INVESTIGATIONS & COMPARISONS OF LINEAR AND VOLUMETRIC EXPANSIVITIES OF SELECTED SOLID AND LIQUIDS

BY

OGUNDELE O. OLUFEMI

School of Science and Science Education
Abubakar Tafawa Balewa University
of Technology, Bauchi.

OCTOBER 1992

INVESTIGATIONS AND COMPARISONS OF LINEAR AND VOLUMETRIC EXPANSIVITIES OF SELECTED SOLIDS AND LIQUIDS

BY

OGUNDELE O. OLUFEMI

A THESIS SUBMITTED TO SCHOOL OF SCIENCE AND SCIENCE EDUCATION,
ABUBAKAR TAFAWA BALEWA UNIVERSITY OF TECHNOLOGY, BAUCHI.

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF
DEGREE OF B. TECH (HONS) PHYSICS IN PHYSICS PROGRAMME.

OCTOBER, 1992

APPROVED

SUPERVISOR .... Date: 24/11/92
Mr. O. K. Likkason

PROGRAMME COORDINATOR .... Date: 27/11/92
Prof. E. D. Mshelia

DEAN
SCHOOL OF SCIENCE & SCIENCE EDUCATION
ABUBAKAR TAFAWA BALEWA UNIVERSITY
BAUCHI.

DEAN OF SCHOOL .... Date: 2/12/92
Prof. Canon Ale

ACKNOWLEDGEMENT

I would like to show my gratitude to my friends who have shown immense support and concern for the progress and completion of this work. First amongst them is Bassey K. Bassey who has, as a room mate been like a brother; for his support and caring. Also, I would like to thank my friends, Bunmi Fagbemi, Meg Daleng, Tony Oyeneye and Cassidy Alu who have been very supportive and helpful along the course of my work. I would like to thank others too many to name for also showing concern and care.

I would also like to thank my class mates, Yakubu, Charles, Gambo, Plang and others for caring and showing their immense support towards the completion of this work.

My appreciation also goes to my supervisors, Dr. M.F. Haque and Mr. O.K. Likkason on their immense help. I thank them for their guidance especially in reading and correcting the original manuscript. My appreciation also goes to Mr. Dauda for patiently helping me and guiding me through my experimental work.

My utmost gratitude goes to my relatives amongst who are my father, Engineer S.O. Ogundele, my mother Mrs J.A. Ogundele and my brother and sister, Bisi and Biodun Ogundele who have shown unflinching support for me.

Most of all I would like to thank God for His blessings and glory bestowed upon me during the course of my studies and giving me the power to endure during the hard times.

DEDICATION

This piece of work is dedicated to my father and mother Mr and Mrs Ogundele and my sister and brother, Bisi and Biodun.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Thermal expansion is the increase in the dimensions of a material due to the application of heat.

This project sets out to investigate the linear expansivities of a set of rods of selected materials which include aluminium, copper, brass, iron, quartz glass and duran glass. The temperature at which the rods were subjected to investigation ranged from 30°C to 80°C. The data obtained from the work were plotted from which values of the linear expansivities **were obtained.**

Aluminium was noticed to have expanded faster in terms of linear dimensions compared to the other rods. This has been attributed to its low cohesive energy state and high value of specific heat capacity at constant volume.

In addition the cubic expansivities of some selected liquids namely; olive oil, ethanol, **glycerol,** ethyl acetate and distilled water were determined and their coefficients of volume expansivities obtained. The liquids were examined at a temperature range of 30°C to 50°C. It was inferred that ethyl acetate expanded in volume faster than the other selected liquids which is probably due to its energy pattern in the atomic set up and its value of **Cv.**

CHAPTER ONE

INTRODUCTION

Thermal expansion is defined as the increase in the dimensions (e.g length, volume, density) of a material with an equivalent increase in temperature.

The uses of thermal expansion in our daily lives are readily observable: mercury thermometers to indicate temperature, thermostats to control our heating and cooling systems and even the use of hot water to "loosen" a stuck jar lid. On a hot summer day, the effect of thermal expansion would also be readily apparent if not allowed for by the design engineer in construction work.

To paraphrase a facetious comment that appeared in a small book 'PHYSICS FOR FOOLS', published in Russia in 1968: Bridges, railroads, tracks and concrete section of highways are always made shorter than they should be since bodies always expand when heated. Even so, after an unusually hot day, newspapers will have photographs of highways that have been buckled and draw bridges that have stuck! The importance of technology of accurate knowledge of thermal expansion is readily apparent when one considers the problems associated with high performance engines, atomic reactors, re-entry vehicles and others.

One of the first scientific problems associated with dimensional changes in solids caused by temperature fluctuations was the measurement of time with pendulums. Although the period T of a pendulum IS almost independent of the amptitude, time does critically depend upon its length as the period is:

$$T = 2\pi\sqrt{\frac{L}{g}} \qquad (1)$$

L is its length and g, the acceleration due to gravity.

For instance a change in temperature of 10 degrees will cause a change in period of about 0.01% [4] if the pendulum is made of brass. Therefore it is not surprising that some of the first quantitative measurements of thermal expansion were made in order to obtain more accurate clocks. These measurements were first made by Petrus Van. Musschenbrock a professor of astronomy in Utrecht about 1730. Musschenbrock measured the thermal expansion of iron, steel, copper brass tin and lead. He found out that lead expanded the most and iron the least. He concluded that it was better to make the rods of pendulum clocks with iron; in his words: "Therefore it is very proper to make the rods of pendulums for clocks or iron. They are not so good of steel and much worse of brass, yet sometimes they are made of copper because it is not so liable to rust but yet that is wrong."

The reverse situation, that of using the expansion of solids to measure temperature even above the boiling point of mercury, was described by J.F Dannell in 1831 and was intended for various industrial applications including pottery and smelting. Since this time, a large amount of information on thermal expansion has been obtained and with advances in technology the quality of the information has improved. A great deal of this information however is worthless or nearly so, because the material was not sufficiently characterised and/or the experiment was not sufficiently documented. In particular accurate data on well characterised materials are needed to understand the behaviour of alloy and other composite systems. Even so, within the past 20 years, measurements on thermal expansion have greatly increased our knowledge in areas such as lattice dynamics, electronic and magnetic interactions, thermal defects and phase transitions.

This work is intended to examine the expansion of various solids (metals and non metals) and some liquids, under thermal conditions. Linear expansions will be studied on Brass, Copper, Aluminium, Quartz Glass, Duran glass and iron rods, while the volume expansion will be examined with Glycerol, Ethyl acetate, Ethanol, Distilled water and olive oil as materials.

From these results curves will be drawn for each case and the coefficients of linear and volume expansion will be calculated to note which of the solids/liquids expand faster, and which ones expand least over a given temperature range. It is expected that results drawn would be of much relevance and great bearing on the existing pattern of material properties that are thermally controlled.

CHAPTER TWO

THEORY

2.0 EXPANSION OF MATERIALS

When a material is heated so that there is a change in temperature from T_1 to T_2 there is a corresponding change in volume, V_1 to V_2, the mean coefficient of volumetric thermal expansion of the material is defined by β_m as

$$\beta_m = \frac{V_2 - V_1}{V_1 (T_2 - T_1)} \tag{2}$$

The limiting value of this ratio (at constant pressure p) as the temperature changes by a differential amount dT is defined as the true coefficient of volumetric thermal expansion B_v or just as the coefficient of thermal expansion with

$$\beta_v = \frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_p \tag{3}$$

For a linear problem, the coefficient of linear expansion α_2 is

$$\alpha_L = \frac{1}{L}\left(\frac{\partial L}{\partial T}\right)_p. \tag{3a}$$

The thermal expansion of the substance on heating from T_1 to T_2 is often expressed as percentage expansion thus

$$\frac{100(V_2 - V_1)}{V_1} \text{ or } 100\frac{\Delta V}{V} \tag{4}$$

Similarly for linear expansion, the corresponding definitions in this case are

$$\alpha_m = \frac{L_2 - L_1}{L_1 (T_2 - T_1)} \tag{5}$$

and **the** % expansion is

$$\frac{100(L_2 - L_1)}{L_1} \text{ or } \frac{100\Delta L}{L} \tag{5a}$$

Where L represents the length. If the expansion is determined from measurements of density, then, the mean coefficient of expansion, $\beta_m = \frac{\rho_2 - \rho_1}{\rho_2 (T_2 - T_1)}$ (6)

and the coefficient of thermal expansion is $\beta = \frac{-1}{\rho}\left(\frac{\partial \rho}{\partial T}\right)_P$ (6_a)

