, Harvey White (McGraw Hill Education, 2017)
4. Introduction to Modern Optics, Grant R. Fowles (Dover Publications Inc, 1990)

Course Prerequisites

Physics as a major subject in B. Sc.

Veer Bahadur Singh Purvanchal University

Instruction Manuals

For

M. Sc. (Physics)

General Laboratory Experiments

Department of Physics

Prof. Rajendra Singh (Rajju Bhaiya) Institute of
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Jaunpur UP 222003

Contents

Brewster's Angle

Objectives : To study polarization of light by using Malus's law and Brewster's angle.

Theory : An unpolarized wave vibrates in more than one direction, called an unpolarized light shown in Figure 1. A dichroic polarizer allows a certain polarized light passing through. The light becomes a polarized light with a beam intensity $I_m = 0.5\ I_0$. The beam intensity I_m is not depending on θ_m. Then, placed an analyzer at the angle θ. According to Malus's law the intensity I is expressed as

$$I = I_m \cos^2\theta,$$

where θ is an angle of transmitted axes of the polarizer and analyzer.

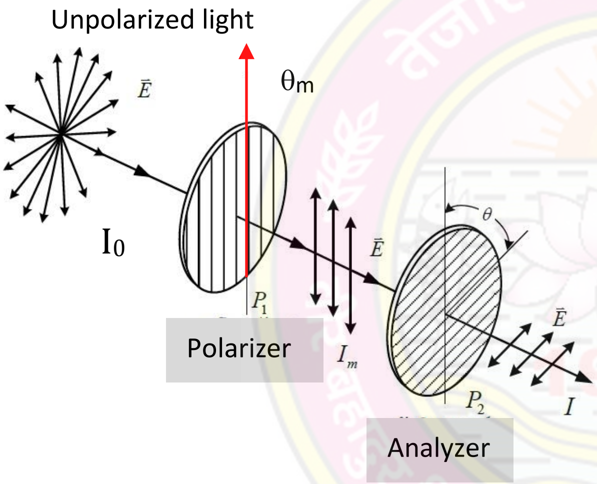


Figure 1 shows the polarization direction of light affected by transmitted axis of polarizer.

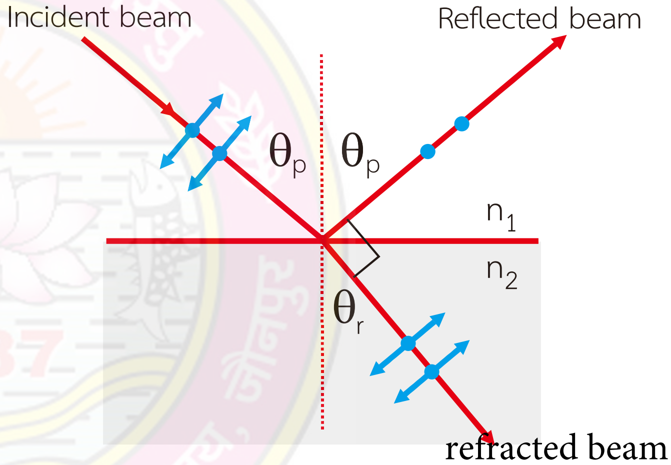


Figure 2 show reflected and refracted beams at the Brewster's angel.

Incidence light having polarizations both in-plane and perpendicular to the plane of incidence, unpolarized light, hits a boundary between two media.The light will partially reflect back to the first medium and refract into the second medium. At the incident angle θ_p , called Brewster's angle, there is no reflected light which has a polarization in the plane of incidence shown in Figure 2. The reflected beam becomes perfectly polarized beam.This Brewster's angle produces the 90^0angle between the reflected and refracted beams. The Brewster's angle is derived by the refractive index of both media as

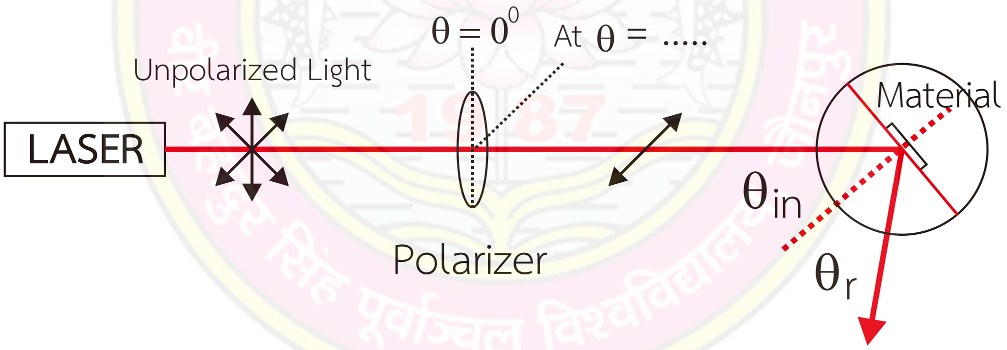
$$\tan\theta_P = \tan\theta_B = \frac{n_2}{n_1}$$

Experiment :

1. Study polarized light by using dichroic polarizer. Set up an experiment as in Figure 1. Then, observe the beam intensity I_m at various θ_m.
2. At certain value of θ_m, observe the θ giving $I = 0$.

θ_m	θ
0°	
20°	
40°	
60°	
80°	

3. Use a polarizer to make an incident beam having in-plane linear polarized light. Then, find the Brewster's angle of given samples.



Sample	Brewster's angle θ_B			The refractive index $n = \bar{n} \pm \delta n$
	# 1	# 2	# 3	
Glass				
Acrylic				

Note : Refractive index of $n_{air} = 1$, $n_{glass} = 1.52$ and $n_{acrylic} = 1.49$.

Fabry Perot Etalon

Objective of the experiment:
To determine the separation between the plates of a Fabry Perot Etalon.

etup Contains:-

(a). Spectrometer 6/7 inches.
(b). Fabry Perot Etalon.
(c). Sodium Vapour Lamp Transformer 35 Watt.
(d). Sodium Lamp Wooden Box.
(e). Philips Make Sodium Lamp 35 Watt.
(f). Spirit Level.

Formula Used:-

The Condition of maxima in Fabry – Perot Etalon is given by;

$$2d \cos\theta_n = n\lambda$$

$$d = n\lambda / 2\cos\theta_n$$

Where d = Separation between the plates.
n= Order of interference
θ= Angle of Incidence.
λ = Wavelength of Light.

Useful Theory:-

The S is a board source of monochromatic light & S is an adjustable slit. Etalon E1 & E2 is placed on turn table of an ordinary spectrometer. The Collimator, collimates the beam which suffers multiplies reflections in the air film of Etalon. The transmitted light is collected by telescope. When viewed through the telescope , circular fringes are observed .Sometimes the fringes are not clear . To obtain a clear fringe pattern, the following adjustment is made. The Spectrometer is turned in such a way that light directly from the source falls on the etalon. Collimator removed from the light path . An oily paper with a fine pin hole is placed in front of the source. Now circular fringes are clearly observed through telescope.

Fabry Perot Etalon

Procedure:-

(a). The Fringe pattern is brought at the centre of the field of view by adjusting the leveling screws provided at the base of the etalon.

(b). The turn table is fixed & the telescope is moved towards right of the fringe pattern. The ross wire of the telescope is made tangential to the first dark ring & the turn table reading is noted. By moving the telescope , the procedure is repeated for successive dark fringes till the clearly visible fringe is reached.

(c). Procedure no (b) is repeated towards the left side of fringe pattern.

(d). The Angular diameters 2θn of the rings are measured as shown below.

Observation Table For Reading;

Least count Spectrometer = ...

Table for plotting cos θn

No. of	Angular Diameter 2θn Left	Right.	Difference	Mean 2θn	θn	cosθn

Calculations & Result:-

A graph is plotted between cosθ_n as a function of n.

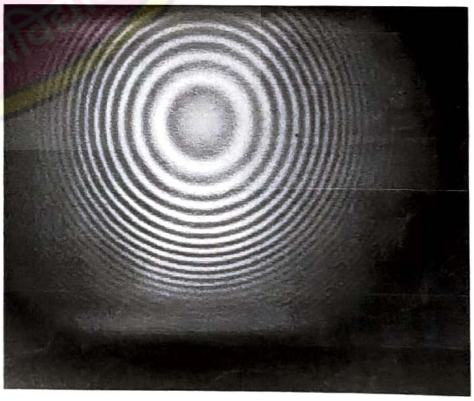
From Graph; n/cosθn = ...

d= Slope x λ/2=........................

λ= ....A°

Where standard value of λ = ...A°.

% Error...........



Output Fringes for Fabry Perot Etalon

Edser Buttler Experiment.

Objective:- To study Fringes separations using CDS prism & Edser Buttler arrangement .

Apparatus required

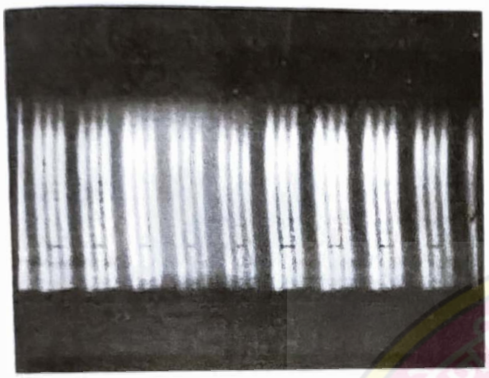
- Common Deviation spectrometer with CDS Prism.
- Edser Buttler arrangement assembly
- Platform for edser buttler.
- Mercury Light Source with wooden box and choke .
- Ordinary Light Source with stand.

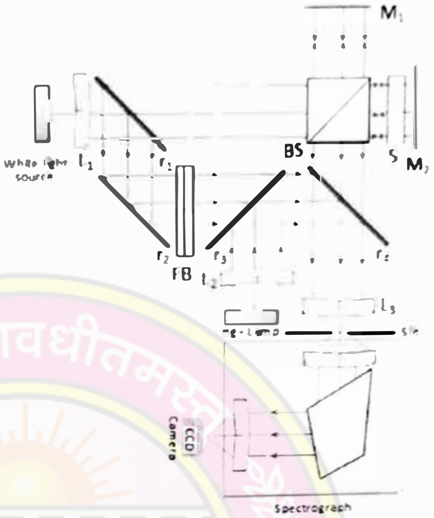
Formula Used:-

$$\mu t = \frac{m\lambda_1\lambda_2}{2(\lambda_1 - \lambda_2)}$$

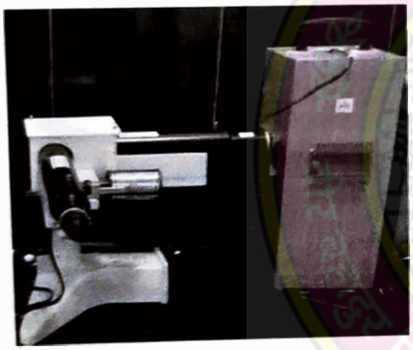
Where m= 1 .

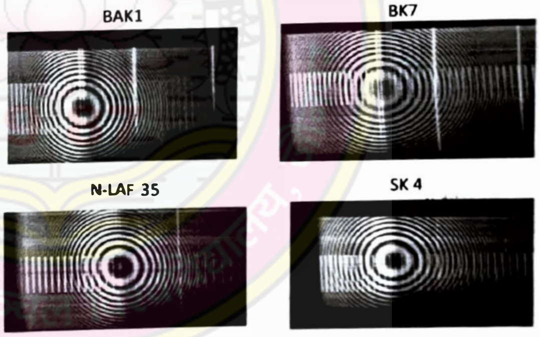
Useful Diagram:-





(a)





(b)

Absorption Spectrum Experiment

Object:- To study the absorption spectrum of iodine vapours and hence to determine the various spectroscopic constants of the iodine molecule.

Setup Contains:-

- Spectrometer with Dia 7 Inch and LC -30 Sec.
- Diffraction Grating (Good Quality).
- Ordinary Milky Lamp House with Stand.
- ½ Mtr Long Iodine Glass Tube Assembly with stand and mount.
- Power Supply for Heating Iodine Tube.
- Sample Crystal of Iodine.
- Connecting Cables.