If the substance is isotropic, the coefficient of thermal expansion, is equal to three times the coefficient of linear thermal expansion, i.e $\beta = 3\alpha$ (7)

The same is not strictly true, however for the mean coefficients where [6]

$$\beta_m \approx 3\alpha_m \left[1 + (T_2 - T_1)\alpha_m\right] \tag{8}$$

Ordinarily, the coefficient of thermal expansion is not measured directly but it is either calculated directly from consecutive observations of expansion or by differentiating an equation that represents the expansion. Under certain conditions, the instantaneous coefficient of linear thermal expansion will satisfactorily represents the true coefficient. The instantaneous coefficient of linear thermal expansion is defined as $\alpha_1 = \frac{L_2 - L_1}{L_{293}(T_2 - T_1)}$ at the mean temperature Tm, (9)

where L_{293} is the length at 293K. If the expansion over a limited temperature range can be approximated by a polynomial [6]

$$\frac{L - L_{293}}{L_{293}} = a_0 + a_1 T + a_2 T^2 + a_3 T^3 + \cdots \tag{10}$$

Then, $\alpha_1' = \alpha_1 + 2a_2 T_m + a_3 (4T^2_m - T_2 - T_1) + \cdots$ (11)

and $\alpha = \frac{L_{293}}{L}\left(a_1 + 2a_2 T_m + 3a^3 T^2_m + \cdots\right)$ (12)

From these equations, it can be shown that

$$\alpha = \frac{L_{293}}{L}\left[\alpha_1 + \frac{a_3}{4}(\Delta T)^2 - \cdots\cdots\right] \tag{13}$$

If $L_{293} \approx L$ and $\Delta T = T_2 - T_1 \rightarrow 0$, then $\alpha \approx \alpha_1$. If the expansion can be represented by a quadratic formulation, $a_3 = 0$ in equation (13) and thus large intervals can be used.

2.1 ATOMIC EXPLANATION

POTENTIAL WELL MODEL

A three dimensional array of atoms which are free to vibrate about their equilibrium positions is a reasonable model for a solid substance. The heat capacity of this model can be calculated by assuming that the vibrations are harmonic and their energies are quantized. While these assumptions are very successful in calculating the heat capacity of real solids, the vibrations must be assumed to be an-harmonic in order to account for thermal expansion. This can be understood qualitatively by considering the vibrations of a single particle in the asymmetric potential well. The equation

$$\Phi = \frac{1}{2}Cx^2 - \frac{1}{3}sCx^3 \qquad (14)$$

is an approximate solution of a non-linear equation of motion

$$m\frac{d^2x}{dt^2} + Cx - SCx^2 = 0 \qquad (15)$$

where C is a constant, m the mass of the particle, x the distance covered, t is the time elapsed, s is the harmonicity constant. And

$$x = A\left(\cos V_0 t - \frac{SA}{6}\cos^2 V_0 t\right) + \frac{SA^2}{2} \qquad (16)$$

where A is the amplitude of the motion Vo is the initial potential energy A.S $\langle \cos V_0 t \rangle - \langle \cos 2V_0 t \rangle = 0$.

The time average position of the particle is

$$\langle x \rangle = \frac{SA^2}{2} \qquad (17)$$

An increase in temperature T, (with the application of heat)causes the vibrational amplitude of the atoms in the crystal lattice of the solid to increase. The potential curve (Fig. 1) of the binding forces corresponds only to a first approximation to the parabola of a harmonic oscillation (dotted lines); generally flatter in the case of large interatomic distances than in the case of small ones. If the vibrational amplitude is large, the centre of oscillation moves to larger interatomic distances.
The average spacing between the atoms increases and therefore does the total volume V(at constant pressure p).

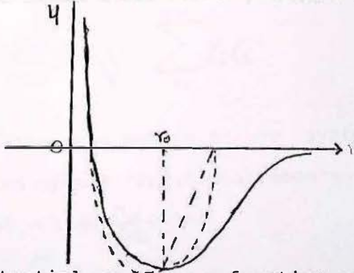


Fig. 1.1 Potential curve as a function of the interatomic spacing r.

A shift in the average position which is proportional to the an-harmonicity constant S has therefore occured. towards the softer side (i.e region of larger r of the potential well).

According to classical theory A^2 is proportional to temperature so that the value of $\langle x \rangle$ can represent the thermal expansion of the system and the coefficient of thermal expansion is a constant that is proportional to S. In the case of a harmonic potential where S = 0, the average position of the particle does not shift and there is no corresponding thermal expansion.

2.2 DERIVATION OF THE GRUNEISEN RELATION

In the quasi-harmonic approximation, the effect of anharmonic interactions is simulated by treating the vibrations as harmonic but with frequencies that are volume dependent. Applying statistical mechanics to this model it can be shown that [1]

$$\frac{\partial^2 F}{\partial V \partial T} = -\frac{1}{V} \sum_{i=1}^{3N} \gamma_i C_i \qquad (18)$$

where F is the free energy of the system and C_i is the contribution of the vibrational mode to the heat capacity at constant volume C_V with

$$C_V = \sum_{i=1}^{3N} C_i \qquad (19)$$

The quality γ_i is a measure of the volume dependencies on the frequency of the vibrational mode γ_i, thus,

$$\gamma_i = \frac{V}{\nu_i} \frac{\partial \nu_i}{\partial V} = \frac{\partial \ln \nu_i}{\partial \ln V} \qquad (20)$$

hence indicates the effect of the anharmonic interactions. If we define

$$\gamma = \sum \gamma_i C_i / C_V \qquad (21)$$

then

$$\frac{\partial^2 F}{\partial V \partial T} = \frac{\partial C_V}{\partial V} \qquad (22)$$

It can also be shown from thermodynamics that

$$\frac{\partial^2 F}{\partial V \partial T} = -B_T \beta \qquad (23)$$

where β_T is the isothermal bulk modulus. The expression

$$\beta = \frac{\gamma C_v}{V \beta_T} \qquad (24)$$

is known as Gruneisen relation and γ is known as the GRUNEISEN PARAMETER.

Since both r and the product of V and BT are weak functions of temperature, the value of B is nearly proportional to C_v at all temperatures. Thus at high temperatures B is nearly a constant and at low temperatures where the atoms must be treated as quantum oscillators $\beta \rightarrow 0$ as T→ 0 K.

2.3 DEBYE EQUATION OF STATE

For many models of a solid, one can separate the free energy F into two parts: Q, the EFFECTIVE FREE ENERGY of the state lattice including the zero point energy and Fth, the contribution of lattice thermal excitations. The thermal pressure is a solid Pth is [6]

$$P_{th} = -\left(\frac{\partial F_{th}}{\partial V}\right)_T \qquad (25)$$

and the static Pressure Pst as

$$P_{st} = -\frac{\partial \Phi_0}{\partial V} \qquad (26)$$

The total pressure is equal to the sum of these quantities. Thus

$$P_{TOT} = -\frac{\partial \Phi_0}{\partial V} = -\left(\frac{\partial F_{th}}{\partial V}\right)_T \qquad (27)$$

In Debye's model of a crystal structure, the effect of anharmonic interactions can be expressed as a change of all lattice frequencies ν_i, of the Debye frequency ν_D and of the characteristic temperature,

$$\theta_D = \frac{h \nu_D}{K} \qquad (28)$$

has a value that is large when compared to E_D. The constant k is best determined by experiment but can be related to the potential energy function.

The Expansion coefficient of a solid is related to the type of bonding exhibited by the crystal and hence its heat capacity [3]. The Expansion coefficient is largest for materials with the shallowest potential curves [3] and these are weakly bound materials such as the Alkali metals.

where Θ_D is the Debye temperature, ν_D the Debye frequency, h is planck's constant and K is the Boltzman's constant;

This is used to approximate the effect of anharmonic interactions and hence the temperature. In this model of the lattice heat capacity, is a function of volume only.