(ii) Convergence Limit ($\bar{\nu}_{CL}$)

Convergence limit corresponds to the dissociation of the excited stat molecule. ***It can be defined as the vibrational energy of the excited molecule jus before dissociation into excited atoms.*** Above the convergence limit, absorption i continuous. It is very difficult to read the convergence limit directly from the spectrum. However it can be determined from the *Birge-Sponer extrapolation* which i shown in Fig (18.6). The convergence limit $\bar{\nu}_{cL}$ can be obtained by adding th vibronic-energy of an energy-level with any arbitrary quantum number $n' = b$ to th sum of the difference of energies $\Delta\bar{\nu}$ of all the subsequent levels above it. So,

$$\bar{\nu}_{CL} = \bar{\nu}_b + \sum_{n'=b}^{n_{CL}} \Delta\bar{\nu} \tag{18.22}$$

where $\bar{\nu}_b$ is the energy of the level corresponding to $n' = b$ and n_{CL} is the quantum number of the level corresponding to the convergence limit. It can be easily understood that the summation term in Eqn. 18.22 is the area of the ΔCDB in Fig. 18.6. Thus

$$\bar{\nu}_{cL} = \bar{\nu}_b + \text{Area of } \Delta CDB \tag{18.23}$$

6

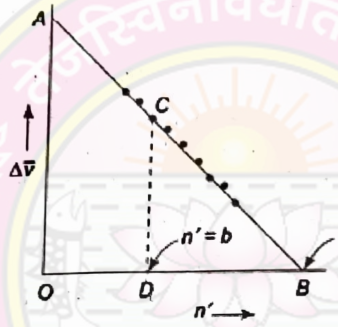


Fig. 18.6

(iii) Anharmonicity constant ($x_e'\, \bar{\nu}_e'$)

The anharmonicity constant gives the deviation of Morse potential from the harmonic oscillator potential and is responsible for the convergence of energy levels at higher quantum numbers n'. The anharmonicity constant can be determined from the Birge-Sponer plot using Eqn. (18.20) which gives, $x_e' \bar{\nu}_e' = m/2$, where m is the slope of the line AB in Fig. 18.6. So

$$x_e' \bar{\nu}_e' = \frac{CD}{2DB}$$

(iv) Dissociation energies (D_0'', D_0')

The dissociation energy of the ground electronic state (D_0'') is the energy required to dissociate the molecule in the ground state into atoms. As can be seen from Fig. (18.5), it is the energy required to raise a molecule from $n'' = 0$ to the level corresponding to dissociation. It is related to the convergence limit $\bar{\nu}_{CL}$ and the energy of atomic excitation X by the relation.

$$D_0'' = \bar{\nu}_{CL} - X \tag{18.24}$$

The dissociation energy of the excited electronic state (D'_o) is the energy required to dissociate the molecule in the excited state into atoms. It is the energy required to raise the molecule from $n' = 0$ to $n' = n_{CL}$ and can be determined by summing up all the energy differences between the successive levels starting from $n' = 0$ to $n' = n_{CL}$.

$$D'_0 = \sum_{n'=0}^{n_{CL}} \Delta\bar{\nu}$$

or $$D'_0 = \text{Area of } \Delta AOB \text{ in the Birge-Sponer Plot (Fig. 18.6)}$$

As the molecule is more stable in the ground state, the dissociation energy of the ground electronic state is expected to be more than the dissociation energy of the excited electronic state i.e., $D''_0 > D'_0$.

(v) Dissociation energies (D''_e and D'_e)

D''_e and D'_e are measured from the bottom of the respective potential energy well in contrast to D''_0 and D'_0 which are measured from the ground (lowest) level of the respective electronic state. The two are related by the Eqn,

$$D_e = D_0 + \bar{\nu}_e/2 \tag{18.25}$$

(vi) The Band gap ($\bar{\nu}_{00}$)

The Band gap energy $\bar{\nu}_{00}$ is defined as the energy required for the transition from the ground level of the ground electronic state ($n'' = 0$) to the ground level of the first excited electronic state ($n' = 0$). It corresponds to the line with lowest wave number i.e. $\bar{\nu}_{min}$, in the absorption spectrum. The band-gap is related to the convergence limit by the relation,

$$\bar{\nu}_{00} = \bar{\nu}_{CL} - D'_0 \tag{18.26}$$

The band gap energy for iodine molecule is 15705 cm^{-1} or 1.95 eV.

Experiment 18.2: To study the absorption spectrum of iodine vapours and hence to determine the various spectroscopic constants of the iodine molecule.

Apparatus: Iodine tube, a power supply, a steel bench with mounts to hold the iodine tube on the bench, a straight filament lamp, diffraction grating (with 15000 lines per inch), spectrometer and iodine crystals.

Theory: In this experiment, iodine molecules in gaseous form are excited by a visible continuous radiation from a high power lamp from their ground electronic state ($n'' = 0$) to various vibrational energy levels of the excited electronic state ($n' = 0, 1, 2, \ldots$). The absorption spectrum is a continuous spectrum crossed by a series of dark lines. There are several weak lines within these dark lines originating due to few transitions to the rotational energy levels. However, these lines are very weak and are not resolved. As a result, the absorption spectrum looks like a series of bands with dark 'band heads'' where the intensity changes abruptly.

The set-up for the experiment is shown in Fig. 18.7. Light from the lamp is first collimated by a lens on one-end of a one-metre long glass tube. The tube has a small inlet with rubber stopper to introduce iodine crystals and can be initially heated by a power supply to vapourise the iodine crystals. Light coming out from the plane glass plate end of the iodine vapour tube passes through the collimator and is incident on the diffraction grating. The diffracted light is viewed from the telescope of the spectrometer. The angles of diffraction are measured for the dark lines or the band-heads, where the intensit changes abruptly. The wavelengths corresponding to these lines with vibrational quantun number $n' = 0, 1, 2, \ldots$ can then be measured by using the relation,

$$\lambda = (a + b) \sin \theta \qquad (i$$

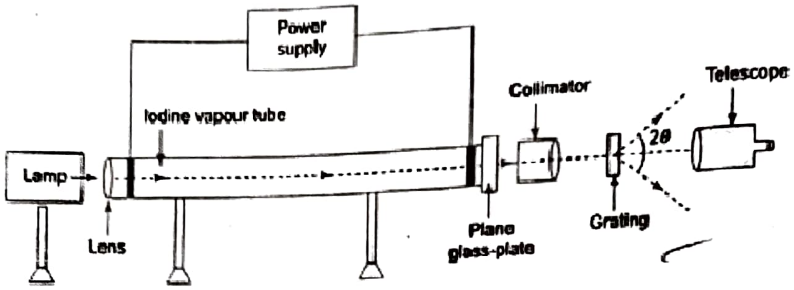


Fig. 18.7

where θ is the angle of diffraction, $(a + b)$ is the grating-constant and the order of spectrum is one. The wavelengths are converted to the wavenumbers $\bar{\nu}$ by using the relation $\bar{\nu} = 1/\lambda$. If now, the difference of the wavenumbers $\Delta\bar{\nu}$ is plotted along y-axis against the respective quantum numbers n' along x-axis, one obtains the ***Birge-sponer plot*** (Fig 18.6). As discussed earlier, the plot gives a straight line with negative slope m and C as the y-intercept.

The ***anharmonicity constant*** $x'_e\,\bar{\nu}'_e$ can be determined as

$$x_e\,\bar{\nu}_e = m/2 \qquad (ii)$$

The ***convergence limit*** $\bar{\nu}_{CL}$ can be obtained from the Birge-Sponer extrapolation as described earlier,

$$\bar{\nu}_{CL} = \bar{\nu}_b + \sum_{n'=0}^{n_{CL}} \Delta\bar{\nu} \qquad (iii)$$

where the summation term is the area of the triangle CDB in Fig. (18.6), $\bar{\nu}_b$ is the energy (in cm^{-1}) corresponding to any arbitrary quantum number $n' = b$ and n_{CL} is the value of n' where the straight line in the Birge-Sponer plot cuts the x-axis (See Fig. 18.6).

The ***dissociation energy*** D'_0 of the excited state is the sum of the $\Delta\bar{\nu}$ terms from $n' = 0$ to $n' = n_{CL}$ or the total area under the straight line in the Birge-Sponer plot from $n' = 0$ to $n' = n_{CL}$.

or
$$D'_0 = \sum_{n'=0}^{n_{CL}} \Delta\bar{\nu} \qquad (iv)$$

or
$$D'_0 = \text{Area of } \Delta AOB \text{ in Fig. (18.6)} \qquad (v)$$

In the absorption spectrum of iodine, the lines corresponding to a few initial quantum numbers are not visible due to the displacement of the excited electronic state towards right w.r.t the ground electronic state. So the first visible line does not actually correspond to $n' = 0$ and hence quantum number $n' = 0$ is arbitrarily assigned to the first line whichever is visible. In such a case, a correction term has to be applied to the dimensions of the ΔAOB which is done with the help of standard lines of iodine given in table-I in the following way:

Table-I gives the wavelengths of some standard lines of iodine with their respective quantum numbers.

Table-I Some standard lines for I_2 ($n'' = 0$)

Quantum No. n'	*Wavelength* λ *(nm)*
17	567.79
25	545.82
26	543.47
27	541.18
28	538.99
29	536.87

If the wavelength of a line with an assigned quantum number $n' = i$ matches with that of a standard line with quantum number j in Table-I, then the corrected magnitudes of OA and OB in ΔAOB in Fig. 18.6 are,

$$OA_{\text{corr}} = OA + m(j - i) \qquad (vi)$$

and

$$OB_{\text{corr}} = OB + (j - i) \qquad (vii)$$

Here, m is the slope of the line AB. The dissociation energy D_o' of the excited state is thus given as,

$$D'_0 = \frac{1}{2} \times OA_{\text{corr}} \times OB_{\text{corr}} \qquad (viii)$$

The ***dissociation energy*** D_0'' of the ground state can simply be determined using Eqn. (18.24), i.e.,

$$D_0'' = \bar{\nu}_{CL} - X \qquad (ix)$$

Here, the energy of atomic excitation, $X = 7598\ \text{cm}^{-1}$ for iodine. The *band-gap* $\bar{\nu}_{00}$ can be obtained using Eqn. (18.26), i.e.,

$$\bar{\nu}_{00} = \bar{\nu}_{CL} - D_0' \qquad (x)$$

From Eqns. (18.18) and (18.19), the intercept of the straight line AB in the Brige-Sponer plot on y-axis is given as, $C = \bar{\nu}_e' - 2x_e' \bar{\nu}_e'$

The ***fundamental vibrational energy*** $\bar{\nu}_e'$ can thus be obtained as,

$$\bar{\nu}_e' = 2x_e' \bar{\nu}_e' + C$$

or

$$\bar{\nu}_e' = m + OA_{\text{corr}} \qquad (xi)$$

where, m is the slope of the line AB and $C = OA_{\text{corr}}$.

Once $\bar{\nu}_e'$ and D_0' are known, the ***dissociation energy*** D_e' can be determined as,

$$D_e' = D_0' + \frac{\bar{\nu}_e'}{2} \qquad (xii)$$

Thus, all the spectroscopic constants of iodine molecule, *viz*, $\bar{\nu}_{CL}$, $\bar{\nu}_{00}$, D_0', D_0'', D_e', $\bar{\nu}_e'$ and $x_e' \bar{\nu}_e'$ can be determined.

Procedure

1. **Set-up** the spectrometer. Focus the cross-wire by moving the eye-piece in or out.

2. Place the diffraction grating on the prism-table normal to the incident light.
3. Place the iodine-tube on the steel bench on the mounts provided for holding it. Keep the end of the tube with a double convex lens towards the lamp and the other end having a plane glass-plate towards the slit of the collimator of the spectrometer.
4. Remove the rubber stopper on the tube and put a few iodine crystals in it.
5. Heat the tube with the help of the power supply. Apply 30 volts initially for vapourising the iodine and then reduce the voltage to 20 V if working in winters or switch-off the power-supply if working in summers.
6. Switch on the lamp and observe the first order absorption spectrum through the telescope. Adjust the slit width so as to get sharp bands with 'band-heads' or dark lines where the intensity of light changes abruptly. First, note the direct slit reading in both the verniers. Rotate the telescope towards right and note the reading in both the verniers setting the cross-wire on successive dark lines*. Bring the telescope towards left of the direct slit reading and repeat the process for the same lines.

   Note: *Take about 10-15 readings in the neighbourhood of the wavelength 541.2 nm which is a standard intense line for iodine. Take readings only in the wavelength range 510 nm – 570 nm which corresponds to the green region of the spectrum.**
7. Find the difference between the corresponding readings. This gives 2θ for each line. Find the angle of diffraction θ for each line and calculate the respective wavelengths using the relation $\lambda = (a + b) \sin\theta$ for first order.
8. Assign a quantum number $n' = 0, 1, 2, \cdots 14$ to the fifteen squential lines keeping in mind that the wavelength decreases as n' increases. Tabulate the quantum numbers and the respective wavelengths. Convert the wavelengths into the wavenumbers $\bar{\nu}$ in cm^{-1}.
9. Calculate $\Delta\bar{\nu}$, the energy difference between the lines corresponding to the successive quantum numbers.
10. Make a Birge-Sponer plot by plotting $\Delta\bar{\nu}$ along y-axis and n' along x-axis. Here n' for a given $\Delta\bar{\nu}$ is the lower value of the two quantum numbers. Extrapolate the straight line obtained, to cut the x and y axes.

Observations

Least count of the spectrometer = ...

Number of lines per inch on the grating = 15000

$$\text{Number of lines per cm} = \frac{15000}{2.54}$$

$$\text{Grating element, } (a + b) = \frac{2.54}{15000} = \ldots \text{ cm}$$

Order of Spectrum = 1

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*Remember that the observations are to be taken for lines in the green region of the spectrum. If the spectrum is mostly in red region, it indicates that the iodine-tube has been over-heated. In that case, switch-off the power supply and let the iodine tube cool-down. Wait till the spectrum appears in the green region and then take the observations.

S.No.	Quantum no. n'	Telescope on				Difference 2θ		Mean 2θ (deg.)	θ (deg.)	$\lambda = (a + b) \sin \theta$ (cm)
		Left		Right						
		V_1	V_2	V_1	V_2	V_1	V_2			
1	0									
2	1									
3	.									
.	.									|
.	.									decreasing
.	.									↓
.	.									
15	14									

For Birge-Sponer Plot

S.No.	Quantum number n'	Wavelength λ (cm)	Wavenumber $\bar{\nu}$ (cm^{-1})	$\Delta\bar{\nu}$ (cm^{-1})
1				
2				
3				
.				
.				
.				

Calculations

Do all the calculations from the $\Delta\bar{\nu}$ vs. n' graph or the *Birge-Sponer plot* which would be like the one shown in Fig. (18.6)

(i) ***The convergence limit,*** $\bar{\nu}_{CL} = \bar{\nu}_b$ + Area of ΔCDB

$$= \bar{\nu}_b + \left(\frac{1}{2} \times CD \times DB\right)$$

$$= \cdots \text{ cm}^{-1}$$

Here, b is any value of n' chosen arbitrarily.

(ii) ***The anharmonicity constant,*** $x'_e\ \bar{\nu}'_e$, $= \dfrac{m}{2} = \cdots$ cm^{-1}

where $m = \left(\dfrac{CD}{DB}\right)$ is the slope of the straight line AB.

(iii) ***The dissociation energy of the ground state,***

$$D''_0 = \bar{\nu}_{CL} - 7598$$

$$= \cdots \text{ cm}^{-1}$$

(iv) ***The dissociation energy of the excited state,***

$$D'_0 = \frac{1}{2} \times OA_{\text{corr}} \times OB_{\text{corr}}$$

where $OA_{corr} = OA + m(j - i)$

and $OB_{corr} = OB + (j - i)$

Here i is the quantum number in the observation table for which the wavelength matches with that of a standard line (given in table-I) corresponding to the quantum number j. For example if, $n' = 10$ in the observation table has a wavelength matching with $n' = 27$ of the standard data, then $(j - i) = 17$.

(v) ***The band-gap*** $\bar{\nu}_{00} = \bar{\nu}_{CL} - D'_0$

$= \cdots \text{cm}^{-1}$

(vi) ***The fundamental vibrational energy,*** $\bar{\nu}'_e = m + OA_{corr}$

$= \cdots \text{cm}^{-1}$

(vii) ***The dissociation energy,*** $D'_e = D'_0 + \frac{\bar{\nu}'_e}{2}$

$= \cdots \text{cm}^{-1}$

Result

The absorption spectrum of iodine vapour is studied. The values of the various spectroscopic parameters obtained are tabulated below along with their respective standard values and the percentage error.

S.No.	*Parameter*	*Experimental value* (cm^{-1})	*Value from table* (cm^{-1})	*% Error*
1.	Convergence limit, $\bar{\nu}_{CL}$			
2.	Band-gap, $\bar{\nu}_{00}$			
3.	The dissociation energies: (a) ground-state, D''_0 (b) excited-state, (i) D'_0 (ii) D'_e			
4.	The anharmonicity constant, $x'_e\bar{\nu}'_e$			
5.	Fundamental vibrational energy $\bar{\nu}'_e$			

Note: *To give the result in eV, use the relation,* $1\ cm^{-1} = 12.4 \times 10^{-5}\ eV$.

Where Wavenumber = 2π/λ

MULTIFREQUENCY ULTRASONIC INTERFEROMETER

(FOR THE MEASUREMENT OF ULTRASONIC VELOCITY IN LIQUIDS)

1. WORKING PRINCIPLE

An Ultrasonic Interferometer is a simple and direct device to determine the ultrasonic velocity in liquids with a high degree of accuracy.

The principle used in the measurement of velocity (v) is based on the accurate determination of the wavelength (λ) in the medium. Ultrasonic waves of known frequency (f) are produced by a quartz crystal fixed at the bottom of the cell. These waves are reflected by a movable metallic plate kept parallel to the quartz crystal. If the separation between these two plates is exactly a whole multiple of the sound wavelength, standing waves are formed in the medium. This acoustic resonance gives rise to an electrical reaction on the generator driving the quartz crystal and the anode current of the generator becomes a maximum.

If the distance is now increased or decreased and the variation is exactly one half wavelength ($\lambda/2$) or multiple of it, anode current becomes maximum. From the knowledge of wavelength (λ) the velocity (v) can be obtained by the relation:

Velocity = Wavelength × Frequency

$$v = \lambda \times f$$

2. DESCRIPTION

The Ultrasonic Interferometer consists of the following parts:

a) The High Frequency Generator : One

b) The Measuring Cells: 11 nos

c) Base to hold the Cell

d) Shielded Co-ax Cable

a) The High Frequency Generator is designed to excite the quartz crystal fixed at the bottom of the measuring cell at its resonant frequency to generate ultrasonic waves in the experimental liquid filled in the " Measuring Cell ". A micrometer to observe the changes in current and two controls for the purpose of sensitivity regulation and initial adjustment of the micrometer are provided on the panel of the High Frequency Generator.

b) The Measuring Cell is specially designed double walled cell for maintaining the temperature of the liquid constant during the experiment. A fine micrometer screw has been provided at the top, which can lower or raise the reflector plate in the liquid in the liquid in the cell through a known distance. It has a quartz crystal fixed at its bottom.

3. ADJUSTMENTS OF ULTRASONIC INTERFEROMETER

For initial adjustment two knobs are provided on high frequency generator, one is marked with "ADJ" to adjust the position of the needle on the Ammeter and the knob marked "GAIN" is used to increase the sensitivity of the instrument for greater deflection, if desired.

The ammeter is used to notice the number of maximum deflections while micrometer is moved up and down in liquid.

4. PROCEDURE

1. Unscrew the knurled cap of cell and lift it away from double walled construction of the cell. In the middle portion of it pour experimental liquid and screw the knurled cap. *Wipe out excess liquid overflowing from the cell.*
2. Insert the cell in the heavy base socket and clamp it with the help of a screw provided on its side.
3. Connect the High Frequency Generator with cell by co-axial cable provided with the instrument. *In Multifrequency Ultrasonic Interferometer Model M-84, frequency selector knob should be positioned at desired frequency (same frequency as that of liquid cell chosen).*
4. Move the micrometer slowly in either clockwise or anticlockwise direction till the anode current on the ammeter on the High Frequency Generator shows a maximum or minimum. If needle is

going out of scale, adjust the deflection within scale using "Adj" and "GAIN" knob.

5. Note the readings of micrometer corresponding to the maximum or minimum (whichever is sharper) in micro-ammeter. Take about 50 readings of consecutive maximum or minimum and tabulate them as shown below:

S. No.	Micrometer Reading corresponding to Maximum / Minimum (in mm)	Difference between consecutive maxima/minima (λ/2)
1	N1	
2	N2	N2 – N1
3	N3	N3 – N2
-		
-		
50	N50	N50 – N49

6. Take average of all the differences (λ/2)

7. Once the wavelength (λ) is known the velocity (v) in the liquid can be calculated with the help of the relation

$$v = \lambda \times f$$

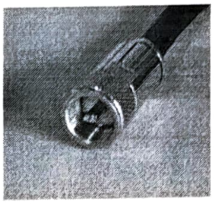
5. PRECAUTIONS:

A. Do not switch on the generator without filling the experimental liquid in the cell.

8. TROUBLE SHOOTING

A) *If needle is lying before 0 (zero) perform below mentioned check points*:

1. *Valve*: Open the top lid and check whether front tube (valve) is glowing. If valve is not glowing, switch off the main unit, remove the tube from its base and place it again. Now switch ON the unit and check whether tube is glowing. If not, please contact us for it's replacement.



2. *Coaxial Cable:* Check the resistance between the central pin of both the connectors with the help of the multimeter available in lab. Resistance should be less than 10 ohm. Similarly check the resistance between the outer sleeves.

3. *Liquid Cell*: Put the liquid cell upside down (without top reflector assembly) and check the resistance between the central hex metal portion and outer wall of the cell. It should show high resistance ≥ 5 M ohm.

4. *Tuning of Generator*: Assemble the setup as per the instruction manual. There are two screws on the back side of the high frequency generator. Switch ON the unit and rotate the screw A clockwise (from front direction) slightly (say around by 25 degree), observe the motion of the needle. If it comes within the scale, leave the screw position as it is and perform the experiment.

   If needle doesn't come within scale, rotate screw A anticlockwise approximately same as rotated earlier and leave it as it is. Now rotate the screw B in clockwise direction, needle should move to right. If not, please contact the manufacturer.

B) *If needle is lying beyong 100 (hundred) perform below mentioned check points*:

1. *Valve*: Open the top lid and check whether back tube (valve) is glowing. If valve is now glowing, switch off the main unit, remove the tube from its base and place it again. Now switch ON the unit and check whether tube is glowing. If not, please contact us for it's replacement.

2. *Tuning of Generator*: Assemble the setup as per the instruction manual. There are two screws on the back side of the high frequency generator. Switch ON the unit and rotate the screw B anticlockwise (from front direction) slightly (say around by 25 degree), observe the

motion of the needle. If it comes within the scale, leave the screw position as it is and perform the experiment.
If needle doesn't come within scale, rotate screw A clockwise approximately same as rotated earlier and leave it as it is. Now rotate the screw A anticlockwise, needle should move to right. If not, please contact the manufacturer.

1.

SAMPLE CALCULATIONS

Sample : Water

Frequency f = 2 MHz

Average $\lambda/2$ = 0.375 mm

Ultrasonic velocity in sample, v = $\lambda \times f$ = 1480 m/sec

Density of liquid ρ = 996.458 kg/m^3

Compressibility β_{ad} $= \dfrac{1}{\rho v^2}$

$$= \frac{1}{996.458 \times (1480)^2}$$

$$= 4.58 \times 10^{-10} \quad \text{N/m}^2$$

Note 1. **Above calculations are for 2 MHz Ultrasonic Interferometer. Check the frequency of Interferometer from Specifications and calculate velocity etc. as given above.**

2. You may take other liquids of your choice.

3. Compressibility is temperature dependent. We may provide suitable water bath on cost to vary the temperature for calculations of compressibility at different temperatures.

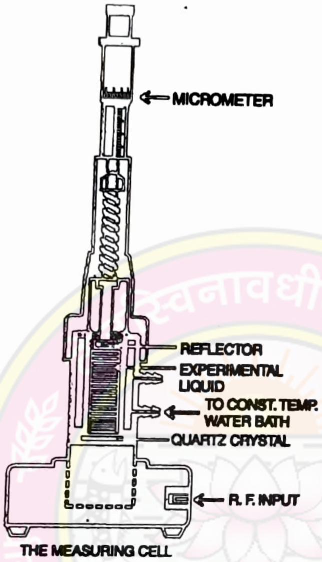


Fig 1. Cross-Section of the Liquid Cell

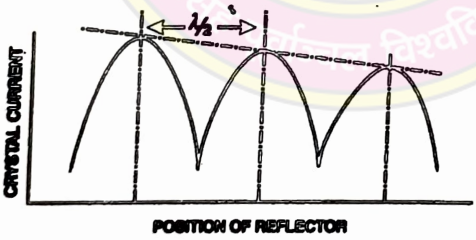


Fig 2. Position of Reflector vs Crystal Current

Note: Extra peaks in between minima and maxima may occurs due to a number of reasons, but they don't effect the value of λ/2.

WORKING MANUAL FOR LABORATORY CIRCULATING WATER BATH

➢ CONSTRUCTION:-

Double walled outer MS sheet duly powder coated. Inner S.Steel 34 grade fitted with glasswool Insulation.

➢ FITTED WITH:-

1. Lid:-Made of Stainless Steel 304 grade.
2. Circulation:-Provided through 1/20 HP for water circulation.
3. Control:-The Water Bath Temperature is controlled by Digital Temperature Controller Cum Indicator.

➢ CONTROL PANEL:-

Consist of:- 1.Digital Temperature Controller cum indicator.

2. Mains Indicator (Red).

3.Main Switch.

4. Switch for pump (at extreme right).

➢ INSTALLATION:-

1. First of all fill the water in the bath for necessary testing. It should be atleast 3" above the perforated SS Tray lying inside the bath. Maximum it should be 2" below the opening at the top.
2. Connect the Bath to 220 /250V, AC supply and switch it ON.
3. Press the red button (marked as set point) and set the temperature by knob(at the left of red button).
4. Green i.e. Temperature Indicator will begin to glow indicating loud ON & the unit will automatically control the Temperature of Bath.
5. Do not change the setting of T/P switch. If Temp. is not maintained at the desired temperature, keep T/P switch between 4 to 5 with the help of screw driver. After achieving temperature nearer to set point adjust T/P switch at low position (2 or 1) to avoid fluctuation in temperature.
6. Avoid any contamination in water. Preferably use double distilled water. If water is contaminated or not be used for few days, drain our the water.