By differentiating equation (28) with respect to V it can be shown with the help of eqn (20) that

$$\frac{\partial \Theta_D}{\partial V} = -\frac{\Theta_D \gamma}{V} \qquad (29)$$

It follows that in this model r is also a function of volume only. It can also be shown from thermodynamics that

$$\frac{\partial F_{th}}{\partial \Theta_D} = \frac{1}{\Theta_D} \cdot \frac{\partial (F_{th}/T)}{\partial (1/T)} = \frac{E_D}{\Theta_D} \qquad (30]$$

where E_D is the Debye energy of the lattice vibrations. The Debye equation of state can be written as

$$P = -\frac{\partial \Phi_0}{\partial V} - \left(\frac{\partial F_{th}}{\partial \Theta_D}\right)\left(\frac{\partial \Theta_D}{\partial V}\right) = -\frac{\partial \Phi_0}{\partial V} + \frac{\gamma E_D}{V} \qquad (31)$$

Gruneisen's relation can be obtained by differentiating P with respect to temperature at constant volume:

$$\left(\frac{\partial P}{\partial T}\right)_V = \frac{\gamma C_V}{V} = \beta_T \beta \qquad (32)$$

If the pressure is set equal to zero in eqn (31), v $(\partial \Phi_0 / \partial V)$ can be expanded in a Taylor series in volume and the constants of the series evaluated at zero Kelvin. Then the Gruneisen equation can be obtained as

$$\frac{V_T - V_0}{V_0} = \frac{E_D}{Q - kE_D} \qquad (33)$$

where

$$Q = \frac{V_0 \beta_0}{\gamma}$$

CHAPTER THREE

MATERIALS AND METHODS

The aim of the work is to calculate the coefficient of thermal expansivity α_L and that of volumetric expansivity β_V from the slopes of sets of expansion curves.

The volume of the pycnometer was determined and the scale calibrated by weighing it empty and then filled with distilled water and weighed again. The results were then recorded.

The pycnometer which was filled with the liquid to be worked on was in thermal contact with a water bath (thermostat) The change in volume was then read from the scale on the tube built to its stopper.

The connecting tube to the thermostat was removed and the dialometer was connected to the bridge on which the rod under examination was clamped and hoses were connected to both springs on the tube. The thermostat was switched on and water was allowed to circulate through the insides of the tube. The change in length was then read on the dialometer with a rotary scale.

When the initial temperature at which measurement was to be carried out was about to be reached, the dial guage was set to zero before expansion of the rod was measured at regular intervals of temperature. The change in lengths

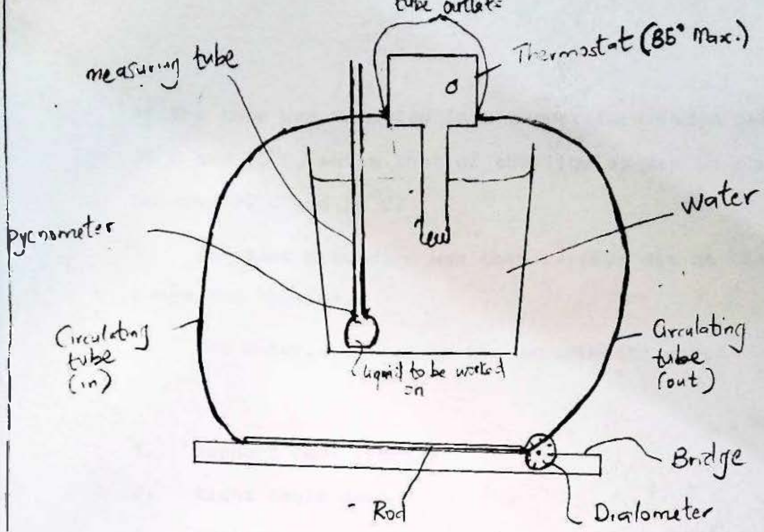


FIg. 1.2 EXPERIMENTAL SET UP

of the tube was measured in a temperature range between $30^{\circ}C$ and $80^{\circ}C$, while that of the liquids was in a range between $30^{\circ}C$ and $50^{\circ}C$.

The same procedure was then carried out on the other tubes and liquids.

The materials used in the experiments were:

		QUANTITY
1.	Support rods (square)	1
2.	Right angle damp	2
3.	Syringe	1
4.	Measuring tubes (300mm length)	2
5.	Dialometer with rotary clock guage	1
6.	Circulating thermostat (with temp. up to $85^{\circ}C$)	1
7.	Plastic wash bottle	2
8.	Flat bottom flask (50ml)	2
9.	Glass Beaker (Tall, 100ml)	1
10.	Universal Clamp	2
11.	Rubber Tubing	2
12.	Plastic bath for thermostat	1
13.	Bridge with cooling coil	1
14.	Electronic precision balance	1
15.	Thermometer	1

The experimental accessories included metal and non-metal tubes (rods). They were aluminium, brass, iron, copper, quartz and duran glass tubes of original length 600mm each.

The liquids chosen for investigations were olive oil, ethanol, glycerol Ethyl acetate and distilled water. The original value of liquids used was 67·4ml eacn.

For quartz glass which has a very-small expansion rate, the temperature bath was first heated to 80°C and the length was recorded at this temperature. The water in the bath was then drained and filled with cold water and allowed to attain the temperature of 30°C. Contraction was then measured.

The experiments were carried out to investigate the expansion properties of these materials/substances. Graphs were plotted as in the next sections.

CHAPTER FOUR

DISCUSSION OF RESULTS

SOLIDS

For the solid rods all the graphs are linear. The graphs showed that aluminium has the fastest rate of expansion while quartz glass has the lowest (Table 2). These are followed in succession by copper, Brass, iron and duran glass. .

From the potential well model diagram on (Fig. 1), it is deduced that aluminium atoms are weakly bound (Figure 2) i.e low interatomic forces because of a shallow potential curve i.e region of attractive forces. Hence, its weak bond. Its vibrational amplitude is the largest during heating hence it produces a large interatomic spacing which means it expands fastest [3].

For the case of quartz glass, it has a stronger interatomic binding force due to a deeper potential curve i.e larger attractive forces, therefore it has the smallest vibrational amplitude hence it produces the least expansion [3,5]. . This is also because of low vibrational amplitude hence the centre of oscillation does not move to larger interatomic distances.

The cohesive energy which is the measure of the strength of materials give alternative explanation for the observed phenomena. For example, the cohesive energy of Aluminium is 327 kJ/mol, while that of copper is 336 kJ/mol and Iron, 413k KJ/mol

[5]. It is seen that Aluminium with the least value of cohesive energy will expand fastest and the rate of expansion will decrease with increase in the cohesive energies.

From the Gruneisen relation, the coefficient of linear expansion is proportional to the specific heat at constant volume at all temperatures (Eqn (24)). From these it is seen that aluminium has the largest value of Cv while quartz glass has the least value of Cv among the selected rods.

LIQUIDS

From the graphs drawn, it is seen that Ethyl acetate and ethanol had linear rates of expansion while distilled water, glycerol and olive oil showed slight irregularity of expansion with increase in temperature. This means that for these three liquids due to the graph producing curves, Figs. 3.10, 3.11, 3.12, their slopes were found at several points and the coefficients of volume expansion were calculated from these points. The mean values of these were then computed.

From the results obtained from the graphs (Table 4) it can be seen that ethyl acetate has the highest rate of expansion of about $1.39 \times 10^{-3}\ K^{-1}$ while distilled water has the least rate of volume expansion of about $3.41 \times 10^{-4}\ K^{-1}$. These are followed in succession by ethanol, olive oil and glycerol.

From the potential well models ethyl acetate would be weakly bound because of low interatomic forces [3] . With the application of heat it would have large vibrational amplitudes which would increase its atomic spacing faster hence its expansion. For distilled water, it could be due to a deep potential well curve which means it is strongly bound, it would have a smaller vibrational amplitude with application of heat and hence it produces a smaller interatomic separation. Thus it has a lower rate of expansion.