TECHNICAL DETAIL:-

1. Temperature Range:- Ambient to 85 °C
2. Accuracy > 1 °C or better.
3. Temperature Sensor:-. PT 100 Thermocouple.
4. Maximum Load:- 500w.

FAULT FINDING:-

No Power from MAINS:-

1. Check Mains Switch.
2. Check SSR / Relay of Temperature Controller.

CONTROL FAILURE:-

1. Check the Relay / SSR of Temperature Controller.
2. Check the Working of Immersion at bottom fitted. Check the Working of Pump Stirrer.

PRECAUTION:-

1. Never operate the Equipment without water.
2. Operate the Equipment on 220 / 230V, AC Supply.
3. Avoid touching the Instrument with wet hands.

Actual measured Frequencies of Multifrequency Ultrasonic Interferometer M-84(Sl No 1819274)

Frequency	Actual Measured Frequency	Tolerance
1 MHz	0.9879 MHz	**± 0.0001 MHz**
2 MHz	2.0070MHz	**± 0.0001 MHz**
3 MHz	2.9799 MHz	**± 0.0001 MHz**
4 MHz	4.0193 MHz	**± 0.0001 MHz**
5 MHz	4.9209MHz	**± 0.0001 MHz**
6 MHz	5.8579 MHz	**± 0.0001 MHz**
7 MHz	6.8687 MHz	**± 0.0001 MHz**
8 MHz	7.9925MHz	**± 0.0001 MHz**
9 MHz	8.8209 MHz	**± 0.0001 MHz**
10 MHz	10.1212MHz	**± 0.0001 MHz**
12 MHz	11.9311MHz	**± 0.0001 MHz**

CURIE TEMPERATURE KIT

FOR FERROELECTRIC MATERIAL

INTRODUCTION

Ferroelectric materials exhibit electric dipole moment even in the absence of an external electric field. Ferroelectric materials are of theoretical and technical interest as they have unusually high and unusual temperature dependent values of the dielectric constant, the piezoelectric effects etc.

Ferroelectricity usually disappears above a certain temperature called the transition (or Curie) temperature. Knowledge of the Curie temperature and the variation of the dielectric constant below and above the Curie temperature is of interest to the physicists and the engineers.

Probably the best-known ferroelectric material is barium titanate $BaTiO_3$; it is a representative of the so-called oxygen octahedron group of ferroelectric materials. The reason for this name is that above the Curie temperature ($\theta = 120^{o}$ C), $BaTiO_3$ corresponds to the cubic structure presented in Fig. 1. In this structure, the Ba^{2+} ions occupy the corners of a cube; the centers of the cube faces are occupied by O^{2-} ions. The oxygen ions form an octahedron, at the center of which the small Ti^{4+} ion is located. The Ti^{4+} ion is considerably smaller than the space which is available inside the oxygen octahedron. It thus brings with it a high ionic polarizability for two reasons: (a) it has a charge of 4e and, (b) it can be displaced over a relatively large distance. This may be the explanation for the occurrence of spontaneous polarization in $BaTiO_3$.

There is an intimate relationship between the ferroelectric properties and the atomic arrangement in ferroelectric materials. Above 120^{O} C, $BaTiO_3$ has the cubic structure indicated in Fig. 1. When the temperature is lowered through the critical temperature of 120^{O} C, the material becomes spontaneously polarized and at the same time the structure changes. The direction of spontaneous polarization may lie along any of the cube edges, giving total 6 possible directions for the spontaneous polarization. Along the direction of spontaneous polarization of a given domain, the material expands, whereas perpendicular to the polarization direction it contracts. Thus, the material is no longer cubic, but corresponds to a so-called tetragonal structure.

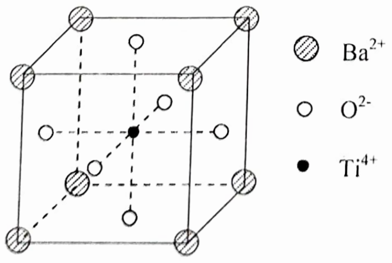


FIGURE 1

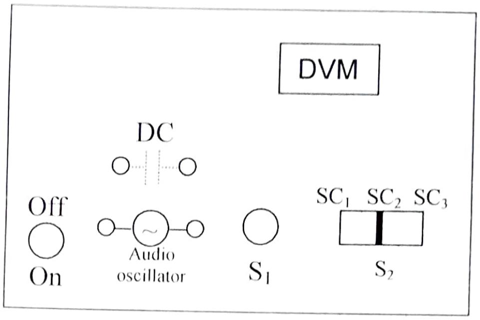
FRONT PANEL DESCRIPTION:

Front panel comprises of

i) Digital Volt meter (DVM) to measure the voltage across the dielectric cell (DC) or standard capacitor (SC).

ii) Switch S_1 to select di-electric cell or standard capacitor.

iii) Switch S_2 to select one of the standard capacitors SC_1, SC_2 or SC_3.



DIELECTRIC CELL

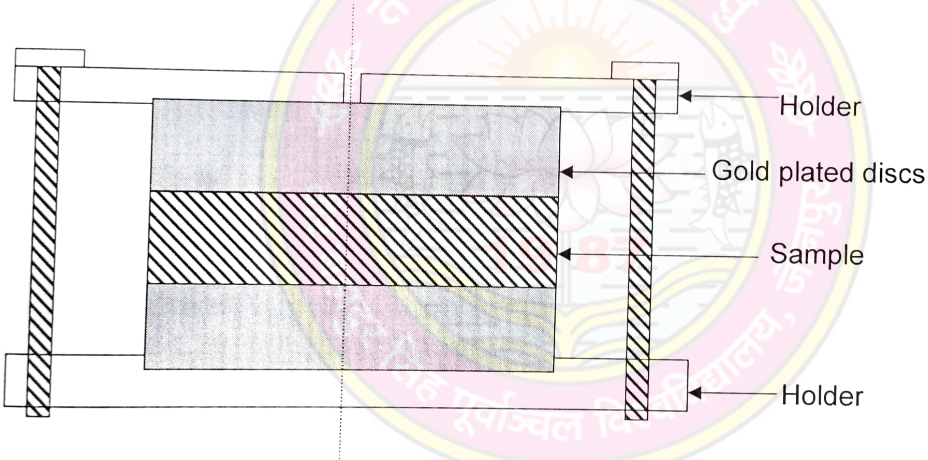


Figure 3

Dielectric cell consists of two 1" dia. Gold plated brass discs fitted in between the cell holder (Teflon plates). Keep the ferroelectric sample in between the metal plates and tighten the three screws such that sample fits in between the metal plates without any air gap.

IMPORTANT: Dielectric cell (metal discs) and sample should be coaxial. Do not apply extra pressure on screws as that may damage the sample.

THEORY

In this experiment an LC circuit is used to determine the capacitance of the dielectric cell and hence the dielectric constant. The circuit details are shown below:

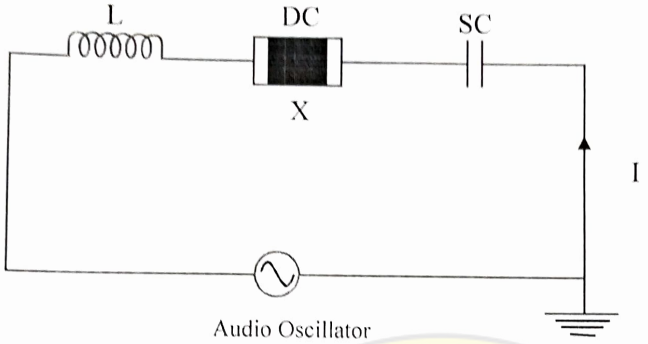


Figure 3

DC : Dielectric cell
SC : Standard capacitor
L : Inductance
X : Ferroelectric sample

The dielectric cell DC is placed in a tubular furnace which is fed by a variable ac power supply. By changing the voltage applied to the furnace, the temperature of the furnace can be varied. The temperature of the furnace can be measured by inserting a thermocouple in a hole (provided on one of the Teflon discs), so that it touches one of the capacitor (metal) plates.

The audio oscillator is incorporated inside the instrument. If C_{SC} and C_{DC} represents the capacitances of the standard capacitor and dielectric cell respectively and if V_{C1} and V_C are the voltages across SC and DC then.

$$\frac{V_{SC}}{I} = \frac{1}{\omega C_{SC}} \qquad \ldots\ldots \quad (1)$$

$$\Rightarrow \quad I = \omega . V_{SC} C_{SC} \qquad \ldots\ldots \quad (2)$$

The same current I passes through the dielectric cell.

$$\frac{V_{DC}}{I} = \frac{1}{\omega C_{DC}} \qquad \ldots\ldots \quad (3)$$

$$\Rightarrow \quad C_{DC} = \frac{I}{\omega V_{DC}} = \frac{\omega C_{SC} V_{SC}}{\omega V_{DC}} = \frac{C_{SC} V_{SC}}{V_{DC}} \qquad \ldots\ldots \quad (4)$$

By measuring V_{SC} & V_{DC} and using the value of C_{SC} we can determine the capacitance of the dielectric cell containing the sample.

If C_0 represents the capacitance of the dielectric cell without the crystal and the plates separated by air gap whose thickness is the same as the thickness of the crystal then C_0 is given by

$$C_0 = \frac{\epsilon_0 A}{d} = \frac{r^2}{36d} \text{ nf} \qquad \ldots\ldots\ (5)$$

where r represents the radius of the crystal and d represents its thickness

The dielectric constant of the crystal at any given temp. is given by

$$\epsilon_r = \frac{C}{C_0} \qquad \ldots\ldots\ (6)$$

CALIBRATION

1) Connect C.R.O. to the terminals provided on the front panel.

2) Switch ON the unit and put the voltage toggle switch towards DC. Adjust CAL. such that sinusoidal waveform appears on C.R.O. and V_{DC} voltage reads 3.5V approx.

3) Switch OFF the unit and disconnect C.R.O. from the main circuit.

PROCEDURE

1) Connect C.R.O. to the terminals provided on the front panel. If no sinusoidal waveform appears on C.R.O. then follow calibration procedure first.

2) Assemble the dielectric capacitor as shown in figure (3) and connect it to the main unit. (For convenience we had send the assembled dielectric cell.)

3) Connect hot air oven to the mains.

4) Place the dielectric cell DC in hot air oven and place the lid on the top. Insert the thermocouple to the hole provided on top Teflon disc of DC via hole provided on the insulating disc. Make sure that thermocouple touches the top metal disc.

5) Switch ON the unit.

6) Select SC1 among standard capacitors.

7) Measure the voltage (using digital voltmeter provided on front panel) across the dielectric cell DC, say V_{DC}, by throwing switch S_1 towards DC and measure voltage across standard capacitor SC, say V_{SC}, throwing switch S_1 towards SC, while heater is switched off (i.e. at room temperature).

$$V_T = V_{SC} + V_{DC}$$

8) Determine the dielectric constant of the crystal using the relation

$$\epsilon_r = \frac{C}{C_0} = \frac{C_{SC}\,V_{SC}}{V_{DC}\,C_o} \qquad \ldots\ldots\ (7)$$

where C_0 is calculated using relation (5)

9) Switch ON the oven and set the desired temperature (Follow instructions to set the temperature of the oven). Measure voltages V_{DC} at different temperatures at 10°C interval in the range RT-90°C. V_{SC} may be calculated as

$$V_{SC} = V_T - V_{DC}$$

NOTE: **Readings should be taken in ascending order only.**

10) Measure V_{DC} at 5°C interval upto 110°C and at intervals of 1 °C - 2 °C until you reach the maximum value of the dielectric constant (or C). Thereafter take few points.

NOTE: **Complete experiment may be carried out using SC_1 only. However, you may choose standard Capacitor SC1 for temperature upto 90°C and SC2 for temperature range 90°C to 110°C and SC3 for 110°C onwards.**

IMPORTANT : **DO NOT INCREASE THE TEMPERATURE OF OVEN BEYOND 200°C.**

1) Make the observation table as shown below:

EMPERATURE (^{o}C)	SC1		SC2		SC3		CALCULATED CAPACITANCE	ϵ_r
	V_{DC}	V_{SC}	V_{DC}	V_{SC}	V_{DC}	V_{SC}		

12) Calculate the dielectric constant (as explained in step 8).

13) Draw a graph of ϵ_r vs. T. At the transition the dielectric constant sharply rises and falls suddenly after the transition temperature and then decreases slowly beyond the transition temperature.

Fig. 5 shows the variations of dielectric constant of $BaTiO_3$ ceramic as a function of temperature (After W. B. Westphal, Laboratory for Insulation Research, M.I.T.). An examination of Figure 5 shows that it is difficult to make measurements at the Curie temperature due to sharp variation. Extension of the curves below and above the transition temperatures allows one to estimate the Curie temperature.

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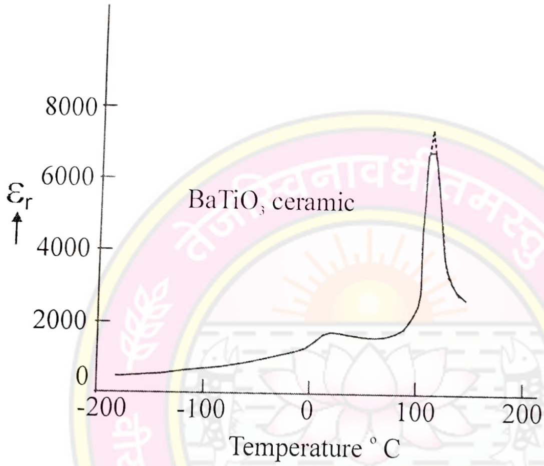


Figure 5

14) Determine the transition temperature (Curie Temperature) from the graph.

NOTE: As the measurements are repeated the nature of the curve remains same but it might not be possible to get the same values.

Component Values (S.No. 1920215)

L = 25 mH

SC_1 = 19 nf

SC_2 = 36 nf

SC_3 = 46 nf

Dimensions of Barium Titanate sample: r =10.5 mm d=1.5mm

INSTRUCTIONS TO SET THE DESIRED TEMPERATURE OF OVEN
(RT – 225 °C)

Note: Upper display (in red) shows current temperature reading and lower display (in green) shows set temperature.

1. Press up key (left most key on the controller cum indicator panel) or down key (middle key) to set the desired temperature.

2. Press enter (right most key) and hold for 1-2 sec.

Note : If after setting of desired temperature, enter key is not held for some time, it will go back to previous set value.

: If thermocouple is not connected to the Unit, upper display will show “open”.

IMPORTANT : DO NOT CHANGE THE SETTING PARAMETERS OF CONTROLLER CUM INDICATOR.

PARTS LIST

1. MAIN UNIT ☐
2. ASSEMBLED DIELECTRIC CELL WITH TEFLON HOLDER ☐
3. PID CONTROLLED OVEN WITH DIGITAL TEMP. INDICATOR & LID ☐
4. THERMOCOUPLE ☐
5. PATCH CORDS (2 nos) ☐
6. SPARE CRYSTAL ☐
7. INSTRUCTION MANUAL ☐

STEFAN'S CONSTANT KIT

INTRODUCTION

According to Stefan-Boltzmann's law the heat energy E_1 radiated per unit area per second by a body at T° Kelvin surrounded by another body at lower temperature T_0° Kelvin is directly proportional to the difference in fourth power of the absolute temperature i.e.

$$E_1 \propto (T^4 - T_o^4)$$

or

$$E_1 = \sigma \cdot (T^4 - T_o^4)\ .$$

where σ is called Stefan's Constant. Its standard value is 5.67×10^{-8} W m^{-2} K^{-4}. If the area of surface is A, then the head energy radiated from the surface becomes

$$E_1 = \sigma \cdot A \cdot (T^4 - T_o^4) \qquad \ldots(1)$$

THEORY

In this kit, the electric energy is used to heat up the two copper circular discs to a particular steady temperature T° K. The steady temperature is measured by thermometers placed in contact with the copper discs. As the steady temperature of the discs is larger than surrounding temperature T_o °K of the atmosphere, the disc will radiate heat energy which can be calculated by Stefans Boltzmann's Law or eqn. (1).

As the temperature of the discs reaches steady state, heat energy, E_1, radiated by discs per second will be equal to the electrical energy, E_2, consumed by heating element per second and is given by

$$E_2 = V \cdot I \qquad \ldots(2)$$

where V = Potential difference across the heating element and
I = Current flowing in the heating element

From equations (1) & (2)

$$V \cdot I = \sigma \cdot A \cdot (T^4 - T_o^4)$$

or $$\sigma = \frac{V \cdot I}{A \cdot (T^4 - T_o^4)} \qquad \ldots(3)$$

V and I can be measured with the help of Voltmeter and Ammeter installed in the kit. The steady temperature (T °K) of copper discs can be read from the thermometers and the area A of the disc can be calculated by measuring the radius of the disc.

By substituting the values of V, I, A, T and T_o in equation (3) one can calculate the Stefan's constant.

The features of the kit are:

i) There is practically no loss of heat energy from heating element by conduction, convection or radiation. Therefore, entire heat energy of the heating element is transferred to discs.

ii) As the efficiency of the heating element is nearly equal to one, almost entire electrical energy supplied to the heater will be converted into heat energy.

PROCEDURE

i) Connect the (sandwiched) heating element between black radiation discs to the Kit terminals marked "Black Plate" and Thermocouple to the terminals marked “SENSOR”.

ii) Switch ON the instrument.

iii) Note down the surrounding room temperature (T+273 °K) as displayed on the instrument.

iv) Adjust with the help of potentiometer P, the potential difference (V) and current (I) for heating element for desired value.

v) Tabulate the temperature reading as a function of time at an interval of 2 min each and plot the graph.

S. No.	Time (t) (min)	Temp (°C)	Temp (°K)
1	0		
2	2		
3	4		
-	-		

vi) From Plot observe the reading of the temperature till rate of rise of Temperature is near 0.5 °C/min indicating the nearly steady state condition (equilibrium).

vii) The several sets of observations are taken by varying the potential difference (V) & current (I) with the help of potentiometer.

viii) Calculate Stefan's constant for each value using relation (3) as indicated in sample calculation

ix) The area of the plate can be calculated by measuring the radius of the disc.

SAMPLE OBSERVATIONS

The area of the copper plates = 335 sq. cm.

S.No.	Voltage	Current	Room Temp. T °K	Steady stete Temp. T °K
1	50	0.58	296	401
2	55	0.63	296	408
3	60	0.67	296	417

SAMPLE CALCULATIONS

$$\sigma = \frac{V \cdot I}{A \cdot (T^4 - T_o^4)} \text{ W cm}^{-2} \text{ K}^{-4}$$

$$\sigma = \frac{V \cdot I \times 10^7}{A \cdot (T^4 - T_o^4)} \text{ ergs cm}^{-2} \text{ sec}^{-1} \text{ K}^{-4}$$

Thus substituting values from table :

1)
$$\sigma = \frac{50 \times 0.58 \times 10^7}{335 \times (401^4 - 296^4)}$$
$$= 4.9 \times 10^{-5} \text{ erg cm}^{-2} \text{ sec}^{-1} \text{ K}^{-4}$$

2)
$$\sigma = \frac{55 \times 0.63 \times 10^7}{335 \times (408^4 - 296^4)}$$
$$= 5.637 \times 10^{-5} \text{ erg cm}^{-2} \text{ sec}^{-1} \text{ K}^{-4}$$

3)
$$\sigma = \frac{60 \times 0.67 \times 10^7}{335 \times (417^4 - 296^4)}$$
$$= 5.4 \times 10^{-5} \text{ erg cm}^{-2} \text{ sec}^{-1} \text{ K}^{-4}$$

Average $\sigma = 5.3 \times 10^{-5} \text{ erg cm}^{-2} \text{ sec}^{-1} \text{ K}^{-4}$

Note: All above measurements and readings varies from instrument to instrument due to change in dimensions.

RESULT

The value of Stefan's constant, with the help of the experiment is

$$\sigma = 5.3 \times 10^{-5} \text{ ergs cm}^{-2} \text{ sec}^{-1} \text{ K}^{-4}$$

Standard Value $= 5.67 \times 10^{-5} \text{ ergs cm}^{-2} \text{ sec}^{-1} \text{ K}^{-4}$

Percentage error = 6.5%

Manufacturer's Notes

Area of copper plates for present setup = 343 sq.cm.

PRECAUTIONS

1. Black body should be connected to the main unit only in switched off condition.
2. Thermocouple lead should be connected as per the color coding (i.e. Red-Red, Black-Black).

PARTS LIST

1. MAIN UNIT ☐
2. HEATER PLATES WITH ATTACHED THERMOCOUPLE ☐
3. INSTRUCTION MANUAL ☐

Instruction Manual For Susceptibillity of FeCl3 By Quinck's Method

Apparatus:- An Electromagnet capable of producing magnetic Field upto 10K Gauss. A continuously variable DC Power supply with current range of 0-6 Amps., FeCl3 Solution. Quinck's Tube (Glass Tube), Wooden stand for Quick's Tube, Digital Gauss Meter with Hall sensor & Wooden Stand.

Definition:- The Magnetic Susceptibility K of a material corresponds to the ease with which a material can be magnetised using a given magnetic field intensity. So it may be defined as the ratio of intensity of magnetization 'I' Produced to the magentic field intensity ' H' so we may have K= I/H and since I corresponds to magnetic moment/unit volume , the susceptibility thus defined is also called Volume susceptibility.

D.C. Power Supply:- It as an low voltage high current power source for energising electromagnet with inbuilt meter 0-6 amp. Controlled by variable knob marked CONTROL to vari current Two terminals are provided for D.C Output.

Electromagnet :- It as an heavy duty variable electromagnet. The variation is made by sliding poles. The nearer the poles the more is magnetic strength. Adjustment in made by rotating two big knobs clock wise and anticlock wise.It can be upto 10K Gauss. for nearest distance of poles.

Gauss meter :- The Instruction manual are separately given.

Principle :- If a paramagnetic salt (like manganese chloride) or ferromagnetic salt (like ferric chloride) is put in a tube and placed between the poles of electromagnet then there is rise of liquid level. If the rise in liquid level is measured accurately, then the susceptibility of the solution can be found.

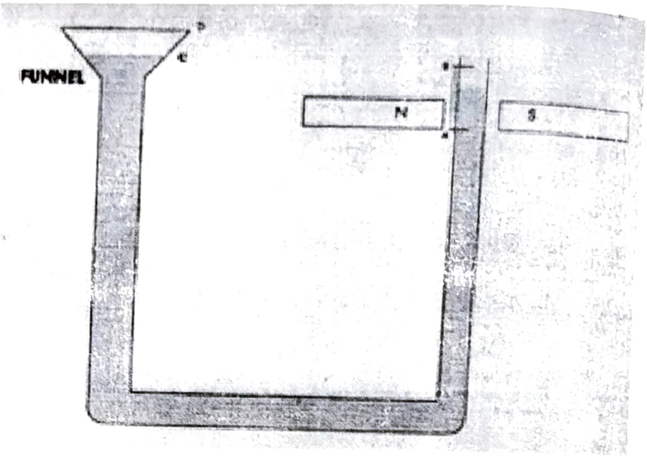
Theory :- As the magnetic field between the pole pieces varies along the vertical direction, so the force on the solution will be vertical.
Now the force on a substance of volume V which in situated in a non uniform magnetic field at a place where *H* is the magnetic field strength in given by.

$$F = \frac{1}{2}(K - K_0)\frac{d}{dx}(H^2 V)$$

Where k ---- magnetic susceptibility of the substance.
k_0 ---- susceptibility of the surrounding medium.

If the surrounding medium is air , then $k_0 = 0$

$$F = \frac{1}{2}(K)\frac{d}{dx}(H^2 V)$$



Let D be the level of solution in funnel and A that in the narrow tube before the application of the field. Let C and B be the new levels respectively with the application of the field. Let the rise in level in narrow tube corresponding to AB be denoted by ***h***.
Let a and a' be the cross sectional areas of the funnel and the tube respectively.

The level in funnel has to sink from D to C, so B will be at a level higher than the level of the liquid in the funnel.

Let d be the level to which liquid has sink in funnel, then

$$a'.d = a.h$$

$$d = \frac{a}{a'}.h$$

Now as ***h*** is the rise in level of the solution in a narrow tube and **d** the fall in level in the funnel the corrected height may be written as (1+a/a')h. This will correspond to the height of the liquid column supported by the forces due to magnetic field.

Let as ***h*** be the density of the solution and ***g*** the acceleration due to gravity then the weight of the column above the point **P** is given by-

$$\left(1+\frac{a}{a'}\right) hp.g.a \qquad \text{....... (2)}$$

Let us consider that at the section **P** the magnetic field is negligible. Let **x** be the vertical co-ordinate above P, then the force on a liquid element of volume ***a.dx***, above the point **P** is given by

$$dF = \frac{1}{2}K.\frac{d}{dx}(H^2\,a.dx) \qquad \text{..........(3) from equation 1}$$

The Force on the entire liquid above the point P is thereby given as

$$F = \tfrac{1}{2}K.a\int_0^{H1}\frac{d}{dx}H^2\,dx = \tfrac{1}{2}KaH_1^2$$

Where H - field intensity at upper level and this force balance the weight (1+a/a') h.p.g.a of the liquid column. So from eq.(2) and (4) we have.

$$\tfrac{1}{2}KaH_1^2 = \left(1+\frac{a}{a'}\right) hpga$$

If a << a' then a/a' may be neglected as compared to 1

$$\tfrac{1}{2} KaH_1^2 = h.\rho.g.a$$

$$K = 2\rho.g.\frac{h}{H_1^2} \text{ e.m.u./cm}^3$$

This corresponds to the volume susceptibility of solution.
The mass susceptibility x_s of the solution is given by

$$\chi_s = \frac{K}{\rho} = 2g\frac{h}{H_1^2} \text{ e.m.u /gm}$$

Now since susceptibility depends on the concentration of salt, we can study the variation of χ_s with concentration.