Also from Gruneisen's relation, it can be seen that the coefficient of volume expansion is equivalent to the specific heat capacity at constant volume Cv at all temperatures (eqn (14)). Water will have a smaller value of Cv than ethyl acetate.

CONCLUSION

From the experiments and results obtained it is seen that, in the case of the solid rods, aluminium has the largest value of α, the coefficient of linear expansivity hence it expands the fastest with increasing temperature.

For the liquids examined, ethyl acetate has the largest value of β_v, the coefficient of volume expansion followed by ethanol, olive oil glycerol and then finally distilled water.

The reasons for the fastest rate of expansion of aluminium and the slowest rate for quartz glass can be attributed to the weaker bond exhibited by aluminium because of its low cohesive energies and interatomic forces (due to a shallow potential curve) while the reverse is the case for quartz glass. Another reason is due to the large specific heat at constant volume Cv for aluminium and the smaller Cv values for quartz.

For the case of the liquids, ethyl acetate's largest rate of expansion among the liquids examined can be attributed to its possesing a weak bond because of small interatomic forces and a deep potential curve [3] . It can also be attribute to its having a large Cv value. However for distilled water the opposite is the case hence its slow rate of expansion.

The results from this work show that the pattern of expansion of substances (liquids and solids) follows the predicted behaviours of these substances and that this correlation in results has been a major objective of this project. The results thus consolidated the behavioural pattern of these substances as depicted from theory and formulations.

REFERENCES

[1] Collins J. G. and White G. K., Thermal Expansion of solids "in progress in low Temperature physics" (C. J. Gorter Editor) 1964. Volume IV John Wiley and Sons, New York, p 450-79.

[2] Daniell J. F. 1831. On a new register pyrométer for measuring expansion of solids and determining the Higher Degree of Temperature upon the Common Thermonatic scale. Phil. Mag 10, p 191-200.

[3] Davies D. A, 1978. Waves atoms and solids. Longman, London and New York, p 198.

[4] Desagulier S. J. T. 1945. A course of experimental philosophy; London, 436-46.

[5] Kittel C. 1976. Introduction to solid state physics. Wiley New York, p 74.

[6] Touloukain Y. S, Kirby R. K., Taylor R.E., De Sal P.D. 1976. Thermal expansion: Matellic Elements and alloys. IFJ/PLENUM. New York, Washington, p 39-89.

TABLE 1: TABLE OF RESULTS OF CHANGE IN LENGTH ΔL AGAINST TEMPERATURE.

1. QUARTZ GLASS ROD:

ΔL (mm)	θ(°C)
0.00	80°
0.015	30°

2. IRON ROD:

ΔL (mm)	θ(°C)
0.00	30
0.05	35
0.10	40
0.104	45
0.19	50
0.24	55
0.29	60
0.35	65
0.38	70
0.42	75
0.47	80

3. **DURAN GLASS ROD**

Δl (mm)	θ(°c)
0.03	30
0.0	35
0.065	40
0.1	45
0.125	50
0.17	55
0.19	60
0.225	65
0.255	70
0.285	75
0.315	80

4. **ALUMINIUM ROD**

Δl (mm)	θ(°c)
0.00	30
0.05	35
0.13	40
0.185	45
0.26	50
0.325	55
0.385	60
0.46	65
0.52	70
0.59	75
0.65	80

5. COPPER ROD

Δl (mm)	θ(°C)
0.00	30
0.055	35
0.09	40
0.145	45
0.20	50
0.255	55
0.32	60
0.37	65
0.435	70
0.47	75
0.51	80

6. BRASS ROD

Δl (mm)	θ(°C)
0.00	30
0.05	35
0.095	40
0.16	43
0.21	30
0.25	38
0.303	60
0.36	65
0.41	70
0.47	75
0.52	80

TABLE 2: TABLE OF RESULTS OF CHANGE IN VOLUME AGAINST TEMPERATURE T OF LIQUIDS USED.

1. **OLIVE OIL**

V (ml)	θ(°C)
0	30
0.05	32
0.12	34
0.19	36
0.28	38
0.37	40
0.48	42
0.60	44
0.72	46
0.81	48
0.92	50

2. **GLYCEROL**

V (ml)	θ(°C)
0	30
0.03	32
0.07	34
0.11	36
0.16	38
0.21	40
0.27	42
0.33	44
0.40	46
0.48	48
0.55	50

3. ETHANOL

V (ml)	θ(°C)
0	30
0.09	32
0.20	34
0.33	36
0.48	38
0.65	40
0.78	42
0.89	44
1.02	46
1.16	48
1.31	50

4. ETHYL ACETATE

V (ml)	θ(°C)
0	30
0.07	32
0.26	34
0.43	36
0.65	38
0.80	40
1,02	42
1.19	44
1.36	46
1.59	48
1.82	50

3. ETHANOL

V (ml)	θ(°C)
0	30
0.09	32
0.20	34
0.33	36
0.48	38
0.65	40
0.78	42
0.89	44
1.02	46
1.16	48
1.31	50

4. ETHYL ACETATE

V (ml)	θ(°C)
0	30
0.07	32
0.26	34
0.43	36
0.65	38
0.80	40
1,02	42
1.19	44
1.36	46
1.59	48
1.82	50

5. DISTILLED WATER

V (ml)	θ(°C)
0	30
0.02	32
0.05	34
0.09	36
0.14	38
0.18	40
0.23	42
0.28	44
0.35	46
0.40	48
0.46	50

TABLE 3: TABLE OF RESULTS OF THE SLOPES AND COEFFICIENTS OF LINEAR EXPANSIVITY, α OF THE GIVEN MATERIALS

MATERIAL	SLOPE $\Delta L/\Delta\theta$ (mm K^{-1})	α (K^{-1})
COPPER	1.0769×10^{-2}	1.7948×10^{-3}
IRON	9.33×10^{-3}	1.555×10^{-5}
DURAN GLASS	5.9184×10^{-3}	9.864×10^{-6}
BRASS	1.10182×10^{-2}	1.697×10^{-5}
ALUMINIUM	1.3×10^{-2}	2.1667×10^{-3}
QUARTZ GLASS	3×10^{-4}	5×10^{-7}

TABLE 4: TABLE OF RESULTS OF THE SLOPES AND COEFFICIENTS OF THE CUBIC EXPANSIVITY, β_v OF THE GIVEN LIQUIDS

LIQUID	SLOPE ($\Delta V/\Delta\theta$) (ml K^{-1})	β_v (K^{-1})
ETHYL ACETATE	0.094	1.39×10^{-3}
ETHANOL	0.065	9.57×10^{-4}
GLYCEROL	0.031	4.53×10^{-4}
DISTILLED WATER	0.023	3.48×10^{-4}
OLIVE OIL	0.058	8.50×10^{-4}

FIG.• 3.1: GRAPH OF CHANGE IN LENGTH AGAINST TEMPERATURE FOR ALUMINIUM.