Let ***m*** be the mass of anhydrous $FeCl_3$ in solution per c.c., Then a straight line will be obtained in the graph between x_s and **m**. The straight line does not pass through origin but cuts.

The axis **m**=o at a finite (through negative) value of χ_s .It is because of the contribution of susceptibility of the solution due to water, which in other words mean that the numerical value of the intercept gives the mass susceptibility of water (χ_w).

Let x_c be the mass suscptibility of anhydrous crystals of anhydrous crystals of $FeCl_3$ then we have

$$\chi_s = m\,\chi_c + (1 - m)\,\chi_w$$

Let M be the molecular weight of anahydrous $FeCl_3$ then the moleclar susceptibility is given by-

$$\chi_m = M\chi_c$$

The molecules susceptibility is the sum of ionic molecules susceptibilities of Fe+++ and Cl -ions

$$\chi_M = \chi_{Fe} + 3\chi_{Cl}$$

Where $\chi_{Cl} = -25.1 \times 10^{-8}$ e.m.u. This expression can be used to find the molecular susceptibility of Fe+++ion.

The magnetic moment of Fe+++ion in terms of bohr magneton is given by

$$\mu\,\beta = 1 / [\beta(3kT\,\chi_{Fe} / N_0)^{1/2}]$$

Where β = (Bohar Magneton and has value equal to 9.27×10^{-21} e.m.u.)
K = Boltzman constant
N_0 =

1. **Fill a U-tube which is thoroughly cleaned with a solution of $FeCl_3$ in water containing 25gm of hydrated salt ($FeCl_3.6H_2O$) per 100 c.c. for the solution.**

2. Now insert the narrow limb of U-tube vertically between the pole pieces of the electromagnets and adjust the funnel limb so that when the magnet is energized the meniscus is i the central region of the uniform magnetic field. Illuminate the meniscus with an electric lam and view it through a travelling microscope or a cathetometer . Bring the horizontal cross wire of microscope on the meniscus and note the reading . Also note the corresponding current i the Ammeter.

3. Switch off the current and again bring the cross-wire on the meniscus and take reading .Note the fall in height h of the meniscus for a particular current. Repeat the experiment over different values of magnetising current. .

4. Repeat the experiment by changing the concentration of the solution.

Observation:- We are providing Digital Gauss / Flux Meter with Hall Sensor prob that can measure magnetic field intensity (H) in terms of gauss directly.

S.No	Current	Gauss/Flux MeterReading (H)

Mass Susceptibility of the solution is given by

$$\chi_s = 2.g.\frac{h}{H_1^2} = 2g\frac{PQ}{OQ}$$

Take similar observation for different amounts of hydrated salt in the same volume solution.

Calculate the concentration ***m*** and susceptibility χ_s s for each set .

B. For mass susceptibility of solution χ_s

Molecular weight of FeCl3,M = (56+3X3.5.5) = 162.5gm
Molecular weight Of hydrous salt = 162.5 + 6(2+16) = 270.5gm
Room teaperature (T) = ...K
Mass of weighing bottle = m_1g
Mass of Bottle + FeCl3 = $m_2$gm
Mass of FeCl3 = (m_2 - m_1)gm =20gm(say)
Volume of the solution = 100cc
Therefore Mass of hydrated salt /c.c = 0.20gm /c.c

Caluculation for conceritration ***m***

270.5 gm of $FeCl_3 . 6H_2O$ Contains 162.5 gm to $FeCl_3$
Therefore 0.20gm/c.c of $FeCl_3 . 6H_2O$ will contain = $\frac{162.5 \times 0.20}{270.5}$ gm/c.c

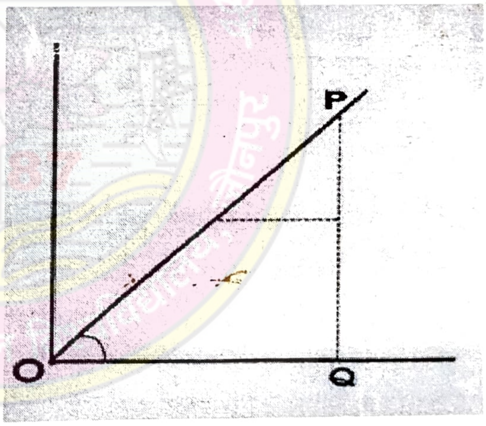
Concentration ***m*** $= \frac{162.5 \times 0.20}{270.5}$

= .... gm/c.c

S.no	Current I	Corresponding feild H From graph	H_1^2	Intial Position of meniscus (cm)	Final Position of meniscus (cm)	Fall in Height h(cm)

Plot a curve between H_1^2 and h,which will give a straight line from the graph.

$$\frac{h}{H_1^2} = \tan \alpha = \frac{PQ}{OQ}$$



$$\chi_{Fe} = \chi_{m-3} . \chi_{Cl}$$

$$= [\chi_{m-3} (-25 \times 10^{-6})]$$

= .... e.m.u.

Magnetic moment of Fe+++ion
Use the relation

$$\mu b = \frac{1}{\beta} / \frac{3\kappa T}{N_0} . \chi_{Fe}$$

Where $K = 1.3805 \times 10^{-23}$ jk
$N_0 = 6.0234 \times 10^{-23}$
$\beta = 9.27 \times 10^{-21}$ e.m.u.
T = ...^{0}K

Precautions:-

1. There should be no air Bubble in Quink's tube.
2. Choose only the prescribed values of magnetizing currents
3. Solution should be prepared carefully so that total salt is dissolved uniformly.

Sources of Error:-

1. Due to evaporation of water the results obtained are slightly less than the actual Values.
2. Due to non - uniformity of the narrow limb bore, error due to surface tension may Occur.
3. Since the bore is very narrow,so there may be deformation of the liquid in the tube due to application of magnetic field and so the rise or fall of the liquid meniscus may be read wrongly.

Advantage- In the case no correction for susceptibility of dust particles present in the solution is Required.

GAUSS METER/FLUX METER

INTRODUCTION:-

This instrument operates on the principle of Hall effect. A Conductor carrying current when placed in magnet field.e.m.f.develops in the direction perpendicular to both electric and magnetic field. .The magnitude of this e.m.f. is proportional to the magnetic field.When the current following through it is constant.

PROBE:-

The Probe is made of highly pure indium Arsenide Crystal and is encapsulated to a nonmagnetic sheet of 5mm*4mm*1mm(approx.)and is connected to a three feet cable. Aremovable cap is provided for protection of the probe.Do not use the probe at safe place Handle the probe carefully.it is very delicate.

RANGE:-

The instrument is provided with Two scale ranges of 2 k Gauss.20 K Gauss.

OPERATING INSTRUCTIONS

1 **To set up:-** Insert the four pin plug atthe end of the probe head in to the socket at the front side of the panel and switch ON the AC/ON switch.

2 **Set zero:-** Set the range select switch and adjust the zero through set zero control until the meter reads zero,the probe being at zero-field.This than normally holds for one range,readjuast for other range i.e.2k and 20k.

Digital Meter:- The measuring result are taken on 3.5 Digital meter.The display is direct in termsof Gausses.at range2k is measuring capability is 199.9 k gausses.and at range 20k,it read upto 19.9 K gausses.

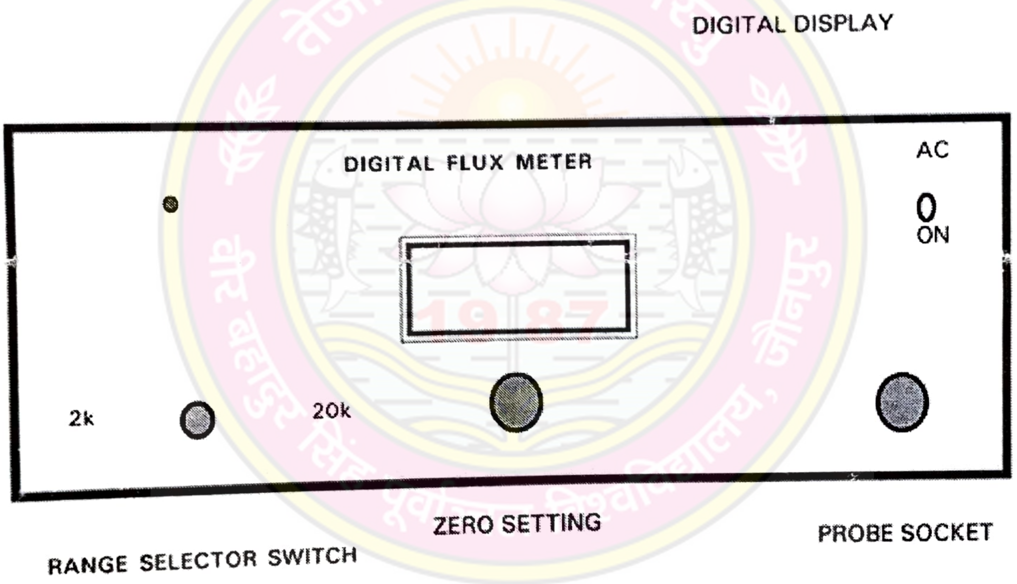
4 **Measurement:-** Plug probe in socket provided in front of instrument,be careful while plugging.the wide spaced pins should push in similar holes of socket. Plug mains lead in A.C. mains and ONthe switch,L.E.D.and display will glow.

Take select range.Rotate set knob till zero is displayed in meter.Place protective cap if possible with the flat face of the probe perpendicular to the direction offield. the said marked with the white dot facing the north pole. Rotate the probe and take it forward for maximum reading.The exac n ading is When probe tip is nearest to magnetic field.

CAUTION :-

The Hall Probe strip should be carefully handled.

FRONT PANEL



FORBIDDEN ENERGY BAND GAP KIT

I. INTRODUCTION

The $p-n$ junction is an important element of most electronic devices, from a simple diode to a transistor to a sophisticated integrated circuit. Therefore, understanding of the $p-n$ junction is essential to the study of more complicated semiconductor devices. The study of the band gap structure of semiconductors is also important because it is directly related to its electrical properties. In forward bias,the relation between voltage and temperature is found to be almost linear within a certain temperature range characteristic of the semiconductor. Two questions that may arise are the following.

(1) Why is the temperature-voltage relation almost linear knowing that a diode is highly nonlinear device?

(2) Can we extract any relevant information from the experimentally determined parameters "a" and "b" in the linear relation

$$T = aV + b? \qquad (1)$$

We will show that the linearity of Eq. (1) is a consequence of the constant current source usually employed in diode thermometers, and that we can obtain the band gap energy E_g from a knowledge of a and b.

II. THEORY

The current-voltage characteristic of a p-n junction can be described by the ideal diode equation

$$I = I_0[\exp(eV/kT) - 1] \qquad (2)$$

where I is the current through the diode, Io is the maximum current for a large reverse bias voltage (formally $V \to -\infty$), e is the electron charge, V is the voltage across the diode, k is Boltzmann's constant, and T is the absolute temperature. The following analysis is based on Eq. (2), and we assume that it describes accurately the $I-V$ characteristics of a $p-n$ junction.

We next introduce some simplifications. First, we will restrict ourselves to regions where we can neglect the number 1 in Eq. (2). If we take a forward bias of 0.1 V at room temperature, we obtain $eV/kT = 0.1/0.025 = 4$, and $\exp(eV/kT) \approx 55$ So, this approximation can be generally justified in the regions of interest.

Second, we need an expression for the reverse current I_0, which depends strongly on temperature, but not on V. It can be shown that I_0 is proportional to the Boltzmann factor $\exp(-E_g / kT)$ and to $T^{3+\gamma/2}$, where γ is a constant. We may thus write

$$I_0 = AT^{3+\gamma/2}\exp(-E_g / kT). \qquad (3)$$

We can neglect the $T^{3+\gamma/2}$ dependence of I_0 in comparison to the exponential dependence on T and can treat $B = A\,T^{3+\gamma/2}$, as almost constant. Therefore,

$$I_0 = B\exp(-E_g / kT) \qquad (4)$$

If we combine Eqs. (2) and (4), and neglect 1 in Eq. (2), we obtain

$$I = B\exp(-E_g / kT + eV / kT). \qquad (5)$$

Experimentally we maintain the current I as a constant, and we may thus write

$$C = eV / kT - E_g / kT, \qquad (6)$$

where $C=ln(I/B)$. if we rewrite Eq. (6), we have

$$T = (e / kC)V - E_g / kC, \qquad (7)$$

which is the linear relation, provided that E_g is constant. If we compare Eqs. (7) and (1), we see that $a = e / kC$ and $b = -E_g / kC$. We divide b by a and obtain

$$E_g = -(b / a). \qquad (8)$$

Equation (8) relates the band gap energy E_g to the experimentally determined values of the parameters a and b in Eq. (1).

III. PROCEDURE

1. Switch ON the main supply.
2. Connect the diode (or LED) under investigation to jack marked "Sample".
3. Adjust the current through the diode for a convenient value, say 70 μA by varying the potentiometer TTP (10 turn potentiometer).
4. Place the silicon oil filled beaker in Oven. Switch ON the Oven (with energy regulator knob at 100 mark) and heat the oil upto 150°C . Measure the temperature using the thermocouple.

NOTE: Graduations on Energy regulator knob does not indicate the temperature, they simply indicates the ON / OFF time of the heater.

5. Now place the diode in the oil and take the voltage across the diode as a function of temperature . Allow Oil to cool and take at least 10 measurements in the range 25°-120°C. **At each temperature adjust the diode current to the chosen value by adjusting the potentiometer.**
6. Remove the diode from the oil bath and place it in ice (if possible) and take a reading.
7. Tabulate the readings as shown below in table I.

Table : I

Current = 70 μA

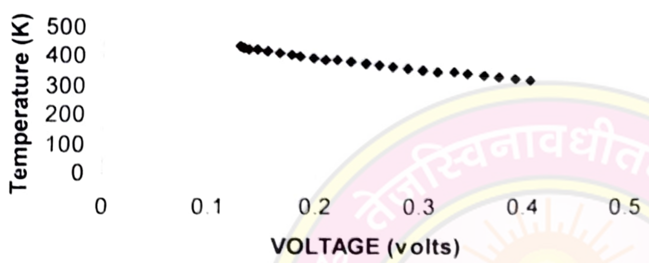
T in °C	T in °K	Junction voltage

5

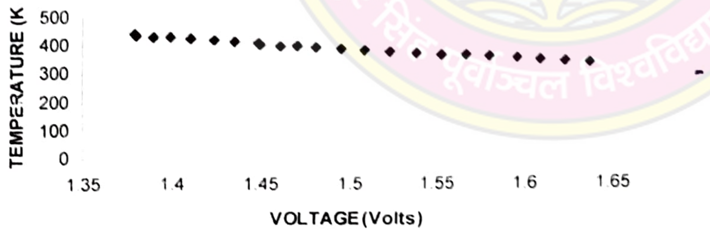
8. Draw a graph between the junction voltage and absolute temperature and calculate the slope "a" of the graph. Extrapolate the graph to 0°K and measure the intercept (b). Now using the relation (8) , calculate the energy band gap.

9. Repeat the experiment with other diode/ LED.

10. Typical results are shown below



T - V graph for diode IN 4007



T - V Graph for Red LED

PRECAUTIONS

1. Avoid use of water for temperature variation as any amount of conduction may lead to short-circuiting of the diode.

Least Square Fit Method for slope and intercept of line:

For straight line y = a x + b

Where

A = slope of line.

B = intersection of line on y-axis.

Slope can be calculated using formula

$$A = \frac{N\sum x_i y_i - \sum x_i \sum y_i}{N\sum x_i^2 - (\sum x_i)^2}$$

And intercept $B = \frac{\sum x_i^2 \sum y_i - \sum x_i \sum (x_i y_i)}{N\sum x_i^2 - (\sum x_i)^2}$

Where

N = Number of points.

x = Voltage

y = Temperature.

7

Temperature (C)	Temperature (K) **Y**	Voltage **X**	Voltage (**X sq**)	tage X Temperature (**X x Y**)	N
30	303	1.53	2.3409	463.59	11
40	313	1.51	2.2801	472.63	
50	323	1.49	2.2201	481.27	
60	333	1.47	2.1609	489.51	
70	343	1.45	2.1025	497.35	
80	353	1.42	2.0164	501.26	
90	363	1.4	1.96	508.2	
100	373	1.38	1.9044	514.74	
110	383	1.36	1.8496	520.88	
120	393	1.35	1.8225	530.55	
130	403	1.33	1.7689	535.99	
	3883	15.69	22.4263	5515.97	

N∑XY =	60675.67		
∑X∑Y =	60924.27	N∑XY- ∑X∑Y=	-248.6
N∑Xsq =	246.6893	N∑Xsq - (∑X) sq=	0.5132
(∑X) sq=	246.1761		

NS

∑Xsq∑Y=	87081.3229	∑Xsq∑Y-∑X∑XY=	535.7536
∑X∑XY=	86545.5693		

Slope A= -484.4115355

Intercept B = 1043.946999

Eg = 2.155082864 eV

Temperature (C)	Temperature (K) **Y**	Voltage **X**	Voltage (**X sq**)	tage X Temperature (**X x Y**)	N
30	303	0.44	0.1936	133.32	11
40	313	0.41	0.1681	128.33	
50	323	0.38	0.1444	122.74	
60	333	0.36	0.1296	119.88	
70	343	0.34	0.1156	116.62	
80	353	0.31	0.0961	109.43	
90	363	0.29	0.0841	105.27	
100	373	0.27	0.0729	100.71	
110	383	0.24	0.0576	91.92	
120	393	0.22	0.0484	86.46	
130	403	0.2	0.04	80.6	
	3883	3.46	1.1504	1195.28	

8

N∑XY = 13148.08
∑X∑Y = 13435.18
N∑Xsq = 12.6544
(∑X) sq= 11.9716

N∑XY- ∑X∑Y= -287.1
N∑Xsq - (∑X) sq= 0.6828

∑Xsq∑Y= 4467.0032
∑X∑XY= 4135.6688

∑Xsq∑Y-∑X∑XY= 331.3344

Slope A= -420.4745167
Intercept B = 485.258348

Eg = 1.154073145 eV

Temperature (C)	Temperature (K) **Y**	Voltage **X**	Voltage (**X sq**)	tage X Temperature (**X x Y**)	N
30	303	0.11	0.0121	33.33	8
40	313	0.09	0.0081	28.17	
50	323	0.07	0.0049	22.61	
60	333	0.06	0.0036	19.98	
70	343	0.04	0.0016	13.72	
80	353	0.03	0.0009	10.59	
90	363	0.02	0.0004	7.26	
110	383	0.01	0.0001	3.83	
	2714	0.43	0.0317	139.49	

N∑XY = 1115.92
∑X∑Y = 1167.02
N∑Xsq = 0.2536
(∑X) sq= 0.1849

N∑XY- ∑X∑Y= -51.1
N∑Xsq - (∑X) sq= 0.0687

∑Xsq∑Y= 86.0338
∑X∑XY= 59.9807

∑Xsq∑Y-∑X∑XY= 26.0531

Slope A= -743.8136827
Intercept B = 379.2299854

Eg = 0.509845401 eV

FOURIER ANALYSIS KIT

INTRODUCTION

In electronics we very often come across signals, which are not simple sine waves. The waveforms of such signals are complex. They contain a number of harmonics. To process such signals it is necessary to know their frequency components and their relative magnitudes. The mathematical tool that does this type of analysis is the FOURIER THEOREM.

According to the Fourier theorem, any single valued complex periodic waveform (V_t) can be thought of as a sum of a series of simple harmonic waves, the first of which has a frequency equal to that of the complex wave.

$$V\,(_t) = V_{dc} + \sin(\omega t + \phi_2) + \ldots + V_n \sin(\eta\omega t + \phi_n). \qquad \ldots(1)$$

The term V_{dc} is called the dc level of the signal. The terms V_1, V_2. V_n are the amplitudes of the fundamental or the first harmonic (ω), the second harmonic (2ω) and so on. The terms $\phi_1, \phi_2 \ldots\phi_n$ are the corresponding phase angles.

The Fourier series of a square wave is given by

$$V\,(t) = \frac{4V}{\pi}\left(\sin\omega t + \frac{1}{3}\sin 3\omega t + \frac{1}{5}\sin 5\omega t + \frac{1}{7}\sin 7\ \omega t + \frac{1}{9}\sin 9\omega t + \ldots\right) \quad \ldots(2)$$

This equation shows that the square wave is made up of sine waves of the fundamental and its odd harmonics. If the amplitude of the fundamental is taken as unity, the amplitudes of the third harmonics is 1/3, that of the fifth harmonic 1/5 and so on.

The Fourier series of a triangular wave is given by

$$V\,(t) = \frac{4V}{\pi}\left(\cos\omega t + \frac{1}{3^2}\cos 3\omega t + \frac{1}{5^2}\cos 5\omega t + \cdots\right) \qquad \ldots..(3)$$

The triangular wave contains the fundamental and its odd harmonics. The amplitude decreases as $1/n^2$ where n is the number of the harmonic (odd).

The Fourier series of a clipped sine wave (half-wave rectified) is given by

$$V\,(t) = \cos\omega t - 0.425\cos 2\omega t - 0.085\cos 4\omega t - 0.03\cos 6\omega t\ldots.. \qquad \ldots(4)$$

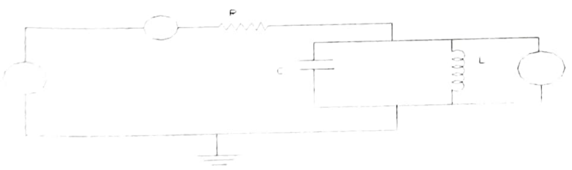
The theoretical relative amplitudes of the Fourier components of the square, triangular and clipped sine wave forms are given in table 1.

TABLE 1. **FOURIER COMPONENTS**

Harmonic	Amplitude (Relative)		
	Square Waves	Triangular waves	Clipped sine waves
First	1.00	1.00	1.00
Second	---	---	0.43
Third	0.33	0.11	---
Fourth	---	---	0.09
Fifth	0.20	0.04	---
Sixth	--	---	0.04
Seventh	0.14	0.02	---

METHOD OF ANALYSIS

The circuit used to analyse complex waveforms is shown in Fig. 1. The waveform to be analyzed is given to the series combination of a resistor and tuned circuit whose resonant frequency (ω) $\simeq$ 7.5 kHz. The tuned circuit is specially designed to achieve high selectivity at this frequency. It selects this frequency and rejects all other frequencies with high efficiency. The voltage across the tuned circuit is given to the vertical input of a CRO.



When the frequency of the input waveform is equal to the resonant frequency of the tuned circuit, the circuit accepts the fundamental component and rejects all other harmonics. As a consequence, a pure sine wave of that frequency is seen on the CRO. As the frequency of the input wave decreased, a pure sine wave of frequency is will appear on the CRO whenever $\omega' = \frac{\omega}{n}$ where $n = 2, 3, 4, \ldots$ The integer n takes only odd values for the square and triangular waveforms. It takes only even values for the clipped sine wave.

A measurement of the frequency of the harmonic and its relative amplitude enables one find out the component harmonics.

THE KIT

The kit consists of a stabilized dual power supply unit, a function generator and the analyser. The power supply system, the function generator and the analyser are housed in main unit.

Square, triangular and sine waveforms are generated by a specially designed integrated circuit function generator whose output frequency can be varied in the range of 500 Hz to 15 kHz. The output level of the sine and triangular waves can be varied using the amplitude potentiometer provided on the front panel of the main unit.

The frequency of the generator can be varied using the 100 kΩ ten-turn potentiometer (TTP). Use of the TTP achieves smooth frequency variation.

The frequency of the generator for any particular setting of the TTP is given by

$$F\,(\text{kHz}) = \frac{44.4}{1+R} \qquad \ldots(5)$$

where (1 + R) is in kΩ. R is the resistance of the TTP. If the dial of the TTP reads 1.02, its resistance is 10.2 kΩ and (1 + R) is equal to 11.2 kΩ leading to a value of 4.46 kHz for the frequency of the waveform. Equation (5) yields frequency values with an accuracy of ± 5%.

FRONT PANEL

The front panel of the main unit containing the function generator and the analyser circuit is shown in Fig. 2.

The output waveforms of the function generator are available at sockets A, C & D. The square wave is available at A. At C, the waveform will be either a sine wave or a triangular wave depending upon the position of the toggle switch S. The frequency of all the three waveforms may be varied using the TTP (ten turn potentiometer).

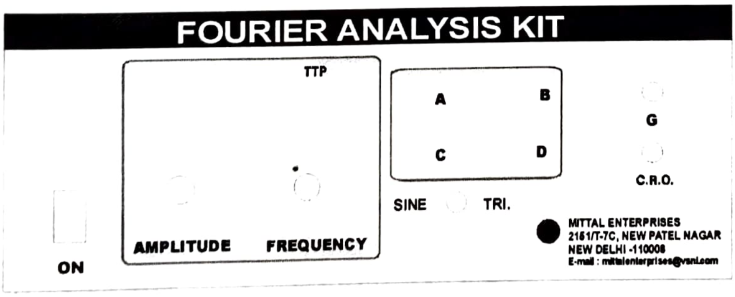


Fig.2

B is the input to the analyser circuit. The sockets marked G is ground terminals. The output of the analyser is available at socket marked CRO.

EXPERIMENTAL PROCEDURE

1. Connect the unit to the mains.
2. Connect CRO and to the Unit.
3. Waveform of the function generator can be seen between the respective terminals and G.