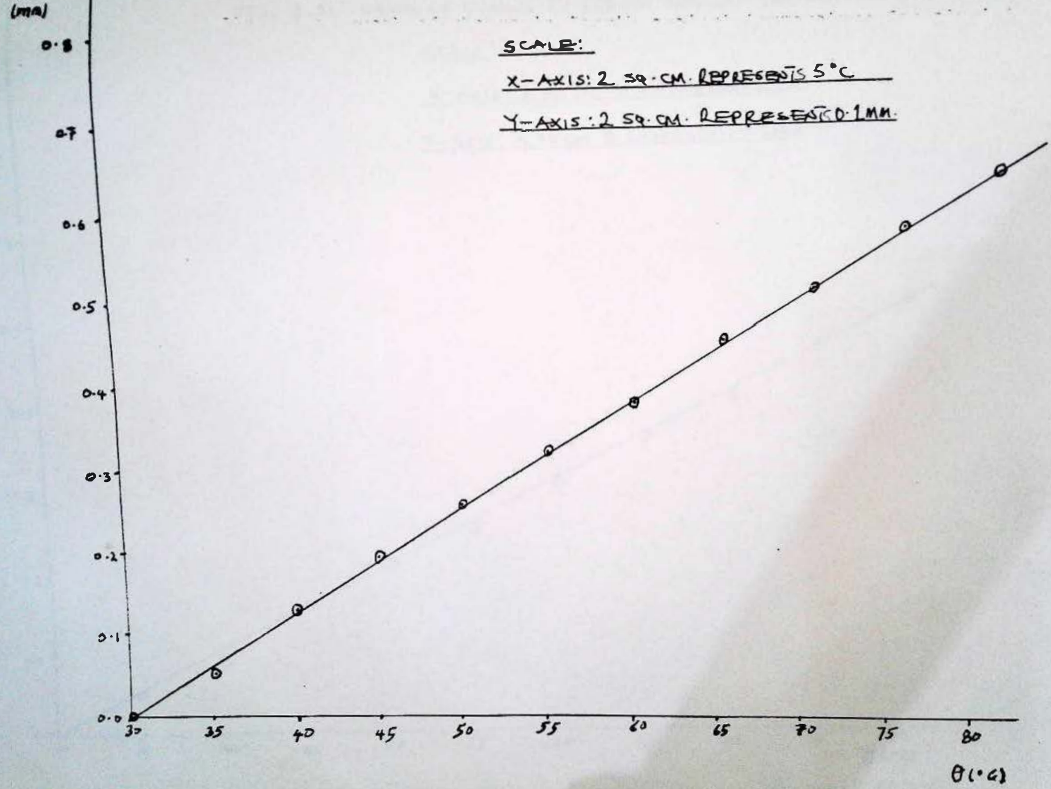
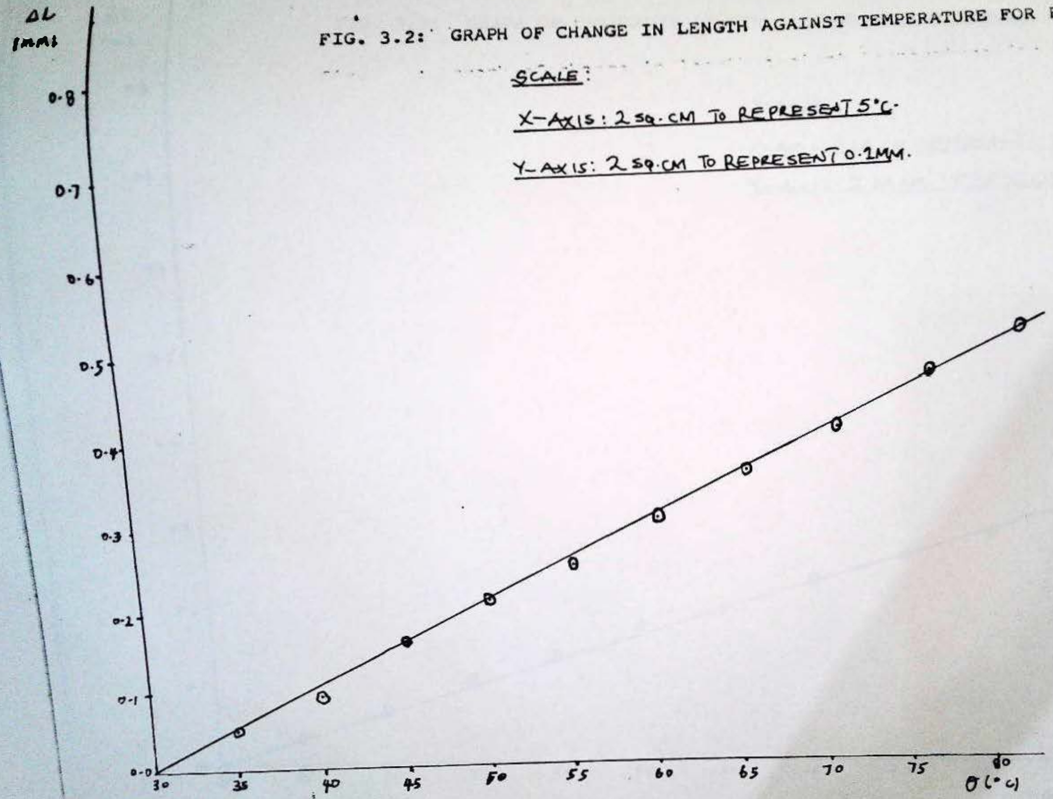


FIG. 3.2: GRAPH OF CHANGE IN LENGTH AGAINST TEMPERATURE FOR BRASS ROD.

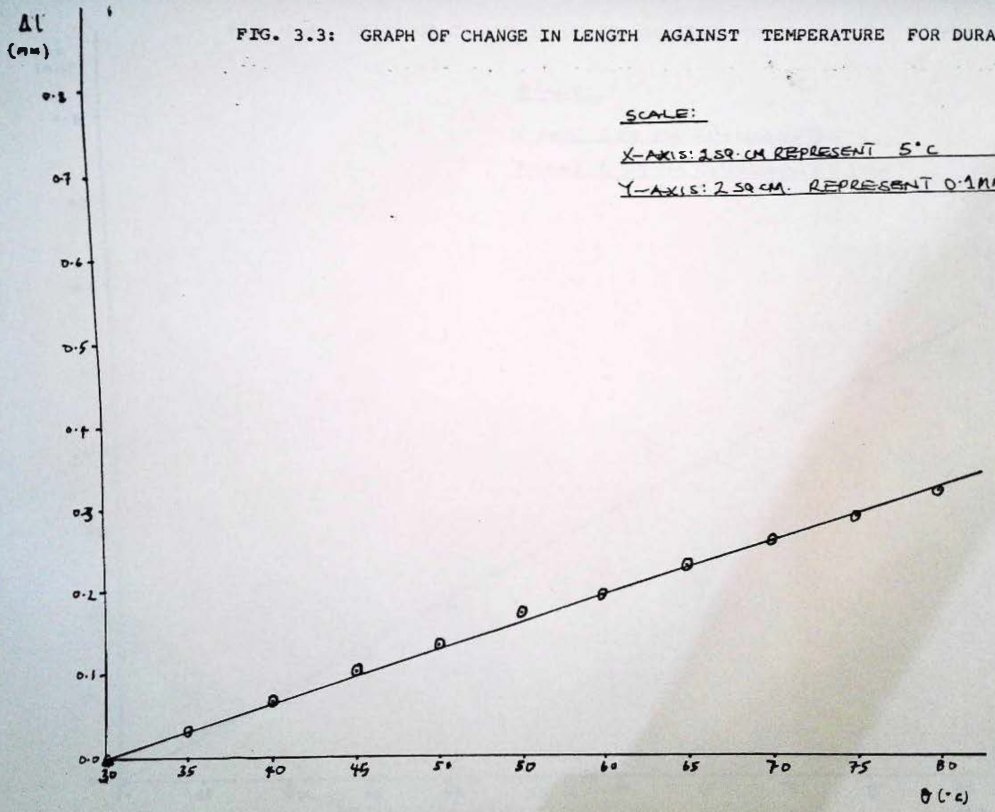


SCALE:

X-AXIS: 2 SQ. CM TO REPRESENT 5°C.

Y-AXIS: 2 SQ. CM TO REPRESENT 0.1MM.

FIG. 3.3: GRAPH OF CHANGE IN LENGTH AGAINST TEMPERATURE FOR DURAN GLASS ROD:

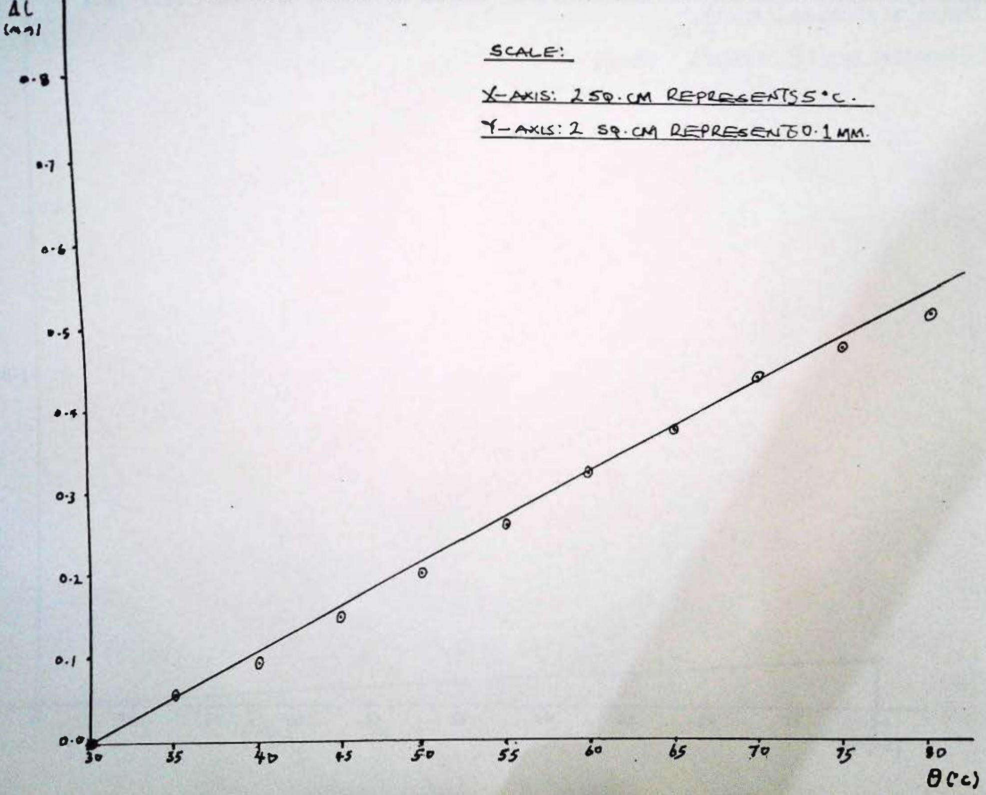


SCALE:

X-AXIS: 2 SQ. CM REPRESENT 5°C

Y-AXIS: 2 SQ CM. REPRESENT 0.1MM.

FIG. 3.4: GRAPH OF CHANGE IN LENGTH AGAINST TEMPERATURE FOR COPPER ROD.



SCALE:

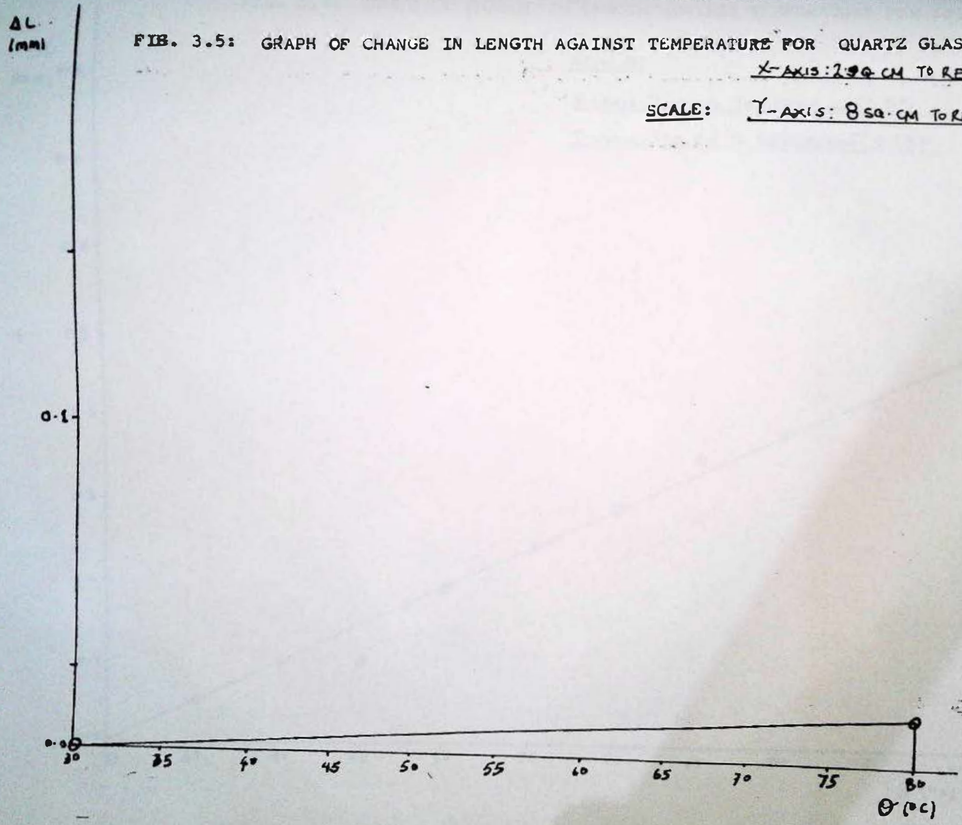
X-AXIS: 2 SQ. CM REPRESENTS 5°C.

Y-AXIS: 2 SQ. CM REPRESENT 0.1 MM.

FIB. 3.5: GRAPH OF CHANGE IN LENGTH AGAINST TEMPERATURE FOR QUARTZ GLASS ROD.