SQUARE WAVE

4. Connect socket marked A to B using the patch cord supplied with the kit, this feeds the analyser with the square wave.
5. Observing the pattern on CRO vary the TTP starting from the zero reading. This varies the frequency of the square wave. At *f*, the natural frequency of the tuned circuit, you will observe a pure sine wave of maximum amplitude. Adjust TTP carefully to get maximum amplitude. Note the reading of the TTP and measure the height of the pattern on the CRO. The height of the pattern may be measured in volts if your CRO has a valibrated scale. Otherwise measure the height using a scale or divider. The height is proportional to the amplitude of the pure sine wave.
6. Decrease the frequency of the waveform and note the reading of the TTP for which you observe pure sine waves of maximum amplitude on CRO. Measure their amplitudes you would observe pure sine wave at 1/3, 1/5, 1/7 and 1/9 and so on of ω.

   The result shows that a square wave contains the fundamental and its odd harmonics. Tabulate your results as indicated in Table 2.

TABLE 2. **WAVEFORM: SQUARE**

ding	R (kΩ)	(1+R) (kΩ)	Frequency (kHz)	Harmonic	Amplitude

Disconnect A and B

TRIANGULAR WAVE

7. Throw the toggle switch towards the sign of triangle. Adjust the amplitude potentiometer so as to get undistorted triangular waves. Connect the CRO to terminal C and observe the waveform . You will now get triangular wave at the socket marked C. Remove the CRO connection from C and connect it to the terminal marked CRO.

8. Connect C to B using a patch cord.
9. Repeat steps 4 and 5 described above.

CLIPPED SINE WAVE

10. Throw the toggle switch towards sine sign. You will now get sine wave output at C. There is a half-wave rectifier between C and B. At D we get the clipped sine wave.
11. Connect D and B. The analyser is now fed by the clipped sine wave.
12. Repeat steps 4 and 5 described above.

PRECAUTIONS

1. The frequency of the waveform should be adjusted carefully to obtain maximum amplitude. This is particularly important at the fundamental. Any mistake here leads to errors in the amplitudes of other harmonics.
2. At higher harmonics the amplitude decreases to low values. For some harmonics the error in measurement may be comparable with the amplitude that is being measured. So no importance need be attached to exact agreement between the theoretical and experimental relative amplitudes. We should only look for their existence.
3. Any distortion of the input waveform leads to erroneous results. If there is a large discrepancy between the experimental and theoretical results examine the waveforms using the CRO. If you find serious distortion of the waveform, inform the company. Arrangements will be made to correct the waveforms.
4. Do not use the function generator for other experiments. It may overload the generator and distort the waveforms.

SUGGESTION

You may use the analyser to analyse the waveforms from any other source. Feed the waveforms between B and G.

TYPICAL RESULTS

Square wave

TTP Reading	R in kΩ	(1+R) in kΩ	f (kHz)	Harmonic	Amplitude
0.49	4.9	5.9	7.52	I	8.80
1.68	16.8	17.8	2.49	III	2.85
2.87	28.7	29.7	1.49	V	1.75
4.05	40.5	41.5	1.07	VII	1.20
5.25	52.5	53.5	0.83	IX	0.99

Triangular Wave

TTP Reading	R in kΩ	(1 +R) in kΩ	f (kHz)	Harmonic	Amplitude
0.49	4.9	5.9	7.52	I	3.20
1.67	16.7	17.7	2.50	III	0.33
2.86	28.6	29.6	1.50	V	0.125

Clipped Sine Wave

TTP Reading	R in kΩ	(1 +R) in kΩ	f (kHz)	Harmonic	Amplitude
0.49	4.9	5.9	7.52	I	0.66
1.07	10.7	11.7	3.79	II	0.25
2.26	22.6	23.6	1.88	IV	0.058

References

1. Mathematics of physics and modern Engineering by I.S. Sokolnikoff and R.M. Redheffer.
2. "Experiments" in Electronics by S.V. Subrahmanyam, Mac Millan, India, 1983.

A NOTE ON THE PROCEDURE ADOPTED TO STUDY FOURIER COMPONENTS OF A COMPLEX WAVE

1. A straightforward method of studying the Fourier Components of a complex wave like the square wave is described below:

   The experiment setup is shown below:

   In this set up, a square wave of fixed frequency feeds the series combination of a tuned circuit consisting of an inductance *L*, a variable capacitance *C* and a resistance of *R*. The voltage developed across the tuned circuitry is displayed on C.R.O.

2. A square wave consists of pure sine wave of fundamental *f*, third harmonic 3*f*, fifth harmonic 5*f*, seventh harmonic 7*f* and so on. Their amplitude decreases in the order 1/3, 1/5,1/7 etc.

3. If we now tune the tuned circuit to *f* we will observe a pure sine wave of frequency *f*, its amplitude depends on Q-factor of the circuit, i.e. on $\frac{8\cdot\pi\cdot f\cdot L}{R}$. If *L* & *R* remains constant, the fundamental will be unity.

4. Let us now tune the circuit of 3*f*, then a pure sine wave of frequency 3*f* will be observed. It indicates the existence of the 3rd harmonic. However its amplitude will not be 1/3 of its fundamental due to the fact that the Q of the circuit is 3 times the Q of the fundamental.
   Same thing happens when the circuit was tuned for 5*f*. 5th harmonic will be observed but its amplitude will not be 1/5 of its fundamental.

Thus the procedure described above gives a wrong idea of the relative amplitudes of the Fourier components even though it shows the existence of the higher harmonics in a straightforward manner.

To avoid the above difficulty we have adopted a procedure that is not so straight forward but clearly and accurately shows the existence of the harmonics and their relative amplitudes. In the KIT, we have kept the resonant frequency of the tuned circuit at fixed value of f, and input frequency of the signal is varied. Since we are not changing the resonant frequency of tuned circuit its Q remains constant.

5. While varying the input frequency, when the frequency of the input square wave signal is f, a sine wave of frequency f will be observed on C.R.O. Let its amplitude be unity.

6. If now the input frequency is decreased to $f/3$, a pure sine wave of frequency f will again be observed on C.R.O. This indicates the existence of the third harmonic $\frac{1}{3f} \times 3f = f$. Since the frequency of the wave appearing across the tuned circuit is again f, its Q does not change. Hence its amplitude will be 1/3rd of the amplitude of the fundamental, as the theory predicts.

7. If we now decrease the frequency to $f/5$, again a pure sine wave of frequency f will be observed i.e. 5th harmonic ($\frac{1}{5f} \times 5f = f$) and so on.

The above explanation justifies the procedure adopted in the KIT for Fourier analysis of complex waves.

STEFAN'S CONSTANT KIT

INTRODUCTION

According to Stefan-Boltzmann's law the heat energy E_1 radiated per unit area per second by a body at T° Kelvin surrounded by another body at lower temperature T_0° Kelvin is directly proportional to the difference in fourth power of the absolute temperature i.e.

$$E_1 \propto (T^4 - T_o^4)$$

or

$$E_1 = \sigma \cdot (T^4 - T_o^4)$$

where σ is called Stefan's Constant. Its standard value is 5.67×10^{-8} W m^{-2} K^{-4}. If the area of surface is A, then the head energy radiated from the surface becomes

$$E_1 = \sigma \cdot A \cdot (T^4 - T_o^4) \qquad \ldots(1)$$

THEORY

In this kit, the electric energy is used to heat up the two copper circular discs to a particular steady temperature T° K. The steady temperature is measured by thermometers placed in contact with the copper discs. As the steady temperature of the discs is larger than surrounding temperature T_o °K of the atmosphere, the disc will radiate heat energy which can be calculated by Stefans Boltzmann's Law or eqn. (1).

As the temperature of the discs reaches steady state, heat energy, E_1, radiated by discs per second will be equal to the electrical energy, E_2, consumed by heating element per second and is given by

$$E_2 = V \cdot I \qquad \ldots(2)$$

where V = Potential difference across the heating element and
I = Current flowing in the heating element

From equations (1) & (2)

$$V \cdot I = \sigma \cdot A \cdot (T^4 - T_o^4)$$

or $$\sigma = \frac{V \cdot I}{A \cdot (T^4 - T_o^4)} \qquad \ldots(3)$$

V and I can be measured with the help of Voltmeter and Ammeter installed in the kit. The steady temperature (T °K) of copper discs can be read from the thermometers and the area A of the disc can be calculated by measuring the radius of the disc.

By substituting the values of V, I, A, T and T_o in equation (3) one can calculate the Stefan's constant.

The features of the kit are:

i) There is practically no loss of heat energy from heating element by conduction, convection or radiation. Therefore, entire heat energy of the heating element is transferred to discs.

ii) As the efficiency of the heating element is nearly equal to one, almost entire electrical energy supplied to the heater will be converted into heat energy.

PROCEDURE

i) Note down the surrounding room temperature (T °K) with the help of the thermometers.

ii) Put ON the switch on the kit.

iii) Place the discs horizontally on the table.

iv) Connect the heating element of discs to the Kit terminals marked "Black plates".

v) Adjust with the help of potentiometer, the potential difference (V) and current (I) for heating element for proper reading in the meters.

vi) Place the thermometers vertically in the holes provided in the discs.

vii) Tabulate the temperature reading (of middle thermometer) as a function of time, as given below, at an interval of 2 min each and plot the graph.

S. No.	Time (t) (min)	Temp (°C)	Temp (°K)
1	0		
2	2		
3	4		
-	-		

viii) From Plot observe the reading of the temperature till rate of rise of Temperature is near 0.5 °C/min indicating the nearly steady state condition (equilibrium).

ix) Note down Readings of all 3 thermometers at equilibrium and take the average of the readings.

x) The several sets of observations are taken by varying the potential difference (V) & current (I) with the help of potentiometer.

xi) The area of the plate can be calculated by measuring the radius of the disc.

SAMPLE OBSERVATIONS

The area of the copper plates = 306.8056 sq. cm.

Least Count of Thermometer = 1 °C.

S.No.	Voltage	Current	Room Temp. T °K	Mean Temp. of Thermometers at equilibrium T °K
1	20	0.25	300	328
2	30	0.35	300	395
3	40	0.47	300	376
4	50	0.58	300	404

SAMPLE CALCULATIONS

$$\sigma = \frac{V \cdot I}{A \cdot (T^4 - T_o^4)} \text{ W cm}^{-2}\text{ K}^{-4}$$

$$\sigma = \frac{V \cdot I \times 10^7}{A \cdot (T^4 - T_o^4)} \text{ ergs cm}^{-2}\text{ sec}^{-1}\text{ K}^{-4}$$

Thus substituting values from table :

1)

$$\sigma = \frac{20 \times 0.25 \times 10^7}{306.8056 \cdot (328^4 - 300^4)}$$

$$= \frac{20 \times 0.25 \times 10^7}{306.8056 \times 3.482 \times 10^9}$$

$$= 4.679 \times 10^{-5} \text{ erg cm}^{-2}\text{ sec}^{-1}\text{ K}^{-4}$$

2)

$$\sigma = \frac{30 \times 0.35 \times 10^7}{306.8056 \cdot (345^4 - 300^4)}$$

$$= \frac{20 \times 0.35 \times 10^7}{306.8056 \times 6.072 \times 10^9}$$

$$= 5.637 \times 10^{-5} \text{ erg cm}^{-2}\text{ sec}^{-1}\text{ K}^{-4}$$

3)

$$\sigma = \frac{40 \times 0.47 \times 10^7}{306.8056 \cdot (376^4 - 300^4)}$$

$$= \frac{40 \times 0.47 \times 10^7}{306.8056 \times 11.892 \times 10^9}$$

$$= 5.141 \times 10^{-5} \text{ erg cm}^{-2}\text{ sec}^{-1}\text{ K}^{-4}$$

4)

$$\sigma = \frac{50 \times 0.58 \times 10^7}{306.8056 \cdot (404^4 - 300^4)}$$

$$= \frac{50 \times 0.58 \times 10^7}{306.8056 \times 18.102 \times 10^9}$$

$$= 5.223 \times 10^{-5} \text{ erg cm}^{-2}\text{ sec}^{-1}\text{ K}^{-4}$$

Average $\sigma = 5.17 \times 10^{-5} \text{ erg cm}^{-2}\text{ sec}^{-1}\text{ K}^{-4}$

Note: All above measurements and readings varies from instrument to instrument due to change in dimensions.

RESULT

The value of Stefan's constant, with the help of the experiment is

$$\sigma = 5.17 \times 10^{-5} \text{ ergs cm}^{-2} \text{ sec}^{-1} \text{ K}^{-4}$$

Standard Value $= 5.67 \times 10^{-5}$ ergs cm^{-2} sec^{-1} K^{-4}

Percentage error = 8.8%

PRECAUTIONS

1. The readings of thermometers are taken only as stated above.
2. All the fittings should be airtight.

PARTS LIST

1. MAIN UNIT ☐
2. HEATER PLATES ☐
3. THERMOMETER (3 nos) ☐
4. CONNECTING WIRES ☐
5. INSTRUCTION MANUAL ☐