SCALE: X-AXIS: 2 SQ CM TO REPRESENT 5°C

Y-AXIS: 8 SQ. CM TO REPRESENT 0.1MM



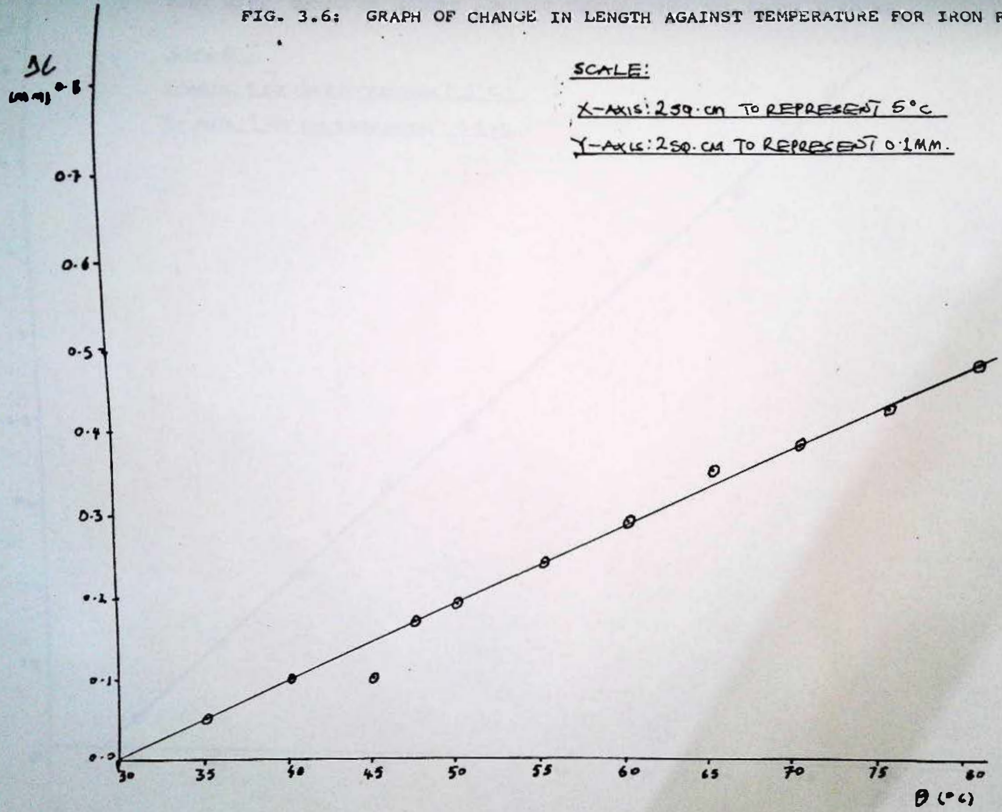


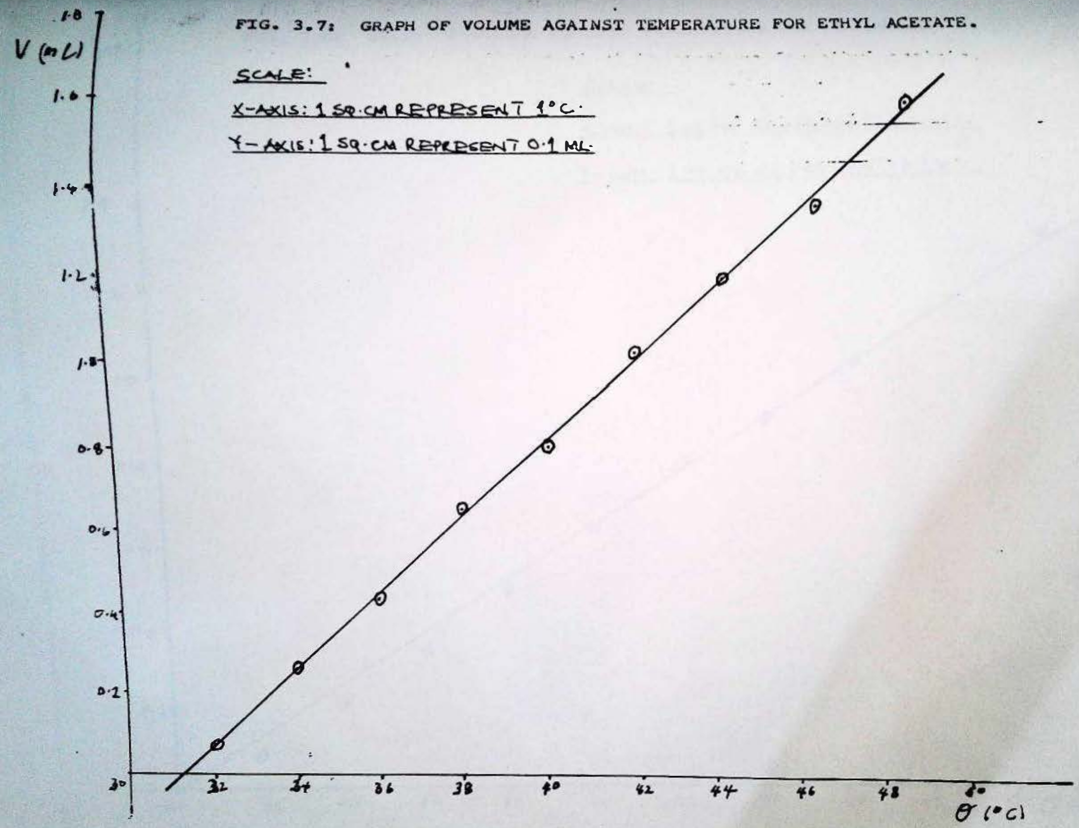
FIG. 3.6: GRAPH OF CHANGE IN LENGTH AGAINST TEMPERATURE FOR IRON ROD.

SCALE:

X-AXIS: 2sq.cm TO REPRESENT 5°C

Y-AXIS: 2SQ.CM TO REPRESENT 0.1MM.

FIG. 3.7: GRAPH OF VOLUME AGAINST TEMPERATURE FOR ETHYL ACETATE.

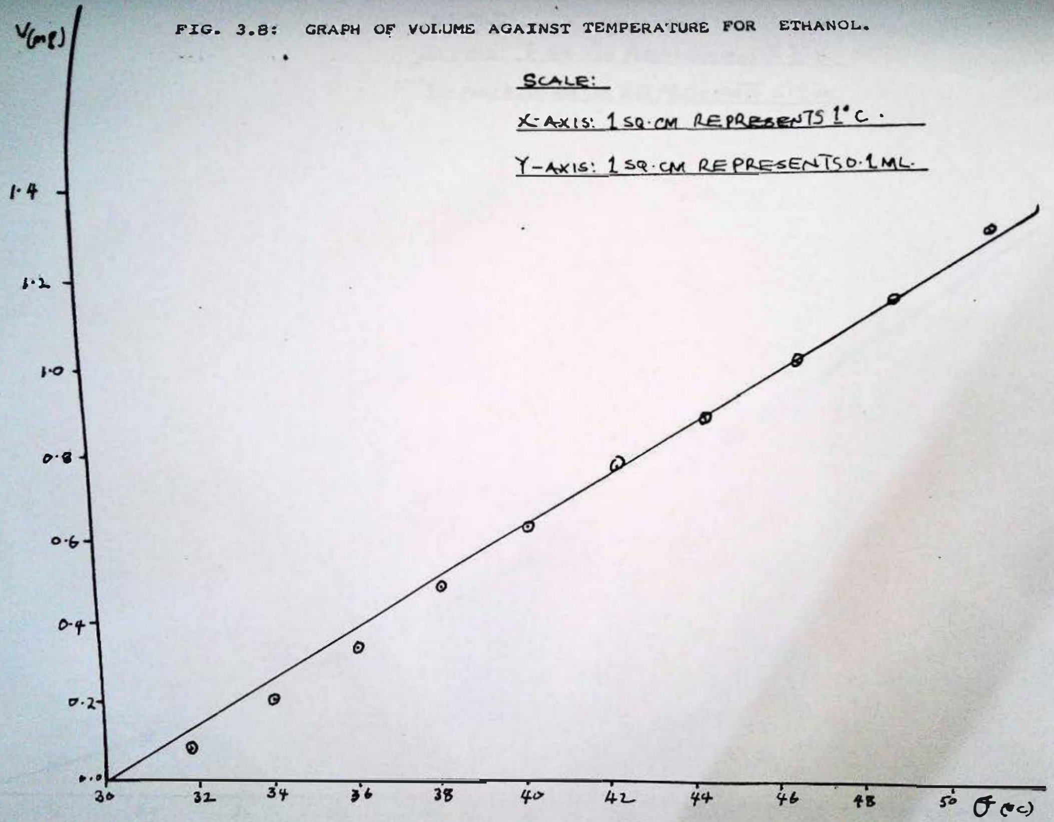


SCALE:

X-AXIS: 1 SQ.CM REPRESENT 1°C.

Y-AXIS: 1 SQ.CM REPRESENT 0.1 ML.

FIG. 3.8: GRAPH OF VOLUME AGAINST TEMPERATURE FOR ETHANOL.



SCALE:

X-AXIS: 1 SQ·CM REPRESENTS 1°C.

Y-AXIS: 1 SQ·CM REPRESENTS 0·1 ML.

FIG. 3.9: GRAPH OF VOLUME AGAINST TEMPERATURE FOR GEYCEROL.

SCALE:

X-AXIS: 2 SQ·CM REPRESENTS 1°C.

Y-AXIS: 2 SQ CM REPRESENTS 0·1 ML.

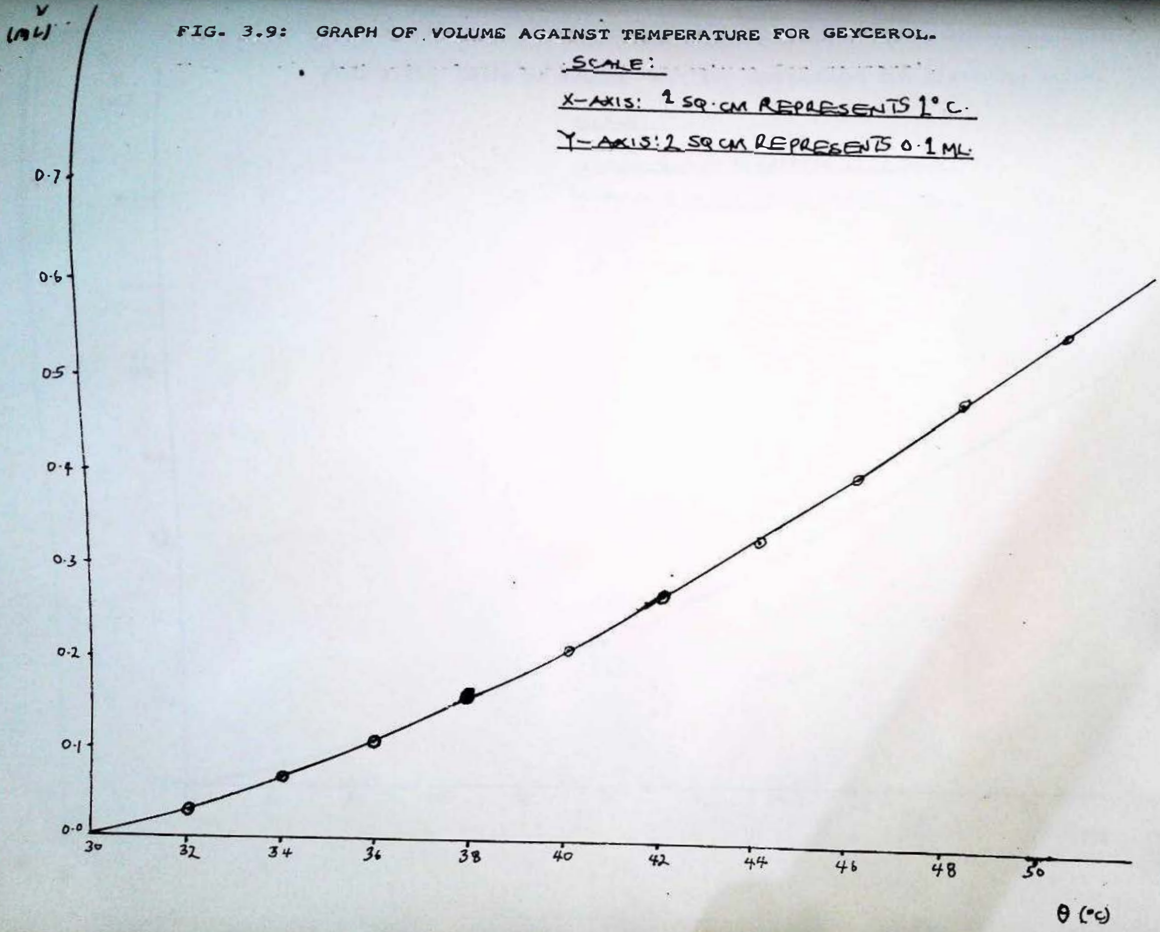
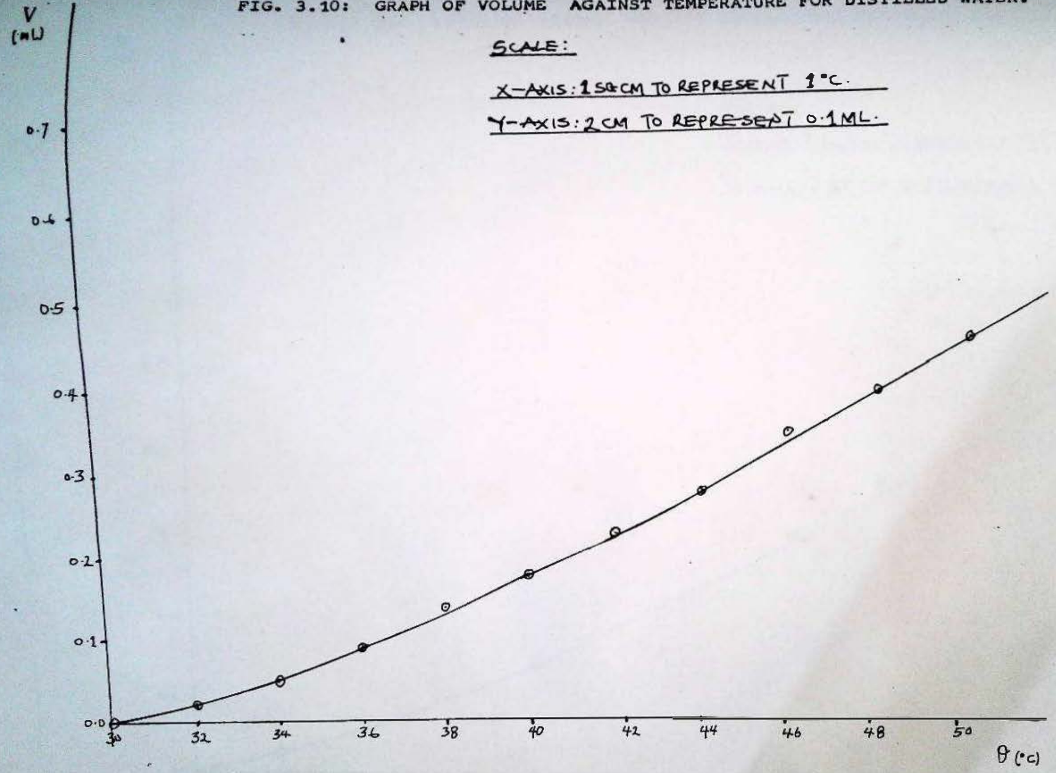


FIG. 3.10: GRAPH OF VOLUME AGAINST TEMPERATURE FOR DISTILLED WATER.

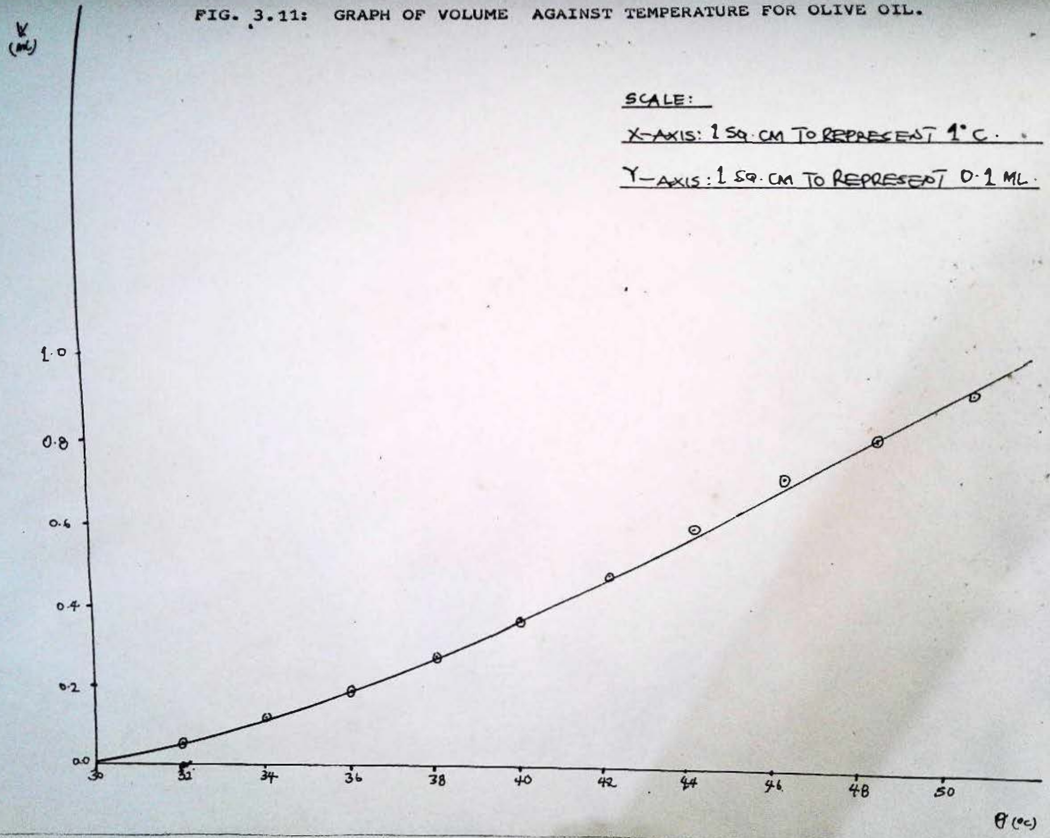


SCALE:

X-AXIS: 1 SQ CM TO REPRESENT 1°C.

Y-AXIS: 2 CM TO REPRESENT 0.1 ML.

FIG. 3.11: GRAPH OF VOLUME AGAINST TEMPERATURE FOR OLIVE OIL.



SCALE:

X-AXIS: 1 SQ. CM TO REPRESENT 1°C.

Y-AXIS: 1 SQ. CM TO REPRESENT 0.1 ML.